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Soil Erosion by Water in Africa

Principles, Prediction and Protection

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Preliminary note

Enhanced soil erosion research in Africa looks back on about 25 years of experimentation and recording with respect to soil loss prediction. A lot of information was gathered during this time which led to contradictory results about the applicability of the Universal Soil Loss Equation (USLE). This book tries to synthesize the latest knowledge and to evaluate it for practical soil loss prediction. This meant the gathering of a lot of data in tabular and graphic form which might be cumbersome for some readers. Nevertheless, we hope that it will be helpful to have these data assembled in order to save time for searching in many different journals which often can hardly be obtained locally. The ultimate aim of the book is to help understand the processes, to make the reader sensitive for recognizing them in the landscape and to allow him to quantify of the influence of agronomic measures on soil loss rather than to give detailed technical data and sketches.

People starting to get occupied with erosion problems will find basic knowledge about processes and effects and the necessary literature for more details. The book is also thought as a help for people concerned with the planning and realization of soil conservation activities. It allows to detect areas of high erosion risk which in turn facilitates the allocation of conservation efforts. The absolute results of calculations can be subject to substantial error whereas the relative differences between single measures are comprehensible. However, if a process varies in magnitude by a factor of 1000 (soil losses can be as small as 0.1 t/ha and as large as several 100 t/ha), an estimate which is wrong by a factor of 2 (= 100% error) is still a reasonable estimate. At the same time, this means that projects and research should continue to improve and enlarge the database in order to improve estimates. For this reason, the authors would appreciate to receive further data on measurements.

In Chapters 1 to 6 the reader finds descriptive information about causes, damages, processes, recognition and measurement of soil erosion. Chapter 7 is dedicated to soil loss prediction with the USLE. For the pure technical procedure of soil loss prediction the reader can refer to Chapter 7.

1 Causes for soil erosion

Soil erosion is a process acting over tens and hundreds of years. Its effects are normally only obvious, if they become disastrous. Until now, research focused on the physical causes of erosion. However, frequent failures of soil conservation projects showed that the causes were much more complex. A FAO study revealed that the lack of adoption of new conservation practices was a major reason for project failure even though technically sound practices were used (Hudson, 1991). Today, it has largely been agreed upon that soil conservation will not be successful in many countries even by using the best available practices if man and the social, economic and political context are not considered. Fones-Sundell (1992) summarized the problem very pointedly by saying: 'Neither engineering nor biological measures alone can eradicate erosion in a socio-economic system which makes non-optimal use of natural resources a necessary and often profitable form of behaviour for the individual.'

The cause-effect diagram in Figure 1-1 illustrates the problem of soil erosion. Soil erosion as caused alone by natural, physical factors (climate, soil, topography) is known as 'geologic' or 'normal' erosion (Bennett & Chapline, 1928). It is small enough to allow the sustainable growth of a natural eco-system. Geologic erosion ranges from several hundred kilograms per hectare for tropical bush and grass vegetation to below 100 kg/ha for tropical forest (Nill, 1993; Roose, 1975). Soil formation in the tropics is supposed to be in the same range. According to measurements in Central Africa, 150 to 400 kg/ha of new soil is formed each year (Owens, 1974). Dunne et al. (1978) found an annual formation rate of 150 to 300 kg/ha in Kenya whereas Kaye (1959) reported a rate of 15 t/ha on limestone in Puerto Rico[1].

Soil loss becomes critical if socioeconomic and political factors favour erosion (man-induced erosion). The main factors are:

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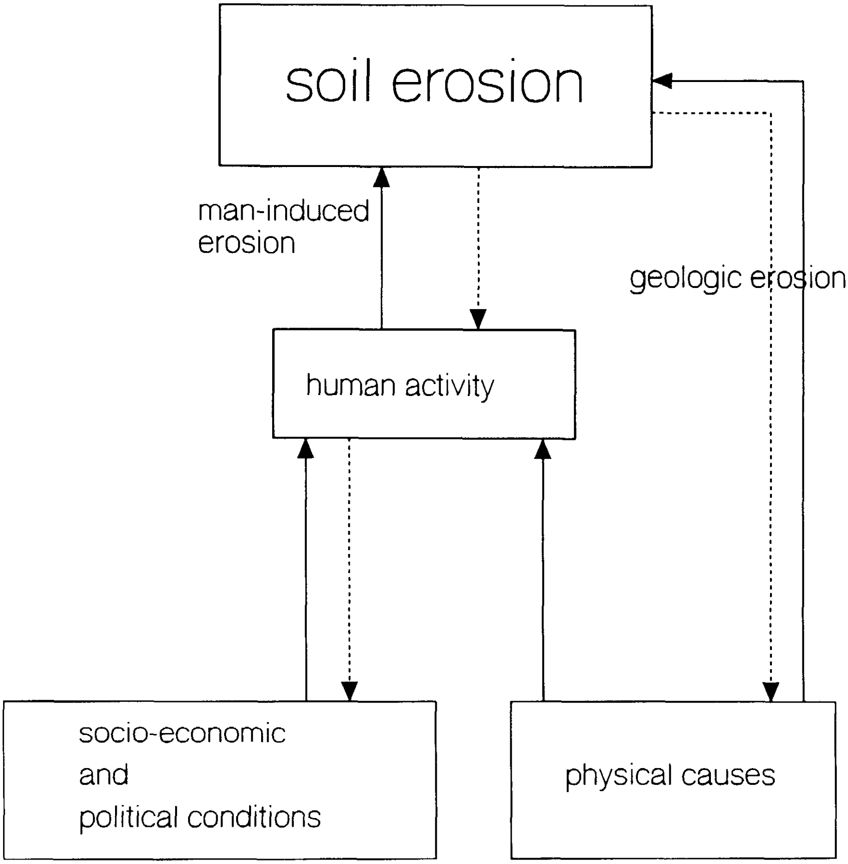
[1] more details about soil formation rates are given in Chapter 7.6.

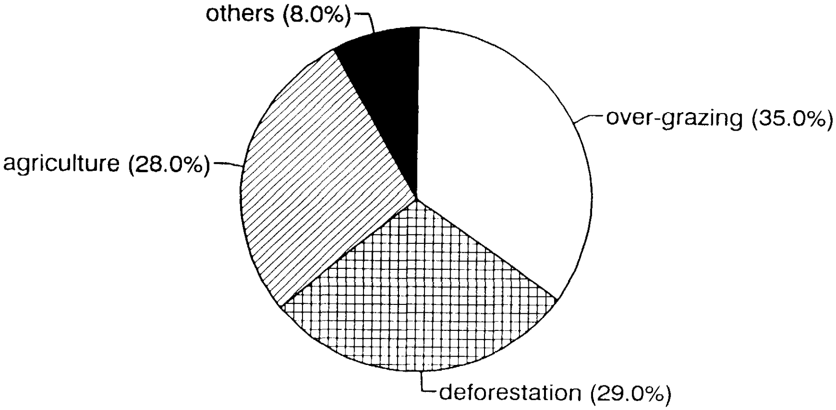
Figure 1-1: Physical as well as socio-economic and political causes are at the origin of accelerated erosion



Poverty of the farmers:

Small farmers are obliged to cultivate their land as often as possible in order to assure their subsistence. The lack of capital hampers the application of intensive conservation measures and the use of inputs to restore soil fertility. Decreasing soil fertility leads to the extension of the cropping area, soil mining and finally migration of the farmers. It is estimated that deforestation proceeds thirty times faster than reforestation (FAO, 1991). Overgrazing, deforestation and agricultural use are major factors for soil destruction (Figure 1-2).

Figure 1-2: Activities which destroy the soil resource (from Mostafa & Osama (1992))



Unbalanced population density:

Overpopulation usually is detrimental for the soil resource. Overpopulation is not only the result of a high population growth. Latest developments suggest that regional overpopulation is often due to migration caused by streams of refugees from wars or environmental disasters. For example, during the Sahel drought of the early 70s, 1 million Burkinese equal to one sixth of the countries population, left their homes (FAO, 1990).

Underpopulation also causes serious damage. Vogel (1988) described the deterioration of a traditional terraced agro-system in Yemen after the migration of the rural population to neighbouring countries. Soil conservation works in India were often abandoned due to the recruitment of the Gurka, which were the more active in soil conservation, into the British Army (Blaikie, 1985).

The institutional frame:

Government institutions insufficiently control the use of natural resources. The lack of defined conservation policy and laws to regulate the use of land, to define the ownership and to facilitate the commercialisation of goods prevents farmers to apply soil conserving production methods.

Politicians often give priority to short term benefits from export crops on the expense of soil conservation. Extension and conservation services are mostly inadequately equipped and trained and suffer from a lack of coordination (Sheng, 1989).

The land tenure system:

Only farmers who own their land or have secure access to their land for a long time are interested in longterm maintenance of this resource. Restricted access to fertile land for social groups or family members (e.g. young people, women) leads to the exploitation of steep slopes and marginal, fragile soils. The traditional heritage system sometimes favours an extensive fragmentation of the land which obstructs the adoption of conservation practices.

Tradition, believes and illiteracy:

The degree of illiteracy influences the adoption of new conservation practices and other cultural techniques. Small farmers commonly perceive erosion as a natural process and are not aware about its influence on productivity. Lack of knowledge exists along with effective local conservation methods (Tato & Hurni, 1992). The adoption of new practices always needs an effort and includes some risks. Farmers, as most other social groups, need time to adopt new ideas.

It is wrong to conclude from these comments that measures should be solely applied according to the socio-economic and political conditions. Soil loss by erosion is irreversible. Therefore, conservation activities can not be delayed until socio-economic and political conditions are favourable. Conservation thinking and conservation activities must proceed simultaneously.

2 Damages caused by erosion

Surplus rain water leaving a field on the soil surface is called runoff. Runoff first causes damage on the field (on-site damage) by entraining fertile topsoil and by reducing the available amount of water for plant growth. Once left the field, the runoff is enlarged from adjacent fields and may enter rills, ditches, small rivers, passes lakes and streams and finally reaches the ocean. On its way, sediment is picked up and deposited which causes further damage outside the fields (off-site damage). Both, on-site and off-site damage need to be considered in order to assess the overall economic and ecologic effect of erosion.

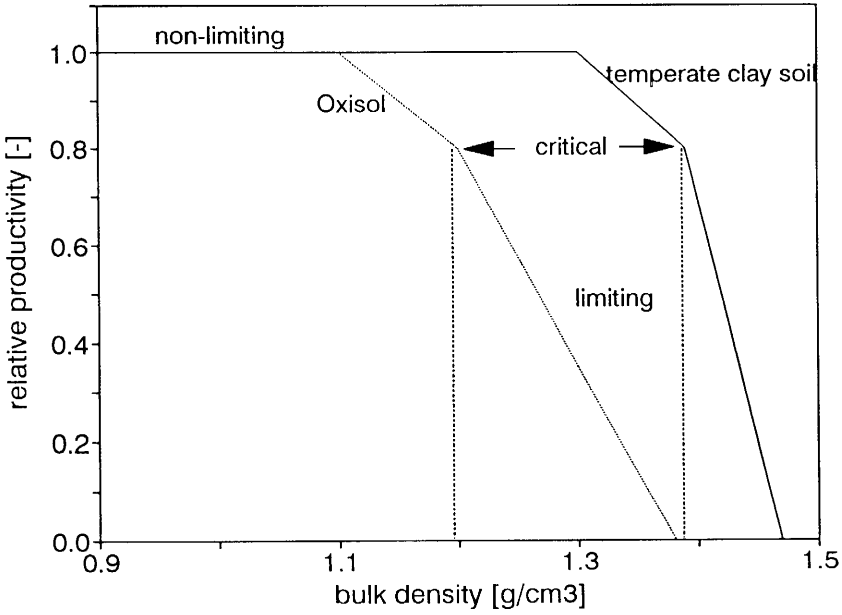
Soil conservationists intend to protect the diverse functions of soils. Functions like infiltration and storage capacity of a soil to prevent floods and its filter function to purify water are of major concern for the urban environment. In the rural environment, however, it is soil fertility.

2.1 Damages in agriculture (on-site)

Soil productivity depends on a number of physical, chemical and biological soil properties. The most important physical ones are texture, structure and depth of the profile. They determine the amount of water and air stored in the soil, its capability to infiltrate and conduct water, its possibility for root growth and the fines which can bind and deliver nutrients to the plant roots. In well structured, deep soils even heavy storms infiltrate. Structural damage on some tropical soils is more severe than on temperate soils as shown by the influence of bulk density on relative productivity (Figure 21-1). Profile depth and surface soil depth determine the water storage and the volume for water and nutrient uptake of the roots.

The chemical fertility depends on the amount of available nutrients in a soil which is governed by soil pH, organic matter content and other characteristics. These are greatly influenced by parent material and the conditions under which a soil was formed as well as by its use.

Figure 21-1: Impact of increasing bulk density of a tropical soil (Oxisol) and a temperate soil on productivity



Soil organic matter (SOM) and biological activity improve physical and chemical soil properties. The organic matter content of a soil is a function of soil climate (humidity, temperature, oxygen) and the supply of organic residues. The surface soil of most tropical soils contains between < 1 and 6 % SOM which, besides a large number of other functions, stores a major part of the plant available nutrients and stabilizes soil structure.

Soil erosion is a major reason for soil degradation. The texture of a soil generally becomes coarser because runoff preferably removes medium to fine particles like small aggregates, silt, dispersed clay and organic matter (selective erosion). Sabel-Koschella (1988) showed on an Alfisol in Nigeria that clay (< 0.002 mm) and silt (0.002–0.05 mm) are enriched in the sediment (Table 21-1).

Table 21-1: Sediment enrichment ratio[2] *for different grain sizes as measured on an Alfisol in Nigeria (Sabel-Koschella, 1988).*

treatment	**grain size [mm]**						
	<0.002	0.002-0.05	0.05-0.125	0.125-0.25	0.25-0.5	0.5-1	1-2
barefallow	1.6	1.6	0.	81.0	0. 9	0.6	0.8
plow	2.3	2.6	0.8	0.7	0.7	0.5	0.4
traditional	1.2	1.6	0.7	0.9	0.9	0.9	0.9
notill	1.5	1.0	1.2	0.9	1.0	0.9	0.8
mean	1.7	1.7	0.9	0.9	0.9	0.7	0.7

The enrichment of the fine soil fraction in the sediment accounts for the higher nutrient contents of the eroded sediment as compared to the original soil. Allison (1973; in Bouwman, 1989) reported a sediment enrichment ratio between 1.3 and 5 for soil organic carbon. Aina et al. (1979) demonstrated the enrichment of organic carbon and major nutrients under different cropping systems (Table 21-2).

Table 21-2: Sediment enrichment ratio for soil organic matter (SOM) and major nutrients under different cropping systems in Nigeria (Aina et al., 1979).

cropping system	**SOM**	**N**	**P**	**K**	**Ca**	**Mg**
barefallow	1.5	1.4	1.1	0.8	1.7	1.8
cassava monocrop	1.4	1.3	0.9	0.9	1.2	1.3
maize-cassava mix-crop	1.4	1.4	1.4	0.7	1.2	1.2
soybean-soybean	1.3	1.1	1.2	0.6	1.2	0.9
pigeonpea-pigeonpea	1.1	1.0	1.4	1.0	1.0	1.1
mean	1.3	1.2	1.2	0.8	1.3	1.3

The impact of soil erosion on production depends on the depth of the arable layer and the quality of the underlying horizons. Soil erosion is more detrimental the shallower the soil, this being aggravated in areas of irregular rainfall.

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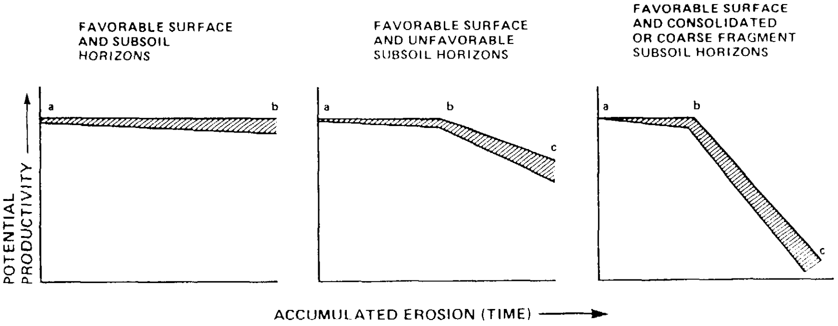
[2] sediment enrichment ratio = (percentage of a grain size class in the sediment) / (percentage of the size class in the original soil)

Loss of fertile topsoil is most harmful on extremely leached Ultisols and Oxisols of the humid tropics where the subsoil contains very low amounts of nutrients and SOM compared to the less leached soils of the drier areas. SOM counteracts P fixation which explains why P fixation increases with increasing topsoil loss. Mbagwu et al. (1984) showed that the removal of 5 cm of topsoil reduced maize yield by 95% on a leached Ultisol but only by 52% on a less leached Alfisol. Maize died off at 30 cm height on an Ultisol in Cameroon which had lost its topsoil during 5 years of barefallow (Nill, 1993).

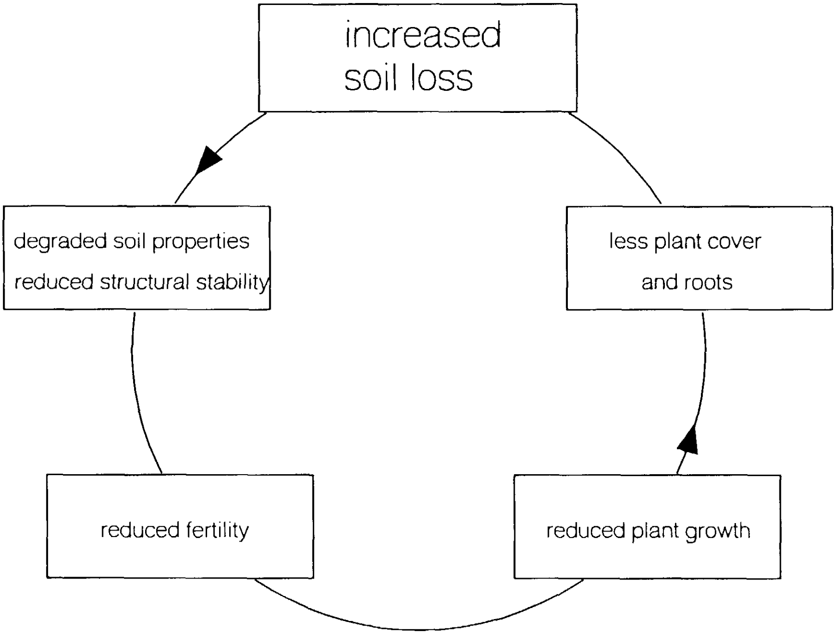
Some crops tolerate erosion better than others. Lal (1976a) measured 52% less maize yield but only 38% less cowpea yield if 10 cm of surface soil were stripped off. Yield decreases are generally in the order gramineae > grain legumes > tuber crops (El-Swaify, 1990).

Figure 21-2: Influence of soil erosion on potential productivity as related to soil type (Pierce et al., 1983)



The extent to which soil erosion effects productivity depends on the depth-distribution of fertility parameters in the profile (Figure 21-2). A deep and homogeneous soil acts with a slow productivity decline with increasing erosion whereas yields drop sharply with increasing soil loss on soils with unfavourable subsoil properties.

Figure 21-3: The vicious cycle of soil erosion



The economic damage of soil erosion is alarming. In Zimbabwe it is estimated that farmers loose three times more nitrogen and phosphorus by erosion than they apply to their fields. 20 to 50 US $ on arable land and 10 to 80 US $ on grazing land would be necessary to substitute these nutrient losses by fertilizer (FAO, 1990). It must be stressed that most erosion damages can hardly be cured (e.g. compaction, structure) or are completely irreversible (e.g. water holding capacity).

Damages to agricultural productivity are not only caused by degrading soil properties but also by direct impact of runoff. Roots and seeds are washed out of the soil. Seeds and seedlings on the foot-slopes are buried by the deposited sediment. Rills and gullies hamper access to the fields, impede farm operations and transport. Deep rills and gullies form drainage systems which drain the adjacent areas and lead to considerable loss of water.

Loss of soil fertility by soil erosion is a self-enhancing process. Soil erosion reduces structural stability and soil fertility. Reduced structural stability decreases infiltration and may increase the amount of transportable material. Reduced fertility causes poor plant growth, canopy cover and root soil interactions. In turn, runoff and soil loss are accelerated (Figure 21-3).

2.2 Off-site damages

Part of the surface runoff and the suspended sediment leave the fields and grazing lands and are concentrated in the surficial drainage system. Depending on the transport capacity of the flow, sediment is picked up or deposited. Rills are widened to gullies, channels are deepened (channel erosion) and stream banks are undercut (stream bank erosion). Ditches, roads and bridges are damaged. The fast runoff leads to a loss of water from the landscape and results in a large fluctuation of the rivers. Some rivers start to become only seasonal. The groundwater table is lowered which affects the vegetation and causes water shortages in wells.

Downstream sedimentation silts up irrigated fields, ditches, channels, dams and harbours. In areas with intensive agriculture, pesticides and nutrients dissolved in runoff or attached to the sediment become a serious problem. Disasters at this extent are difficult to quantify but national economies suffer important expenditures for their restoration.

The amount of sediment transported by some streams can be enormous. For example, the river Perkerra in Kenya receives an average of 195 t per year from each hectare of its 1310 km^2 large watershed (Dunne, 1975 in: Walling, 1984), corresponding to an average lowering of the watershed by about 15 cm in 10 years. Dam heights on three of Morocco's dams had to be increased in order to maintain the storage capacity. In order to preserve the current water storage capacity in Morocco, one new dam with 150 million m^3 needs to be constructed each year (FAO, 1993).

The frequent flood disasters in India are another well-known example. They are explained by the deforestation of the Himalayas. Sediments of the Brahmaputra and Ganges river in India have formed a 50000 km^3 large shallow in the Gulf of Bengal. The Kosi River in Bihar/India has buried 15000 km^3 of fertile land with gravel and sand (Kollmannsperger, 1979).

Studies on the west-coast of Sumatra showed that the sediment load of the rivers which was increased by deforestation, mining and channel construction led to the destruction of the coral riffs off-shore (Hettler, 1994). Riffs are rich fishing grounds and help to protect the coast line. These are some examples, out of a large number which could be cited here, in order to show the importance of off-site damage.

Present investments into soil conservation efforts are small compared to the immense investment in civil engineering aiming to repair the results of erosion. It is supposed that investing in soil conservation would have a higher cost-efficiency ratio and would protect both the soil resource and the downstream areas and facilities.

3 The erosion process

Soil erosion can be regarded as a result of four processes
(Foster & Meyer, 1972):

- detachment by raindrop impact
- transport by raindrop impact (splash erosion)
- detachment by the shearing forces of flowing water
- transport in surface runoff (sheet or interrill erosion, rill and gully erosion)

Rain falling on a soil causes increasing water saturation or/and the formation of a seal at the soil surface. As a result of both processes, infiltration into the soil is decreasing. Water on the soil surface occurs as soon as rain intensity exceeds the infiltration rate. Before any runoff can occur, a small amount of water is needed to humidify the soil surface (detention storage). Once the detention storage is filled up, ponding occurs in the small depressions and irregularities of the soil surface (surface roughness) which form the retention or depression storage. Overflow of some depressions provides excess water to the ponds underneath. These, if filled up, in turn spill their water further down-slope. Thus, more and more water is moving down-slope which may concentrate, dig out rills[3] of increasing size and finally may cut deep gullies into the soil.

The amount of surface runoff (SRi) during a storm can be expressed as:

$$SRi = Pi - (I + DS + RS) \qquad (1)$$

with	Pi	rain volume of storm i [mm]
	I	infiltration [mm]
	DS	detention storage
	RS	retention storage

Sheet and splash erosion occur in areas of shallow sheet or interrill flow (few millimeters deep) whereas rill erosion is caused by concentrated rill flow. In the rills, fine sediment is transported as suspended load whereas coarser particles are dragged along as bedload.

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[3] per definition rills can be closed by normal farm operations.

The amount of transported soil and the size of particles depends on the transport capacity of the flow. For a flow of given width, the transport capacity increases with increasing flow velocity (Figure 3-1) and flow depth. Both depend on slope.

If the overland flow on a smooth surface is regarded as a water sheet with a certain depth and velocity, a unit volume of water can be picked out as an element with a defined weight (w) (Figure 3-2). W equals a force with a down-slope component f1 parallel to the slope and a component f2 perpendicular to the slope. The down-slope force f1 increases with gradient and speeds up the velocity of the element. In the Manning formula which is widely used to calculate flow velocities in channels, velocity augments as a function of the 0.5 power of slope (Figure 3-3) whereas transport capacity increases with the cube of flow velocity (Engelund & Hansen, 1967).

Figure 3-1: Transport capacity increases with runoff velocity as shown by the amount of transported sediment (Auerswald, 1993)

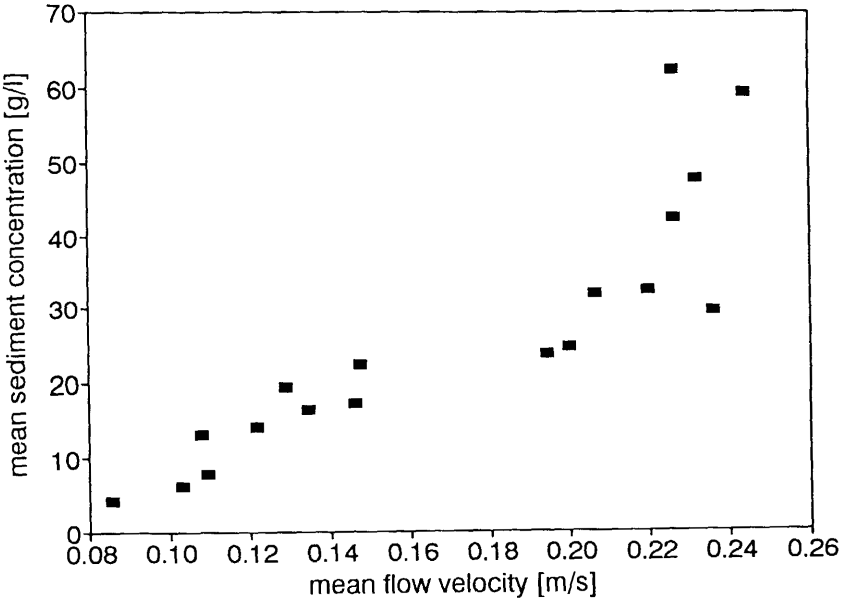


Figure 3-2: Runoff velocity increases with increasing gradient due to the down slope force (f1) which is a component of the weight (w) of a unit volume water

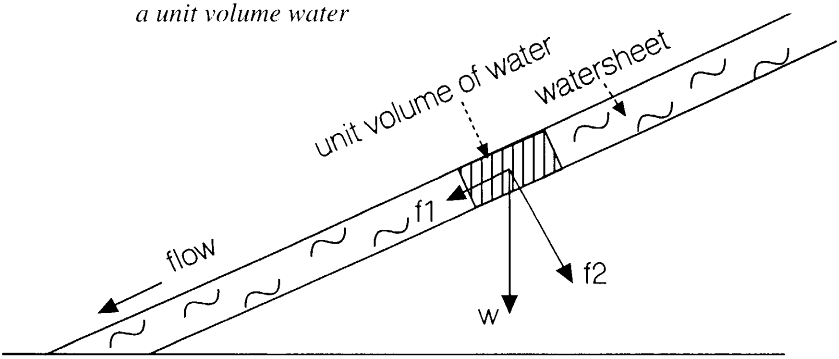
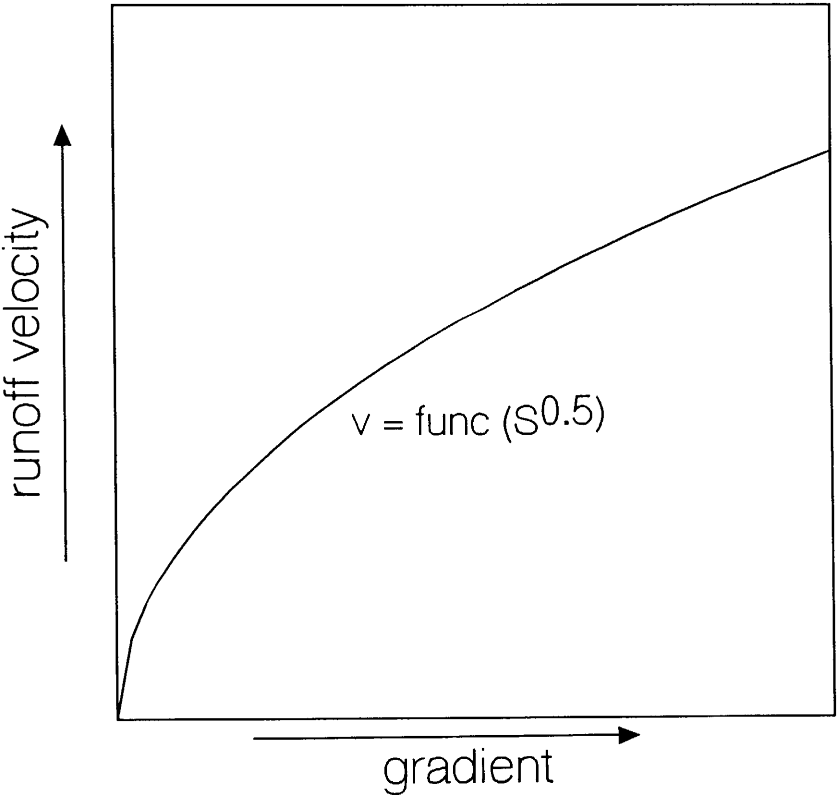
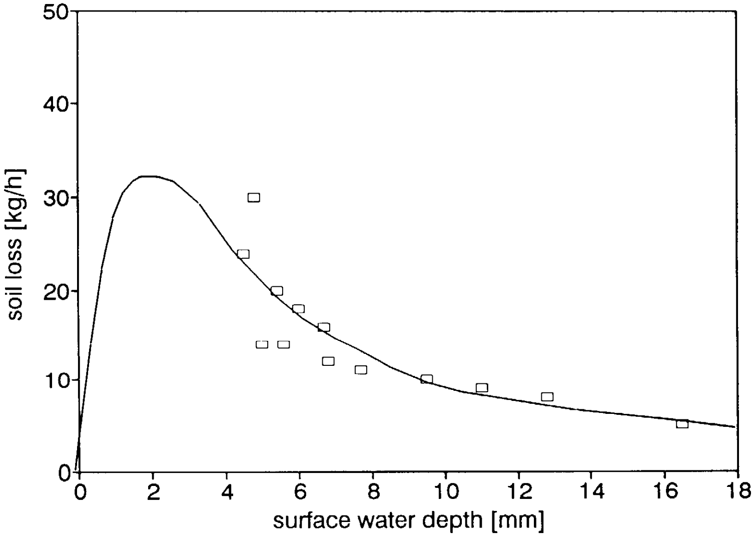


Figure 3-3: Runoff velocity as related to gradient



Flow velocity is not equally distributed over the depth of the flow. In a laminar flow, velocity (v) increases to the square of depth (d) (Horton et al., 1934) which means that the water layer at the water surface is much faster than the layer close to the soil. This velocity distribution causes a force which lifts up soil particles from the ground and transport them. Depending on their size, they are either rolled and dragged along the soil surface as bed load or lifted up into the flow and transported as suspended load. In the shallow sheet flow, velocity is small. However, soil loss is enhanced by the energy supplied by the pounding rain drops. The drop impact causes turbulence in the flow. Particles are heaved up, settle down and are heaved up again, thus, being transported towards the rills. In experiments of Mutchler & McGregor (1983), maximum soil loss occurred in flow depths of 2 mm (Figure 3-4).

Figure 3-4: A surface water layer decreases or increases soil loss depending on its depth (Mutchler & Mc Gregor, 1983)

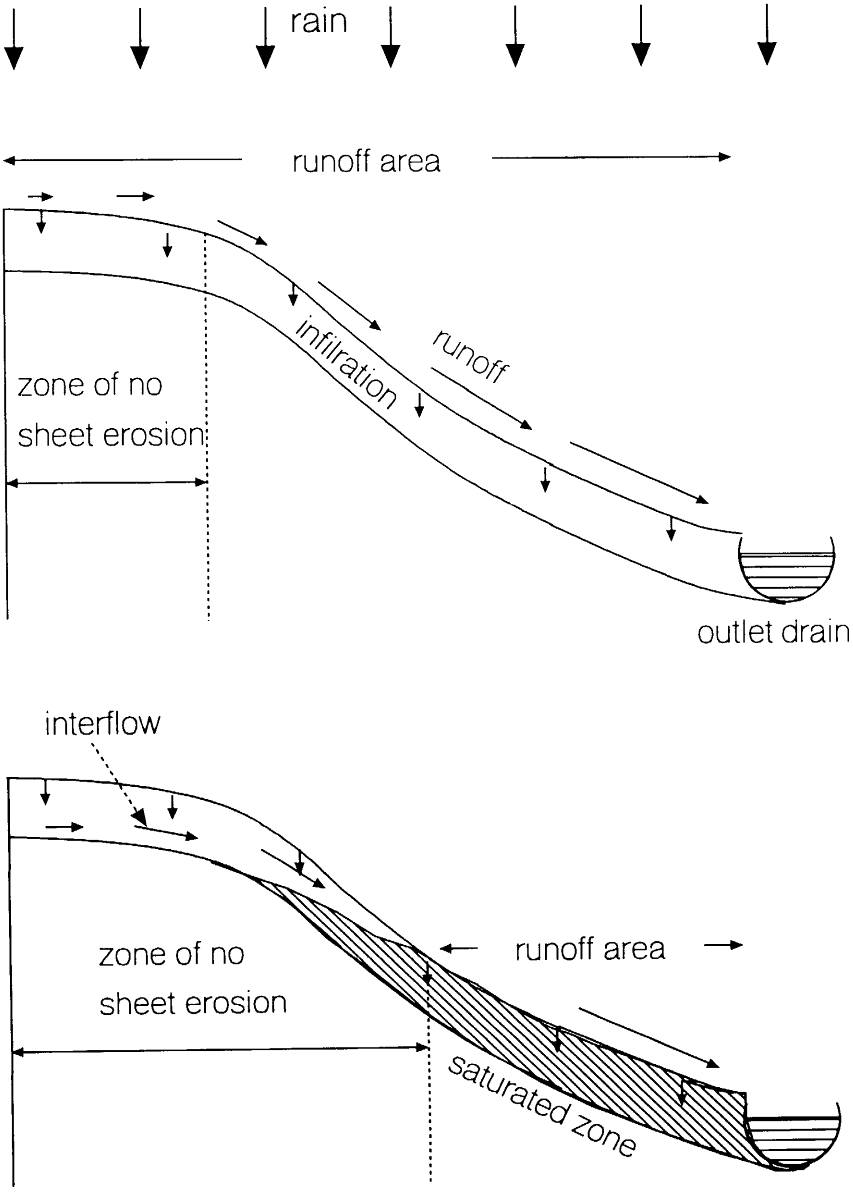


Flow depth in rills is generally deep enough to minimize the influence of raindrop action. The amount of soil loss in the rills, therefore, depends almost solely on the shearing forces of the flow and the saturation of its transport capacity. If the transport capacity of the rill flow is saturated with sediment from the interrill areas, the rills do not deepen. If the sediment concentration is smaller than the transport capacity, the flow picks up more sediment from the rills.

Runoff is distinguished into two basic flow patterns attributed to differences in runoff generation. Horton flow occurs if runoff is caused by a rapid sealing of the soil which limits infiltration right at the surface (Horton et al., 1934). Dunne flow occurs if runoff is caused by saturation of the soil profile due to excess of rain, dense layers or shallow soil depth (Dunne 1978). Horton flow is characteristic for structurally weak soils which have enough fine earth to form a seal. Infiltration is rapidly decreasing after the onset of a rain even though the subsoil may still be dry. The runoff coefficient may reach 70 to 80% for single rains. Soil loss is limited by the amount of available sediment rather than by transport capacity. Dunne flow is characteristic for structurally stable soils rich in oxides, clay and organic matter. High infiltration rates can be maintained until the soil becomes saturated. Even if enough sediment of transportable size is available at the soil surface, soil loss is limited by runoff. Transport by splash erosion becomes more important.

Rain falling on a slope causes either runoff from almost the entire slope (sealing soils with Horton flow) (Figure 3-5a) or only from part of the slope (soils with high infiltration rate and Dunne flow) (Figure 3-5b). Close to the upper slope end, runoff, even if present on structurally weak soils, is still too small and slow to transport soil. On structurally stable soils runoff seldom occurs on the upper part of the slope. It infiltrates into the soil and proceeds vertically or laterally in the soil. The lateral or interflow may add to soil saturation of the area further down-slope where runoff starts. Thus, runoff on both soil types but more so on soils with Dunne flow, leaves a 'zone of no sheet erosion'. Soil profiles on the watershed boundary are,therefore, relatively uneroded and can sometimes be used as a reference for the extent of erosion damage on the mid and down slopes.

Figure 3-5: Runoff generation on slopes with sealing (a) and permeable (b) soils (after Chorley, 1978)



The runoff volume produced by a rain depends on rain properties as well as soil and vegetation properties. Roose & Piot (1984) measured mean runoff coefficients (RC) of 20 to 40% and as high as 70% for individual storms. In own experiments with natural rain, RCs varied between as much as 30% on an Alfisol to as little as 1% on an Oxisol. Small rains of 2-3 mm could already generate runoff on sealing soils (Table 3-1) (Nill, 1993). Runoff starts on some soils only some minutes after the beginning of rain. Pontanier et al. (1984) found 1 to 4 min of artificial rain sufficient to generate runoff on hard setting soils ('sols hardés'), 2 to 20 min on Vertisols and 5 to 20 min for Ultisols. However, on the Acrustox shown in Table 3-1, 1.5 hours of rain with an intensity of 64 mm/h did not cause any runoff.

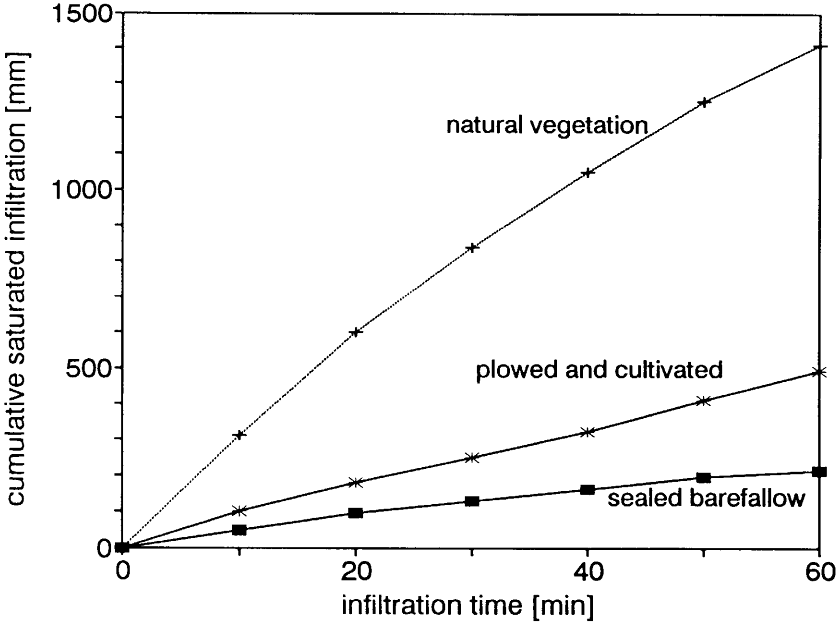
Table 3-1: Mean runoff coefficients from natural rain on seven soils (Nill, 1993)

soil	number of storms	runoff coefficient	smallest runoff generating storm
	[-]	[%]	[mm]
Paleustalf	81	30	2
Andisol	451	18	3
Kandiudalf	320	18	3
Trophumult	249	15	3
Tropudult	357	11	5
Hapludult	135	11	3
Acrustox	135	1	7

Soil covered by vegetation generally infiltrates more water than uncovered soil. Sabel-Koschella (1988) measured a 7 times higher infiltration volume under a natural savannah grass fallow (1410 mm/h) compared to a sealed barefallow (210 mm/h) (Figure 3-6). If plowed and cultivated, the same soil infiltrated 450 mm/h.

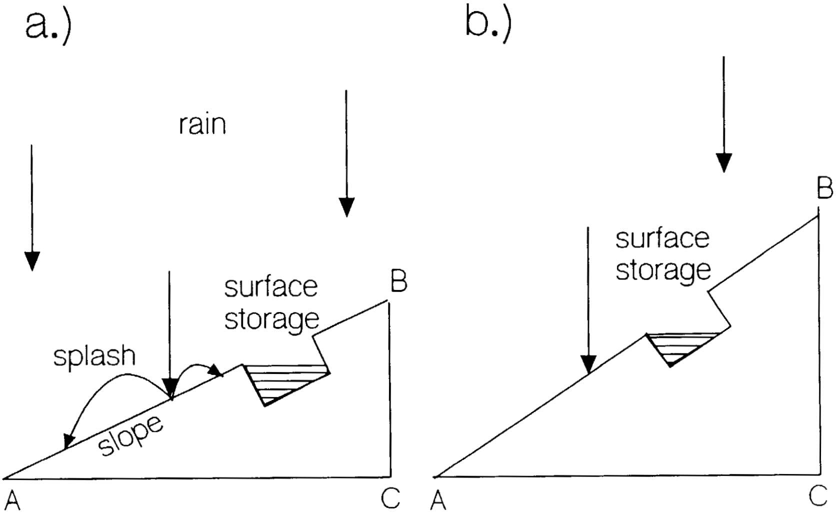
With increasing area, the total runoff volume becomes more. As shown for plots of 70 to 550 m^2 (Mutchler & Greer, 1980) and watersheds between 0.1 and 100 km^2 (Dunne, 1978), runoff per unit area becomes smaller with increasing watershed size due to longer travelling time of the overland flow. The longer the flow stays within the watershed the more water and soil can be retained in depressions or infiltrate.

Figure 3-6: Infiltration as influenced by management and vegetation



Experiments on the influence of gradient and slope-length on runoff led to varying results. The trials showed more, less or unaffected runoff volumes with increasing slope. In seven out of eight studies in the US, for example, annual runoff volume increased logarithmical with gradient, whereas slope length had no effect on the amount of runoff per unit area (Wischmeier, 1966). One reason for a positive relation between slope and runoff is the decreasing surface retention with increasing slope comparable to a cup of water which is more and more inclined (Figure 3-7). In contrast to these results in the US, Poesen (1984) measured less runoff with increasing slope on sealing soils. The compaction of the soil by impacting drops is less because the impacting force does not act perpendicular to the surface and the number of drops per unit area is smaller (Figure 3-7). Thus, on steep slopes surface sealing is weaker and runoff can be smaller than on gentle one's. Additionally, the number and depth of rills were higher on the steep slopes. The rills dissected the seals and enlarged the infiltrating surface area.

Figure 3-7: Rain volume per unit area and surface storage decrease on the slope of length AB with increasing gradient. Splash is always transported further downslope than upslope



4 Soil loss determining factors

4.1 Rainfall

One driving force for water erosion is rainfall. The raindrops which pound on the soil surface either infiltrate into the soil or leave the field as surface runoff. The rain volume which runs off on the soil surface not only depends on the properties of the soil, vegetation and topography, which will be discussed in the subsequent chapters, but also on the quantity, distribution and type of rain. Investigations showed that soil loss is largely determined by rain volume, energy load, intensity and their distribution within single storms (Flanagan et al., 1988) and during annual seasons (Lal, 1990).

An example for the last effect was given by Temple (1972) who noted 8 times more runoff from a rain at the end of the rainy season compared to a similar rain at the beginning of the rainy season.

Kinetic energy (E) of a storm is calculated by (Morgan, 1986):

$$E = 1/2 * mv^2 \text{ (J)} \qquad (2)$$

with m mass of falling rain [kg]
v terminal velocity of the falling drops [m/s]

Terminal velocity of raindrops increases with diameter to a maximum of 9 to 10 m/sec for the largest drops which have diameters of about 6 mm (Gunn & Kinzer, 1949; Laws, 1941; Laws & Parsons, 1943). Drop diameter increases with increasing storm intensity up to intensities between 76 and 100 mm/h (Carter et al., 1974; Hudson, 1963). Pressures between 2 and 6 MPa are exerted to the soil for very short times (50 ms) when a rain drop hits the soil surface (Ghadiri & Payne, 1981). This pounding action destroys aggregates, displaces particles (splash erosion) and has a sorting effect which leaves a thin layer of coarser particles at the soil surface. Thin water layers of 14 to 30% of the drop diameter in thickness enhance splash erosion whereas thicker layers protect the soil (water mulch) (Mutchler & Young, 1975).

Tropical rains are characterized by high and distinct intensity peaks. Maxima of up to 800 mm/h are reported from Jamaica (El-Swaify & Dangler, 1982). For northern Nigeria, Kowal & Kassam (1977) measured common peak intensities of 120 to 160 mm/h and showed that mean drop diameters where higher in tropical storms than in temperate areas. From western Nigeria, intensity peaks of 190 mm/h are reported (Wilkinson, 1975). Peaks occurred during the first five minutes in more than half of the storms. Hudson (1961) measured peak intensities of up to 340 mm/h in southern Africa. The erosivity of storms may additionally be enhanced by strong winds (Lal et al., 1980). In convective storms high windspeeds commonly coincide with intensity peaks (Raussen, 1990).

In order to predict soil erosion, Wischmeier & Smith (1958) found out that the product of a storms total kinetic energy (E) times its maximum 30 minute intensity (I_{30}) is linearly related to soil loss:

$$R = \sum_{j=1}^{m} (E * I_{30}) \ [N/h] \tag{3}$$

and

$$E = \sum_{i=1}^{n} (11.89 + 8.73 \log I_i) * P_i \ 10^{-3} \ [kJ/m^2] \tag{4}$$

with		
	R	longterm mean annual erosivity [N/h]
	E	kinetic energy [kJ/m2]
	I_{30}	maximum storm intensity during 30 min [mm/h]
	I_i	intensity for storm interval i [mm/h] for $0.05 < I < 76.2$ mm; for $I > 76.2$ mm $I = 76.2$ mm
	P_i	rainfall volume during interval i [mm]
	n	number of storm intervals with equal intensity [-]
	m	number of erosive storms per year [-]

The R factor of Wischmeier & Smith (1958) has proven appropriate for temperate areas. For tropical Africa, however, several constraints are to be faced. The calculation of reliable R factors depends on daily rainfall records over 22 year periods (Wischmeier & Smith, 1978). The necessary subdivision of individual storms into intervals of similar intensity and the recognition of the maximum 30 min intensity asks for self-recording raingages with low paper feed rates. These data are normally not available for a sufficient number of years and meteorological stations. The R factor overestimates large storms which cause only little runoff but underestimates small storms with much runoff (Foster et al., 1982; Laflen et al., 1985). Both occur frequently on tropical soils. Therefore, other authors proposed a number of different erosivity indices for tropical areas, which were either easier to calculate or which can be better applied to the local conditions. Fournier (1962) developed an index for river basins in West Africa:

$$C = \frac{Pm^2_{max}}{P_{ann}} (mm) \tag{5}$$

where P_{ann} is the annual amount of rainfall and Pm_{max} the rainfall amount during the wettest month. A regression of a modified version of Fournier's index with the R factor was used by FAO for the design of an iso-erodent map of Africa north of the equator and the Middle East (Arnoldus, 1978).

For southern Africa, Hudson (1986) reported that only intensities above 1 inch/h (25.4 mm/h) caused significant splash. Therefore, his index KE>1 considers only the energy of rain falling at intensities > 25.4 mm. For the calculation of kinetic energy he used:

$$KE = 29{,}8 - \frac{127{,}5}{I} \left[\frac{J}{m^2 * mm} \right] \tag{6}$$

with I storm intensity [mm/h]

The energy term as calculated by Kowal & Kassam (1977)

$$E_i = 41.4\, P_i - 120 \quad \left[\frac{J}{m^2} \right] \tag{7}$$

with P_i storm volume [mm]

described soil loss better than EI_{30} (Salako et al., 1991).

Delwaulle (1973) simplified the calculation of erosivity by substituting rainfall energy by rainfall amount (P_i) and Lal (1976b) additionally used shorter intervals for the maximum intensity (I_{max}):

$$EI_{30i} = Pi * I_{max} \text{ (mm}^2\text{/h)} \quad (8)$$

For I_{max} he chose the maximum 7.5 min intensity. Sabel-Koschella (1988) obtained similar results for m values between 5 and 25 min.

Roose (1977) evaluated mainly 13 stations in West Africa and found a linear regression between the EI_{30i} and monsoon type rainfall (P_i) between June and September of:

$$EI_{30i} = 1.001\, P_i - 10.004 \text{ [N/h]} \quad (9)$$

and a curvi-linear regression for high intensity storms during the rest of the year. As an empirical approach for the estimation of erosivity in West Africa he proposed:

$$R = (0.85\ (+/-)\ 0.05) * \text{Pann [N/h]} \quad (10)$$

Roose (1977) verified his regression for 20 rainfall stations and drew an iso-erodent map of West Africa. Further iso-erodent maps were compiled for Zimbabwe, Kenya, Tanzania and Uganda based on KE > 1 (Moore, 1979; Stocking & Elwell, 1976). An iso-erodent map for Zambia was supplied by Lenvain et al. (1988) using:

$$EI_{30} = 10.5\, Pm - 7.03\, b + 5.74\, c - 1.04 \text{ [N/h]} \quad (11)$$

with Pm mean monthly rainfall [cm]
b mean number of days with rains > 1mm [-]
c mean maximum daily rainfall per month [cm]

For the iso-erodent map of South Africa (Smithen & Schulze, 1982) erosivity was estimated by 'effective rainfall', a modified Fournier's Index and a 'burst factor'.

4.2 Soil properties

The influence of soil properties on soil loss can be ideally studied on runoff plots stripped from all vegetation for some years. Thus, it is assured that no influences of the former vegetation bias the results. Table 42-1 demonstrates the influence of soil properties on barefallow soils subject to 1200 mm/a.[4] Soil losses are as low as < 1t/ha on an Oxisol and as high as 280 t/ha on an Andisol (Nill, 1993).

Table 42-1: Soil loss on different barefallow soils corrected to an annual erosivity of 800 N/h (approx. 1200 mm/a).

soil type (US soil taxonomy)	mean annual soil loss[t/ha]
Acrustox	0.5
Tropudult	12
Trophumult	20
Hapludult	57
Kandiudalf	89
Paleustalf	147
Andisol	280

However, the soil properties causing these differences are not evident as mostly a range of soil properties found in different soils and their combination are responsible. The important soil properties decisive for the extent of erosion are listed in Table 42-2.

Mineral composition, especially the content of metal oxides, is known to influence soil erodibility. Metal oxides act as binding agents between soil particles, thus increasing structural stability. Soil loss on subsoils decreases with increasing content of Al- and Fe-oxides (Roth et al., 1974; Römkens et al., 1977). It is supposed that especially the amorphous part of the Fe-oxides is reactive. In experiments of Chauvel et al. (1976) kaolinitic clay mixed with > 5% iron oxides showed a self structuring behaviour (formation of shrinkage cracks) when drying out whereas at iron oxide contents < 5% it formed a coherent matrix. Only 3% of the total Fe-oxides were actively participating in the aggregation process. Rapidly sealing

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[4] Soil loss was calculated from soil erodibility values which were adjusted to 800 N/h mean annual erosivity (approx. 1200 mm/a).

soils generally suffer higher soil losses than non-sealing soils. The type of clay mineral also influences the formation of seals and the infiltration capacity of the soils. Soils rich in smectitic clay (e.g. Vertisols) swell and shrink with varying moisture content. Infiltration is, therefore, high in the dry state while cracks are open. In the moist state these soils become extremely sticky and plastic, cracks are closed and infiltration reaches very small values. Soils rich in kaolinitic-oxidic clay, on the contrary, are well aggregated in the dry and moist state. They are less susceptible to sealing than soils with 2:1 clays (Levy & van der Watt, 1988; Shainberg et al., 1991). The stable structure of the former enables high infiltration rates.

Table 42-2: Soil properties influencing soil erosion.

soil properties	
permanent	
↓	mineralogy
↓	Fe-, Al-oxides
↓	texture
↓	soil organic matter
↓	pH and exchangeable cations
↓	aggregate stability and size
↓	bulk density
↓	electric conductivity of soil water
↓	soil temperature
↓	antecedent moisture
variable	

Type and quality of the parent rock act on the texture of the formed soil. For example, sandy soils form from granite whereas clayey soils form from basalt. Soils high in silt and low in clay and sand are highly erodible. Erodibility decreases with a decrease in silt, regardless whether the corresponding increase is in the sand or the clay fraction (Wischmeier & Mannering, 1969). The high erodibility of silty soils is explained by their weak structural stability. They rapidly form surface seals upon raindrop impact. Erosion is less on clayey soils due to their better aggregation and on sandy soils due to their non-sealing surface. Fine sand (0.05–0.1 mm diameter), however, behaves like silt and is therefore attributed to the silt fraction for soil erosion aspects (Wischmeier & Smith, 1978).

Soil organic matter (SOM) influences soil loss by improving soil structure, root penetration, water capacity and infiltration. With increasing SOM, erodibility decreases (Wischmeier & Smith, 1978). SOM consists of very heterogenious particles ranging in size between several mm down to < 0.002 mm. Chemically very reactive organic molecules compare with more inactive one's and resistant components with rapid decomposing one's. The role of SOM as a binding agent is more important on soils deficient of other structuring components. Therefore, the importance of SOM decreases with increasing clay content (Wischmeier & Mannering, 1969). Valentin & Janeau (1989) found that structural stability was only improved by organic matter if the ratio of organic matter to clay was $\geqq 0.07$. In tropical cropping systems SOM is high after the fallow and declines rapidly during the cropping period. Thus, erodibility changes during a cropping cycle from low values during the fallow and at the beginning of cultivation to higher values towards the end of cultivation. In own trials the erodibility during the first year of barefallow after bush and forest fallows was only 40% and 80%, respectively, of the final erodibility which was reached after about 3 years of barefallow (Nill, 1993).

Aggregate size and stability have a permanent and a variable component, the latter of which reflects, among other influences, vegetation and management. Erodibility decreases with increasing aggregate stability as seal formation is delayed and infiltration increased. However, the effect of aggregate size is less clear. Mostly soil loss was found to become smaller with increasing aggregate size (Ekwue, 1991; Falayi & Lal, 1979) for aggregate diameters between 0.5 and 50 mm. Luk (1983) tested aggregate classes between 0.5 and 30 mm and found higher splash and sheet erosion from larger than from smaller aggregates. Wischmeier & Smith (1978) also attributed higher erodibilities to larger aggregates. However, Ambassa-Kiki & Lal (1992) only found a soil loss decrease up to 10 mm aggregate diameter. For aggregates between 10 and 100 mm no effect was measured.

The effect of the exchangeable cations is especially important on less weathered soils of the semi-arid to arid tropics. These soils are weakly structured due to low SOM and oxide contents and have often sandy to loamy texture. Na, as a monovalent cation, has a pronounced dispersing influence on soil structure. 3 to 5% of Na on the exchange complex are enough to disperse the soil (Shainberg, 1985) and erodibility increases with increasing Na content (Singer et al, 1980). Mg saturated soils were found to be more erodible than Ca saturated soils caused by the larger hydration shell of the

Mg ion which weakens bonds between soil particles. The stronger aggregation in the presence of exchangeable aluminium explains the higher stability of acid soils. The electrolyte composition of the soil solution also exerts an influence on soil loss through flocculation/dispersion effects. For example, saline soils rapidly disperse after dilution of the soil solution at the on-set of rain.

On previously moist soil runoff starts earlier and reaches higher runoff volumes than on initially dry soil. For this reason, rains occurring at the on-set of the rainy season generally cause less runoff and soil loss than rains at the end of the rainy season. Not much data are available about the influence of soil and water temperature on soil loss. With increasing temperature water viscosity decreases. Aggregate destruction caused by the pressure of encapsulated air during rapid wetting of the aggregates is enhanced if the wetting velocity is higher. Water mulch by less viscose water (= „more liquid") will be less protective against raindrop impact. Auerswald (1992) explained a soil loss difference of 17 % between artificial rain applied in the morning and in the afternoon with a temperature difference of 8 °C.

4.3 Topography

Topography influences soil loss by the length, gradient and shape of a slope. Soil loss increases very sensitively with gradient and commences already on slopes < 1 %. Mutchler & Greer (1980) measured losses up to 5 t/ha from dry soil and up to 11 t/ha from wet soil on a 0.2 % slope when a simulated 60 min storm was applied. In Senegal, annual losses from groundnut fields on a 1 % slope reached 15 t/ha (Fournier, 1967).

Uncertainties arise, however, where the influence of gradient has to be quantified. Most studies propose an equation for soil loss from interrill areas of the form

$$A = a * S^b \tag{12}$$

with	A	soil loss
	S	gradient
	a, b	constants

Values for b between 1.35 to 2 were suggested (Hudson, 1986; Hudson & Jackson, 1959; Musgrave, 1947; Zingg, 1940). A value of b = 0.67 was suggested for soil loss from rills (van Liew & Saxton, 1983). In the USLE the influence of gradient is described by

$$S = (65.41 * \sin^2 \alpha + 4.56 * \sin \alpha + 0.065 \ [-] \qquad (13)$$

with α slope gradient [degrees]

More recent analysis of slope/soil loss data revealed a change of the relationship at > 9 % slope (McCool et al., 1987). Soil loss for very low slopes was found to be overestimated by the LS factor (Murphee & Mutchler, 1981). Runoff on low slopes flows slowly and quickly forms a water layer deep enough to act as surface mulch. It further became apparent that soil loss depends on the ratio of rill to interrill erosion. Soil loss is higher on soils very susceptible to rilling (McCool et al., 1989) and the potential for rilling is greater on steep slopes (Mutchler & Greer, 1980). S factors for the Revised Universal Soil Loss Equation (RUSLE) are, therefore, calculated by:

$$S = 10.8 * \sin\alpha + 0.03 \quad [-] \qquad (14)$$

$$S = 16.8 * \sin\alpha - 0.5 \quad [-] \qquad (15)$$

$$S = 3 *(\sin\alpha)^{0.8} + 0.56 \quad [-] \qquad (16)$$

with α slope gradient [%]

Equation 14 and 15 are used for slopes > 4.6 m long and gradients of < 9% and > 9%, respectively. On slopes < 4.6 m long rill erosion is negligible on most soils and equation 16 is to be used.

Increasing slope length enhances soil loss as more runoff can accumulate on long slopes. For slope length, the following term is used (Wischmeier & Smith, 1978):

$$L = [l / 22.1]^m \quad [-] \qquad (17)$$

with l slope length [m]
m slope length exponent [-]

The product L* S is called the topography or LS factor. The LS factor was derived from soil loss data of slopes ranging from 3 to 18 % and 9 to 90 m (30 to 300 ft) long (Wischmeier & Smith, 1978). Beyond these ranges no measurements were taken. However, the equation was regarded applicable by the authors to slopes 300 m long and 50 % steep (cf. Chapter 7.3). Foster et al. (1982) estimated that the LS factor can be applied in the tropics to slopes up to 25 % whereas Hurni (1980) used the LS factor for slopes > 50 %. The LS factor was verified in West Africa on slopes between 4.5 and 23.3 % (Roose & Sarrailh, 1989) whereas Sheng (1990) reported an overestimation of soil loss by the LS factor on 30 % slopes.

The effect of slope length on soil loss is interrelated with slope steepness. This is expressed in the slope length exponent m of the LS factor which is 0.5 for slopes > 5 % and decreases to $m = 0.15$ for slopes $\leq$ 0.5 % (cf. Chapter 7.3). In the earlier development of the equation, an exponent of 1.6 was used (Zingg, 1940). Dangler & El-Swaify (1976) reported an underestimation of soil loss by the L factor as used by the USLE. However, on soils from West Africa $L^{0.3}$ was found to give better results (Roose & Sarrailh, 1989). In the RUSLE, m varies between 0.02 and 0.83 depending on the soils susceptibility to rilling (McCool et al., 1992).

Soil loss is also influenced by the shape of a slope. It decreases in the order convex > regular > concave slope form. On a convex slope, where the gradient increases in the order up-slope < mid-slope < down-slope, a large runoff volume coincides with the maximum gradient (down-slope). On the contrary, on a concave slope the maximum gradient is up-slope where runoff is still smaller.

4.4 Cover, tillage and protection techniques

Cover, tillage and protection techniques depend on management, in contrast to rain erosivity, soil erodibility and slope. This makes them of foremost importance to soil conservation. Management practices can be distinguished according to the basic erosion processes that they influence:

I. Methods which reduce the runoff volume or the sediment transport capacity

All methods which increase water infiltration or reduce runoff velocity also reduce soil loss. If runoff is slowed down, the water stays longer on the field and gets more time to infiltrate. Additionally, the water layer on the soil surface becomes deeper and protects the soil from raindrop impact (cf. Chapter 3).

These methods include:

- ▷ reduced tillage
- ▷ no-tillage
- ▷ tillage and planting across the slope (contouring)
- ▷ soil cover by inorganic or organic mulch
- ▷ surface forming practices (ridging, tied-ridging, bedding)

II. Methods which reduce the slope length

Thereby, the runoff producing up-slope area and runoff volume are reduced. Soil may still be transported but physical obstacles divert runoff and/or cause deposition. This group includes:

- ▷ hillside-ditches
- ▷ filter-strips with grasses, hedges or tree rows
- ▷ earthen and stone bunds
- ▷ terraces

The single methods mentioned above are described and discussed in the following.

4.4.1 Reduced tillage and notillage

Tillage breaks down soil aggregates, disturbs soil structure, pore continuity, and biological activity and produces transportable soil material. Reducing tillage intensity and frequency increases the number of continuous pores, maintains aggregation and reduces organic matter decomposition. Thereby, binding agents between soil particles like fine roots, fungal hyphae, root and bacterial exudates are conserved. The soil stays more consolidated as compared to tilled soil. Thus, infiltration and resistance against impacting drops and shearing forces of the water are higher than on tilled soil.

4.4.2 Contouring

Contouring necessitates that all tillage and planting operations are carried out across the slope. These operations produce a low surface relief across the slope. Runoff is slowed down and the surface storage is increased. With increasing gradient, the surface storage capacity decreases (cf. Figure 3-7) and the risk of spilling over with consequent rill formation increases. Therefore, the efficiency of contouring reaches a maximum on slopes between 3 to 8% (Wischmeier & Smith, 1978).

However, the effect of contouring is uncertain in handtillage systems where the soil is tilled from the bottom of a field moving up-slope and were a general down-slope movement of the soil from hoeing can be observed. Thus, tillage in such systems is not on contour in the strict sense. Only contour planting can be achieved.

4.4.3 Soil cover by organic mulch

Surface cover is one of the most efficient measures for soil loss reduction. Organic material is easily available in areas with sufficient rain. Residues of the previous crop, weeds and additional mulch material from outside the field can be used (leaves; twigs from bushes, hedges; straw; wood cuttings; organic household waste like peelings, shells and husks). Left at the soil surface, they protect the soil against the pounding drops and prevent seal formation. The stalks and leaves form barriers where the water ponds (= water mulch). Runoff is slowed down due to twisted pathways. Additionally, residues and mulch reduce variations in soil temperature, humidity and thereby biological activity and improve structure and infiltration. Earthworms which move to the soil surface in order to pick up food create large continuous pores. Mulch efficiency depends on the surface area covered by the material (cf. Figure 74-2).

Incorporation of the residues diminishes the coverage. The deeper the residues are incorporated into the soil, the less protection they offer against erosion. The efficiency of surface mulch may also be reduced on soils with extremely unstable structure (e.g. soils with high sodium saturation or hard setting soils) where aggregates already disperse on moistening[5]. On such soils superficial incorporation may provide higher infiltration rates because the

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[5] A test can be carried out by submerging dry aggregates or fragments of 1-2cm diameter in water. Unstable aggregates break down immediately

decomposition products of the residues stabilize soil aggregates and the residues act as stabilizing framework.

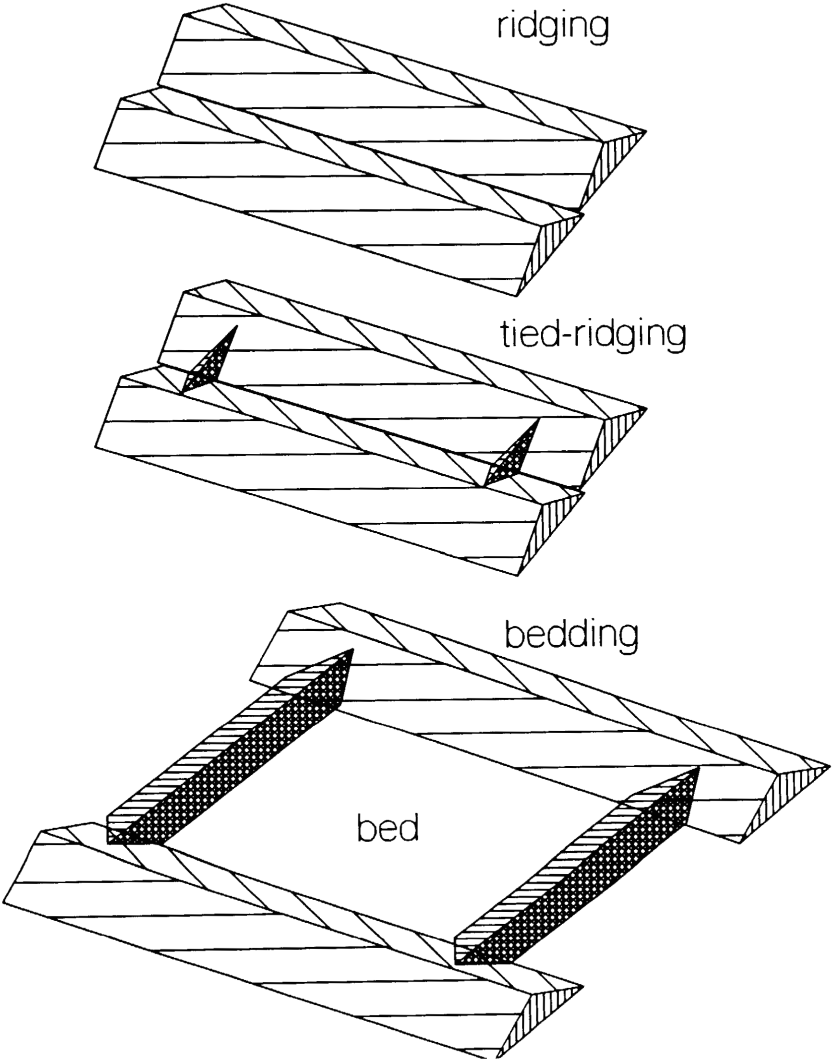
4.4.4 Inorganic mulch

Several forms of plastic foils are used in intensive agriculture and gardening to protect the soil, reduce evaporation and suppress weed growth. However, these mulches play a marginal role in small scale agriculture. An important natural mulch material are stones and gravel of various sizes. Stone pavements and surficial gravel concentrations on soil surfaces frequently indicate erosion processes. The gravel was enriched at the surface by the selective removal of the soil. With increasing cover of the surface, the soil underneath becomes protected. However, the active use of gravel as mulch material deserves much more attention than recently given. In highly leached soils of the humid tropics, the use of gravel from basic rocks may additionally deliver some nutrients.

4.4.5 Surface forming practices (contour ridging, heaping, tied ridging, bedding etc.)

These methods create physical obstacles (Figure 445-1) which reduce especially the slope length. Runoff is slowed down, stopped or deviated sideways on a reduced gradient. Alike contouring, the protective effect of these methods depends on the gradient of the slope, the side slope and height of the obstacles and their distance from one another. Contour ridges are small earthen dams of about 10 to 30 cm height placed across a slope.

Figure 445-1: Ridging, tied-ridging and bedding reduce slope-lenght and decrease runoff velocity



The protection by ridges is low on very low slopes because soil loss is generally low. On steep slopes, it is low because the amount of water which can be retained by a ridge decreases with increasing gradient. A 15 cm high ridge does not store any water on slopes >25 % (Foster et al. 1992). At the same time the risk of spilling over and of break throughs in the ridges is enhanced. Thus, maximum efficiency is obtained on medium slopes (cf. Figure 751-1). The efficiency of ridges also depends on ridge height and the side slope. The higher the ridge, the more water can be stored. The lower the side slope of the ridge, the slower the runoff. Meyer & Harmon (1985) showed that on side slopes < 0.5 % the suspended sediment in the runoff is deposited and most of the sediment originates from the ridge-sides. Above 2% side slope deposition ceases and the sediment is moved out of the field. With side slopes of 5–6 % rilling of the furrows commenced.

The effect of furrows also depends on storm size. Large storms may surpass the carrying capacity of the furrows and cause overflowing of the ridge top. Overflowing may cause very severe damages and should be avoided in any case. Thus, efficiency is less for areas with frequent large storms. The 10 year storm which is the largest, regularly occurring storm within 10 years, can be used to calculate the efficiency of contour ridging for an area.

As the ridge-sides act as runoff producing area for the furrows, the runoff producing area increases with the length of the furrows and so does the runoff volume. In order to avoid overflowing of the ridge tops or rilling, furrow length should be limited.

Not much is known about the effect of **ridges placed along the slope.** Measurements on slopes of 7 to 13 % indicate an erosion enhancing influence (P factors[6] between 4 and 6). On slopes of 13 to 20 % the negative effect was less pronounced (P = 0.31 to 3.4) but still important (Reining, 1991).

Heaps of varying sizes are frequently used especially for tubers but also for other crops like groundnut or bambara nut. The loose, rich topsoil used for the heaps is favourable for tuber formation. Water logging is prevented by the heaps and mineralization is enhanced. However, not much is known about the effect of heaping on soil erosion. Unfortunately, size and arrangement of heaps on a slope are mostly not described in literature.

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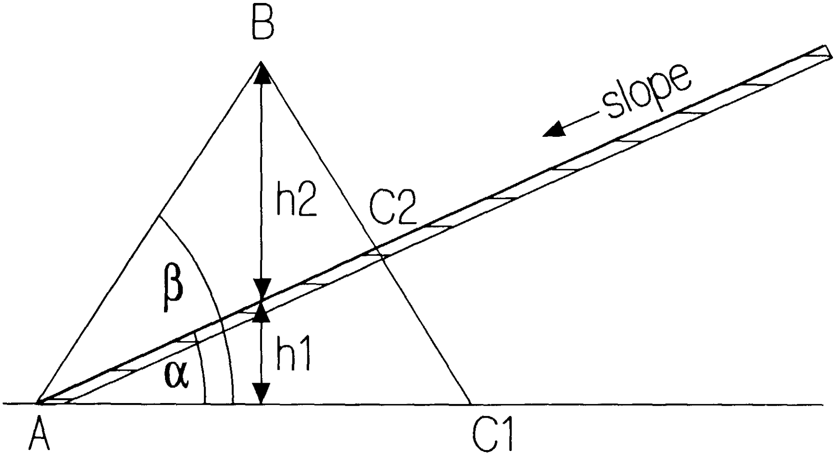
[6] A P Factor < 1 indicates less erosion compared to a barefallow field whereas P > 1 indicates no protection. More information is given in Chapter 7.5

Figure 445-2: Relation between slope and height of heaps on the slope



Heaps on a slope A → C2 enlarge the average gradient α by the gradient ß-α on the sidewalls (Figure 445-2). Taking the maximum angle of about 40° (α+ß)[7] into account which forms if topsoil is poured on a heap, the actual gradient of the slope is changed on the heaps into a gradient of about 80 % (= 40°) on the sidewalls. This also implies that the heaps become lower with increasing slope as demonstrated by heap height (h1+h2) for heap ABC1 on level ground compared to h2 for the heap ABC2 in Figure 445-1. Runoff from the heaps enters into the furrows among the heaps and moves downward in a concentrated flow. Runoff volume depends on the size and arrangements of the heaps. Compared to small heaps, large heaps have a larger runoff producing sidewall area and less drainage paths between the heaps. If the heaps form furrows along the slope, rapid water movement results. If they are arranged in quintuples, the water has to flow around the heaps and a reduction of the flow velocity can be assumed. If the heaps are arranged up and down-slope, runoff is directed straight down-slope and will reach a higher speed.

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[7] The maximum slope angle for heaped up soil (angle of repose depends on the particle size distribution. Surface soil < 40 mm = 38.7°; aggregates 1-2 mm = 40.2°; surface soil sieved to < 2 mm = 37.6° (Auerswald, 1993).

The influence of heaps on soil loss further depends on surface soil depth. On soils with a thin surface horizon, all soil is scraped together for the heaps. The underlying soil which can have very different properties is exposed. A pattern of very different soil erodibilities is created this way which can include, for example, a less erodible surface soil on the very steep side-walls of the heaps and an erodible subsoil between the heaps. Overall soil loss should be notably increased in this case.

4.4.6 Bufferstrips

Bufferstrips (filterstrips) are < 1 m to several m large strips of planted grasses, hedges or natural vegetation on contour. They slow runoff down and maintain higher infiltration rates within the strips as compared to the adjacent field. If runoff occurs, soil is transported within the cropped area and deposited in the vegetated bufferstrip. The runoff either infiltrates completely in a bufferstrip or crosses the strip. If all runoff infiltrates, all transported sediment is deposited. If part of the runoff passes through the strip only a part of the sediment is deposited. First, the coarser, heavier sand particles and aggregates settle whereas the small particles of clay and organic matter are further transported and may leave the strip on its lower side. Thus, quantitatively a large part of the sediment can be retained by a bufferstrip while an important amount of fertile soil is still lost. Compared to temperate soils, this is more relevant on leached tropical soils. Their low cation exchange capacity (CEC) is largely associated with the organic matter. Another inconvenience of strips with incomplete infiltration is that the water which leaves on the lower side can speed up again and pick up new sediment.

1 to 4 m large bufferstrips on 4-20 % slopes can reduce soil loss by 10 to 90%. Strips with natural fallow vegetation can already be spared out when cultivating the field. Compared to such strips, planted strips have a lower efficiency in the 1st year. Efficiency declines after an optimum due to increasing sedimentation in the strips. A 40 m wide bufferstrip for example dropped from 99 to 75 % efficiency during 9 months (Barfield & Albrecht, 1982). In agreement with other authors, Schauder & Auerswald (1992) could show that a 30m wide grass strip on a 8 % slope retained 64 % of the sediment which entered the strip (ca. 1t/m strip width). The efficiency increased with increasing strip width (cf. Figure 752-1).

Bufferstrips are more acceptable to farmers if they give some yield. Introduction of fruit trees or woody species may be of more interest than pure grass strips and can encourage farmers to protect the strips against fires. Some common grass and tree species used for bufferstrips and biological control are listed in Table 42-1 Annex. An extensive databank on suited woody species is available from ICRAF/ Nairobi[8].

4.4.7 Contour bunds (stone bunds, earthen bunds, diguettes)

Bunds are a form of high ridges which are mounted at a distance of several m from one another (Figure 447-1). They can be constructed from soil or stones or both combined (earthen core with stones on the outside) (Figure 447-2). Bunds are used to control erosion and to conserve water. Impermeable bunds (from earth or with an earthen core) stop runoff completely and direct it sideways. They are more rigid in their action and are to be constructed more solid than permeable bunds. Waterlogging in front of impermeable bunds can be a problem for sensitive crops.

Runoff hitting a permeable bund (e.g. stone bund) is slowed down, slowly penetrates the bund and leaves partially on its lower side. Reduced velocity also favours infiltration on the lower side. However, the runoff may regain velocity and pick up new sediment. Thus, the area below a bund may be eroded whereas the area in front of the bunds is sediment-enriched. Therefore, small terraces form after a couple of years.

Bunds are recommended on slopes of less than 12% (Table 449-1) but are also used on steeper slopes with success. In order to diminish maintenance work, the bunds should be planted to permanent vegetation (grasses, woody species, trees).

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[8] Multipurpose Tree & Shrub Database (ca. 120.- US$) ICRAF, P.O. Box 30677, Nairobi, Kenya

Figure 447-1: Contour bunds on a 10% slope. After some years small terraces form naturally

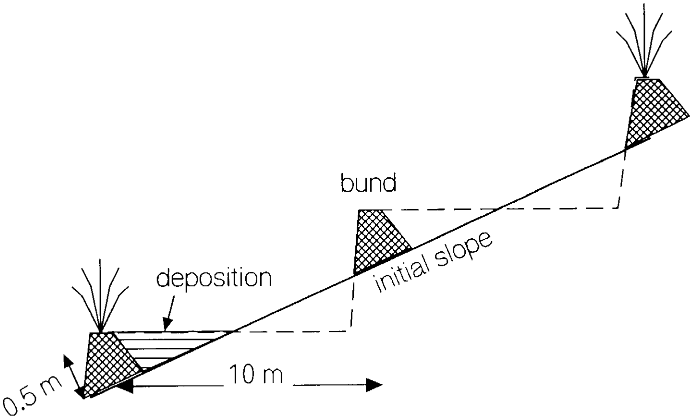
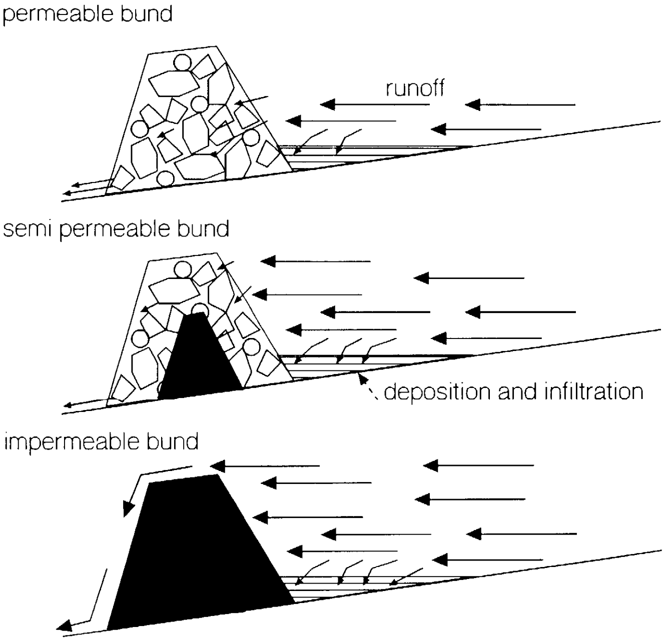
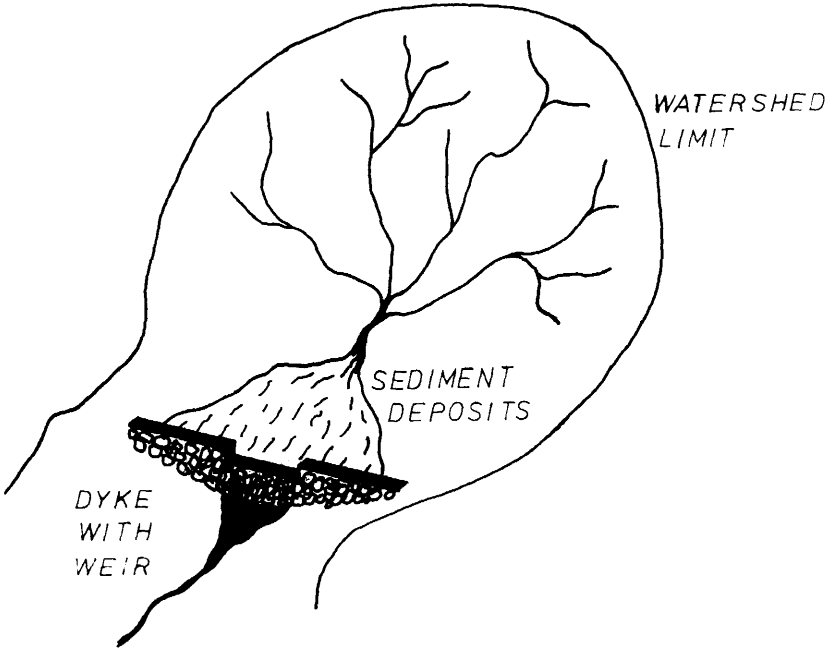


Figure 447-2: Bunds are constructed as permeable, semi permeable or impermeable works



Dykes are a large version of bunds which is especially used in semi-arid to arid areas to store water and to slow down torrential floods. They are the transition to the even larger dams. Alike bunds, dykes are constructed as permeable (digues filtrantes) or impermeable obstacles (digues déversantes). Between the two extremes there are a couple of intermediate solutions with impermeable lower and permeable upper parts (Figure 447-2). In the first case, the water is slowed down and momentarily stored while it percolates through the dyke. In the second case, the water is stopped and stored behind the dyke. The water quantity exceeding the dykes storage capacity either flows over the top of the dyke or is conveyed by a weir or spillway. Behind the dyke, water infiltration is increased and sediment deposited (Figure 447-3). The deposits are either used for irrigated cultivation in the border zone while the water is retreating or for a crop which uses the water stored in the soil. Clayey deposits serve for brick construction.

Figure 447-3: Dykes form deposits which are used for cultivation



4.4.8 Protective ditches

Several types of ditches can be established on contour to slow down runoff and collect eroded sediment. Drainage ditches are constructed by disposing the excavated soil down-slope of the ditch (Figure 448-1). The ditches are laid out on contour or with a slight side-slope of 0.4 to 0.5% (see Hudson, 1975for planning principles). Drainage ditches reduce slope length into several segments. The down-slope concentration of runoff is thereby avoided. The sediment spilled into the ditches needs regular excavation. Maintenance efforts are therefore high.

The Fanya Juu terraces are a modified version of drainage ditches especially used in East Africa (Figure 448-1). The excavated soil is disposed up-slope thereby forming an earthen bund which traps further sediment.
Hillside ditches (Figure 448-2) are a form of reverse slope or level bench terrace. The bench is generally not used for cultivation but as foot path or road.

Figure 448-1: Schematic diagram of drainage ditches and Fanya Juu terraces

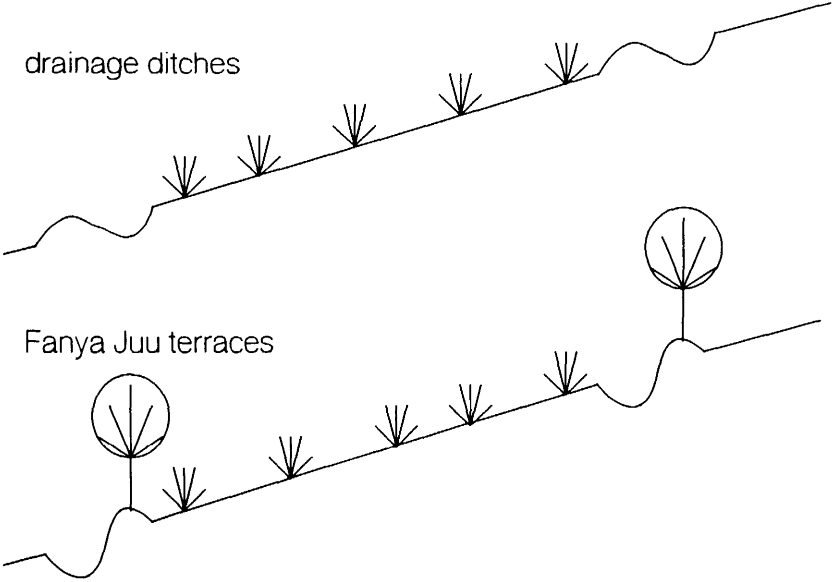


Figure 448-2: Hillside ditches facilitate access and transport (after Sheng, 1989)

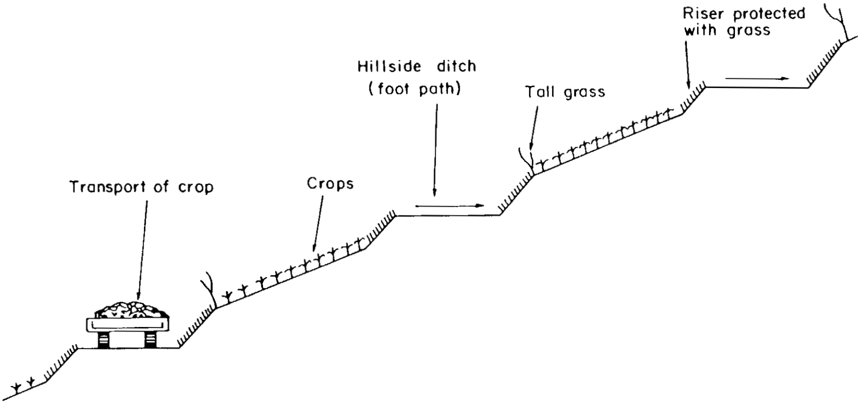
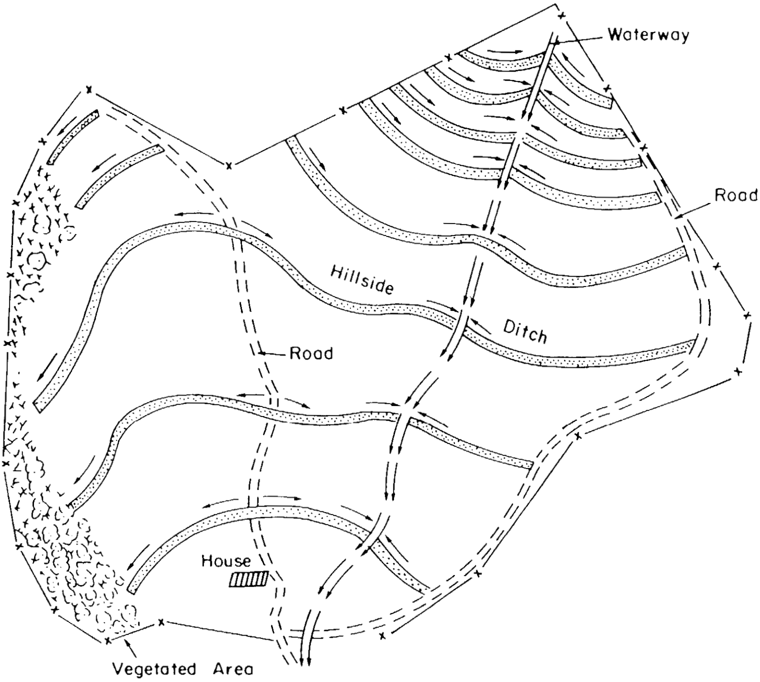


Figure 448-3: Watershed conservation plan with hillside ditches (Sheng, 1989)



Cultivation is carried out on the graded interterrace area along with further protection measures. Hillside ditches may be used for slopes of up to 47% (Sheng, 1989). They divide the slope into shorter segments and divert runoff at non-erosive velocity.

A version of the hillside ditch is the broad based terrace used in mechanized agriculture. It can only be used on gentle slopes. The interterrace space and the terrace interval on the graded terrace is used for cultivation. The terrace is kept as low as possible in order to allow the passage with farm equipment. Figure 448-3 shows how these measures are laid out in a watershed or farm. The runoff collected by the ditches must be disposed safely by constructed waterways or by conveying it into densely vegetated areas.

4.4.9 Terraces

Terraces are described by a number of characteristics. Important features are the vertical height, the horizontal length, the ratio of the raiser b/a, the reverse slope a, the side slope, the terrace interval and the interterrace interval (Figure 449-1). They are used for a range of purposes as:

- ▷ to divide a slope into shorter segments
- ▷ to reduce the slope angle on the terrace interval
- ▷ to convey the surface runoff to controlled water ways at a non-erosive velocity
- ▷ to harvest water from interterrace intervals for water conservation
- ▷ to store water for paddy cultivation
- ▷ to store sediment eroded from the interterrace interval

A number of different terrace types was developed to cope with these tasks. Most of them can be described as modified bench terraces (Figure 449-2).

The level bench terrace has a wide-spread use for paddy cultivation whereas the reverse slope and outward slope bench terrace are favourable for upland crops of the humid tropics. The conservation bench terrace is used in semi-arid to arid areas for water harvesting. Bench terraces are used on slopes between 12 and 50% and are built by hand, animal drawn equipment or machines.

Figure 449-1: Key parameters for terrace planning

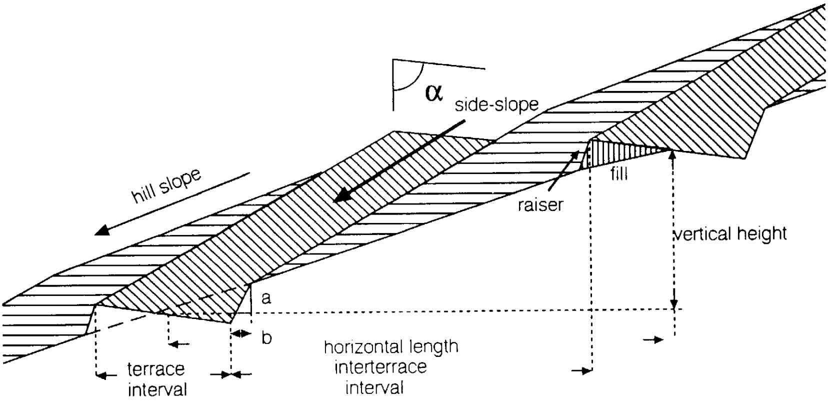
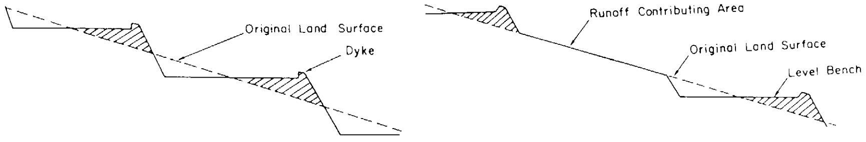
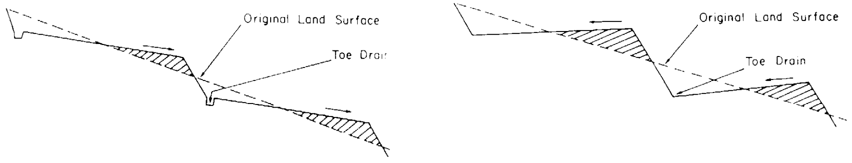


Figure 449-2: Different types of bench terraces (Sheng, 1989)


1. LEVEL BENCH TERRACES

3. CONSERVATION BENCH TERRACES

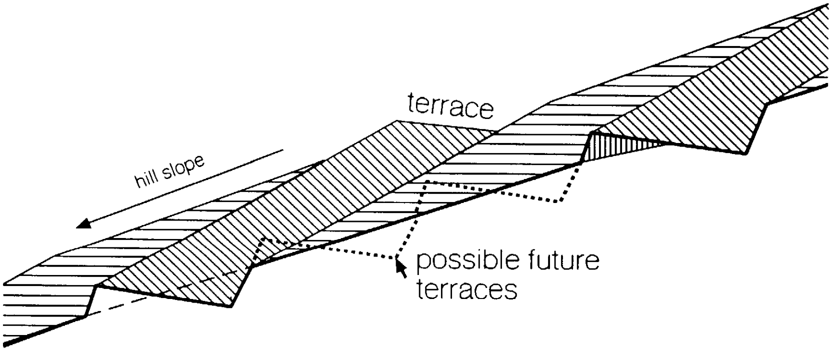

2. OUTWARD SLOPING TERRACES

4. REVERSE SLOPING TERRACES

The intermittent terrace is used if terracing is not completely carried out for the entire slope (Figure 449-3). The design is carried out as for bench terraces but only every 3rd terrace is constructed. This leaves the option to later construct further terraces in between which gradually transforms the intermittent terraces into bench terraces.

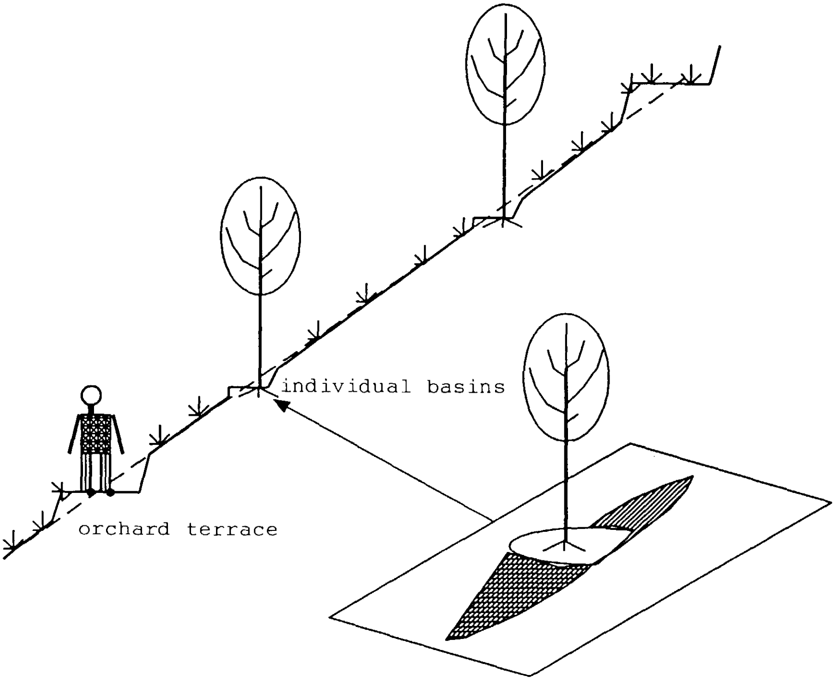
Orchard terraces are used for tree plantations on very steep slopes in order to facilitate access and maintenance (Figure 449-4). The terrace interval is not planted to trees but stabilized by grasses. The distance between the orchard terraces is determined by the spacing of the trees which are planted in the interterrace interval. In combination with orchard terraces individual basins can be used to plant the trees in the interterrace interval (Figure 449-4). The individual basins prevent erosion and loss of fertilizer and herbicides. They conserve water especially if mulched.

Figure 449-3: Intermittent terraces which can later be transformed into bench terraces (after Sheng, 1989)



The area between the individual basins is vegetated.

Figure 449-4: Orchard terraces in combination with individual basins are used on very steep slopes (after Sheng, 1989)



Some characteristics and applications summarized by Sheng (1989) are listed in Table 449-1.

Table 449-1: Characteristics and applications for different types of terraces (after Sheng, 1989)

terrace type	width of terrace interval [m]	reverse slope [%]	land slope [%]
bench terraces (hand made)	2.5–5.0	5	12 – 47
intermittent terraces	2.5–5.0	5	12 – 47
natural terraces (caused by bunds)	8–20		< 12
orchard terraces	1.8	10	47–58
individual basins	1.5 round	10	< 58
hillside ditches	1.8–2.0	10	< 47

The length of the terraces is generally < 100 m and a side slope of 1% is proposed. The terrace interval depends on slope and soil depth. The gentler the slope and the deeper the soil, the larger the terrace interval. The slope of the raiser is built with a ratio of 0.75 : 1.

5 Indicators for soil erosion

Erosion leaves finger prints which also give information on the type and intensity of the processes. Some of these finger prints are dramatic and hardly to be overlooked while others are less distinct and hidden. Such parameters and finger prints can be studied and provide useful information in a first survey on the general erosion risk.

The **age of a landscape** indicates its erosion susceptibility. Old landscapes are characterized by gentle slopes, plateaus and plains whereas young landscapes show a rugged relief with steep slopes and deeply incised valleys (Roose, 1975) resulting in higher erosion potential. Long periods of 'normal' or **'geological' erosion** cause a lowering of the landscape, the final form of which is a peneplain. A peneplain is characterized by a low and gently undulating relief (Figure 5-1). However, often the process is interrupted by tectonic upheaval or tilting of a landscape. The base level[9] is lowered and a new erosion cycle starts. Tectonic movements and several erosion cycles create a landscape of plains at different altitudes (pediplains) which are separated by distinct scarps (Figure 5-1). The oldest surface corresponds to the highest surface. Remnants of the older surface were separated from the faster eroding pediplains and form isolated steep hills (inselbergs) or plateaus on the pediplain below which occur frequently in the savannah areas of West and East Africa (Thornbury, 1985). These remnants were maintained because they were resistant to erosion. An example from Cameroon shows how pediplanation has created four levels during > 60 million years (Figure 5-2) (Segalen, 1967).

Gully erosion leaves very striking features in the landscape and destroys agricultural land. In Lesotho, for example, it is estimated that 4% of the arable area is occupied by gullies (Wenner, 1989). Gullies vary greatly in size. They are defined as deep enough in order that crossing is impossible with agricultural machines while rills can still be closed by ordinary tillage methods (Hudson, 1986).

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[9] lowest point of the landscape to which the water can flow

Figure 5-1: Concepts of a peneplain with gentle, undulating relief (above) and a pediplain with a distinct scarp between two levels (after Thornbury, 1985)

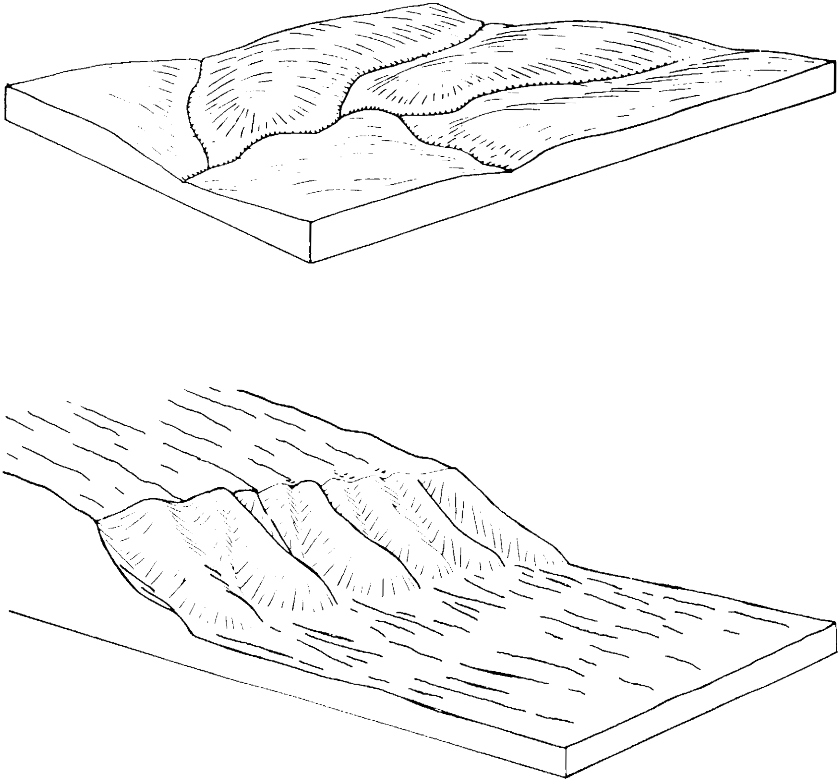


Figure 5-2: Pediplains at different altitudes as formed in Cameroon by more than 60 million years of erosion (after Segalen, 1967)

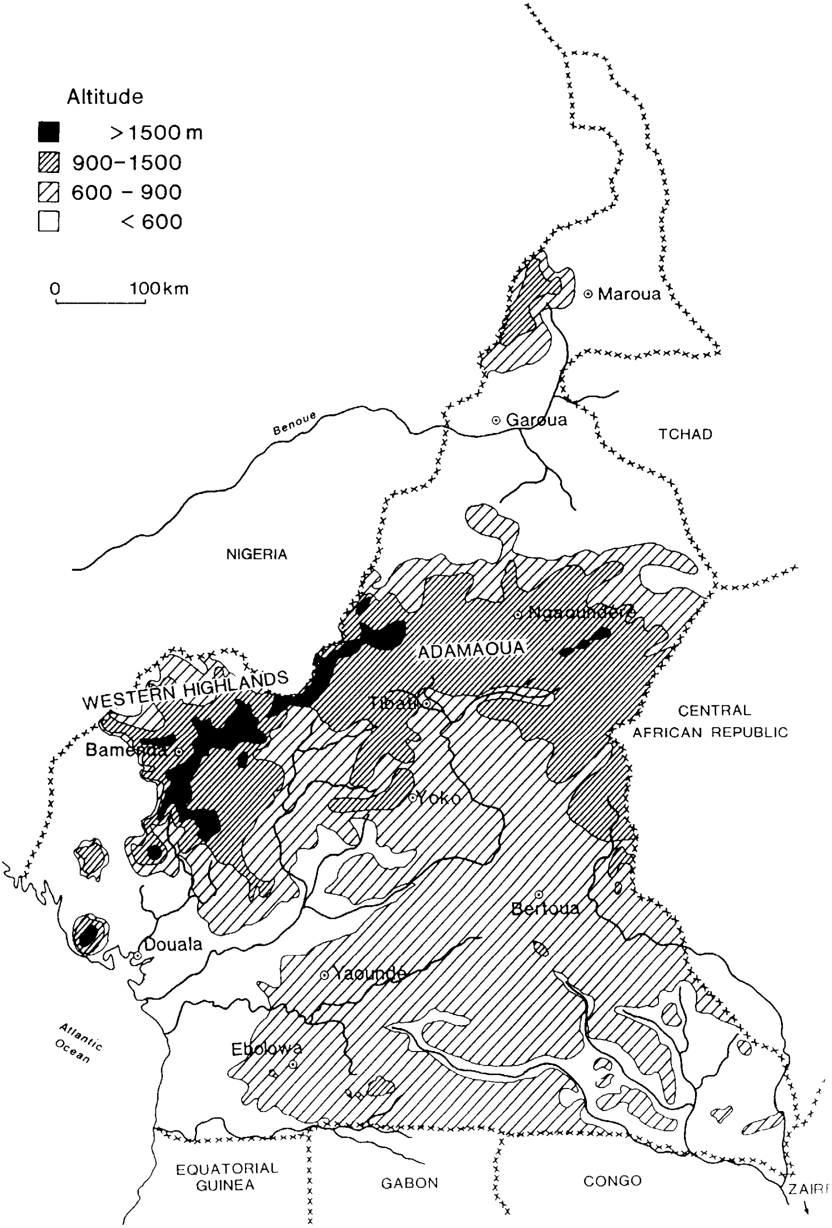
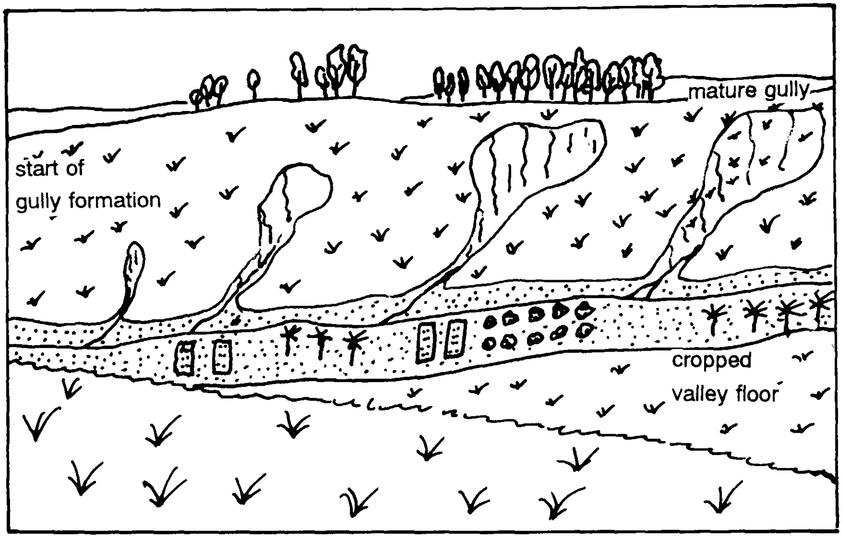


Figure 5-3: Development of gullies from initiation to maturity (modified after Hoeblich, 1992)



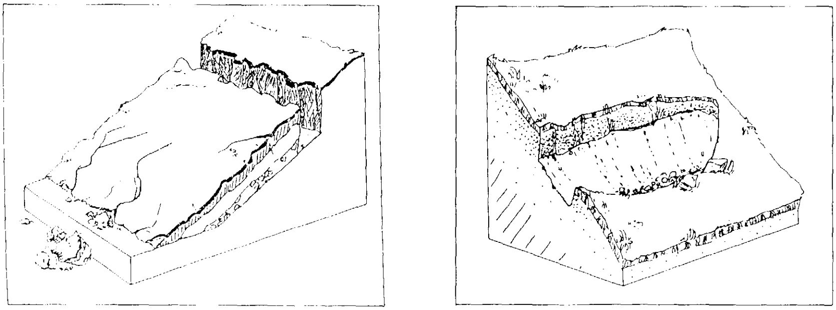
Large gullies reach several tens of meters deep and wide and several kilometers long. Gully incision starts were large runoff volumes are concentrated into linear flow. Possible sites are runoff convergence points of several fields or spillways from roads (Moeyersons, 1989). The water from the impermeable road surface collects in the road ditch and, instead of entering in intervals into a reinforced evacuation ditch, is often led into the adjacent area where it triggers gully formation. Lowering of the base level or large storms which coincide with a sparsely vegetated soil can also initiate gully formation (Oostwoud Wijdenes & Bryan, 1991).

Gully formation is facilitated on soils with a coarse textured surface soil underlain by clay-rich subsoils (Lal, 1992). Concentrated lateral subsurface flow creates subsurface pipes which in turn can start gully erosion (Firth & Whitlow, 1991). Once a gully is initiated, it is enlarged by regressive gully head cutting along with undercutting and collapse of the side-walls. The gully head moves more and more up-slope and secondary gully branches form. Soil cracks form parallel to the gully side-walls. Surface water enters the cracks which increases pore water pressure and decreases soil coherence thus destabilizing the side-walls. It was demonstrated on sodic soils that gully head advance was determined by rainfall, antecedent soil moisture, headcut height (plunge-pool effect) and runoff contributing area (Stocking, 1981). Gully development depends on the depth of the weathered layer and the watershed area. Gully incision stops if the solid rock underneath is reached. Vegetation which forms during less erosive years can also stop further gully enlargement. However, this may only be temporarily. Heavy storms or man-made damage to the protective vegetation can reactivate the gully. If the runoff producing area becomes smaller with progressive head cut regression, a mature stage of the gully is reached (Figure 5-3) (Hoeblich, 1992). Gully reclamation is laborious and costly. It is more efficient to avoid concentrated flow than to protect the soils against its damaging effect.

Landslides are another form of easy recognizable down-slope soil transport which causes disasters. 21.000 people were killed in 1970 in Peru, when an earthquake started the movement of 25 million m^3 of earth which destroyed two entire towns (Schuster, 1978). Landslides occur if the weight of a sloping soil mass exceeds the shear strength of the soil. Cracks occur on the upper side of the soil mass and the soil slumps down-slope along a weakness plane. Such weakness planes within a soil or geologic substrate can be due to different layers of the soil (e.g. permeable layers over less permeable layers) or natural layering of the geologic substrate (e.g. schist). Imbalances are caused either by increasing the soil weight on the slope (e.g. construction, water saturation) or the instability of the weakness planes (undercutting by roadcuts, water saturation). Landslides are classed according to material (soil, stone), humidity (e.g. mudflows), the type and direction of the movement and its velocity (e.g. creep, flow). An example of a translational and a block slide is given in Figure 5-4.

Major determinants for landslides are **slope, climate, geology, layering and hydrologic properties, seismic activity, vegetation and human activities** (Gasser & Zöbisch, 1988). Moeyersons (1989) reported that landslides in Rwanda occur especially on slopes > 58% and on schist whereas on sand stone and quartzitic rocks no slides were observed. Slides on slopes < 58% only occurred if road construction caused slope instability. Landslides were more frequent on slopes > 62% in Uganda (Temple & Rapp, 1972) and on slopes > 53% in New Zealand (O'Laughlin, 1981).

Figure 5-4: Left: blockslide; right: translational slide (in: Gasser & Zöbisch (1988); after Griggs & Gilchhirst (1977) and Schauer (1975))

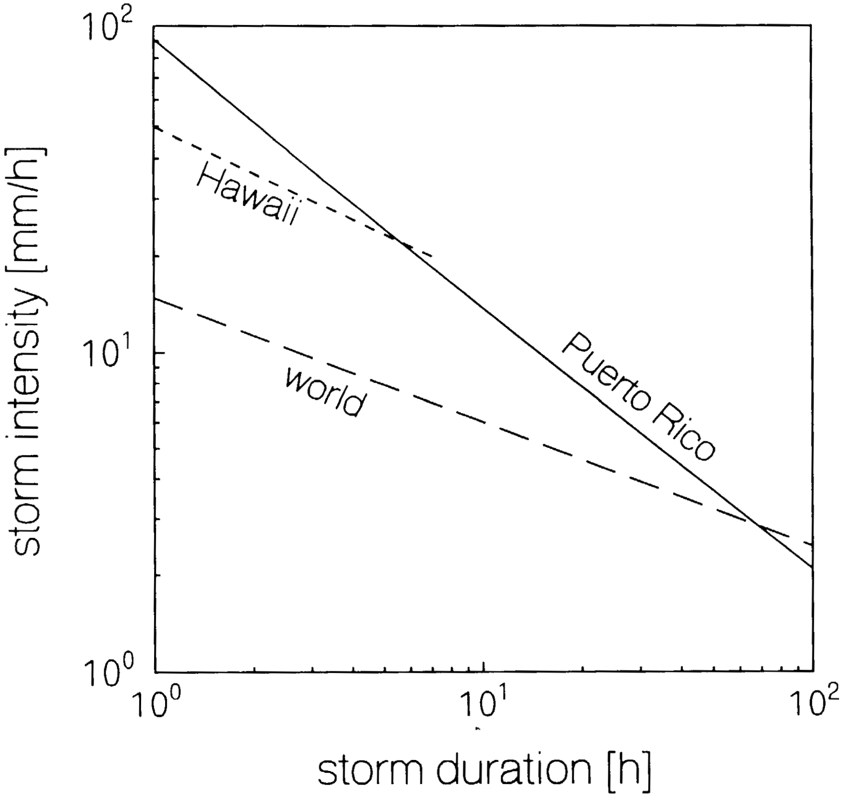


Landslide frequency is determined by a rainfall duration-intensity threshold which varies due to geology and climate (Figure 5-5) (Larsen & Simon, 1993). Long duration, low intensity rains cause deeper landslides on volcano-clastic material in Puerto Rico whereas short and intense storms cause shallow slumps (Larsen & Simon, 1993). Vegetation decreases landslide frequency. Plant roots increase the shear strength of the soil. A perennial vegetation consumes an important part of the rain as interception water and for transpiration. Thus, a vegetated soil is drier than an unvegetated soil. These influences of vegetation outrule the physical weight of the vegetation and the weight increase of the vegetated soil due to increased infiltration.

An indication for soil creep is the 'sabre growth' of trees. The slowly down-slope moving soil inclines the trees which in turn redirect their growth upwards. The result is a trunk form which resembles a sabre (Figure 5-6).

Construction of terraces and roads is often at the origin of landslides. The cuts weaken the slope stability or locally increase water infiltration (e.g. on the foot of reverse sloped terraces) which changes soil coherence. A similar influence is exerted by overgrazing of land. The grass cover is locally destroyed and livestock paths cut the slope and destabilize it (Wenner, 1989).

Figure 5-5: Critical values of storm duration and intensity for increasing landslide frequency (Wilson et al., 1992; Larsen & Simon, 1993; Caine, 1980) (from Larsen & Simon, 1993)



Another informative source for erosion susceptibility is the geologic map. In-situ soils are formed from the parent material underneath. Areas with parent materials which form medium to light textured soils are more endangered by erosion than those with materials that generate clayey or very sandy soils. A tentative classification for different parent materials is given in Table 5-1.

Figure 5-6: Sapre growth of trees caused by soil creep (Kittler, 1962 in: Gasser & Zöbisch, 1988)

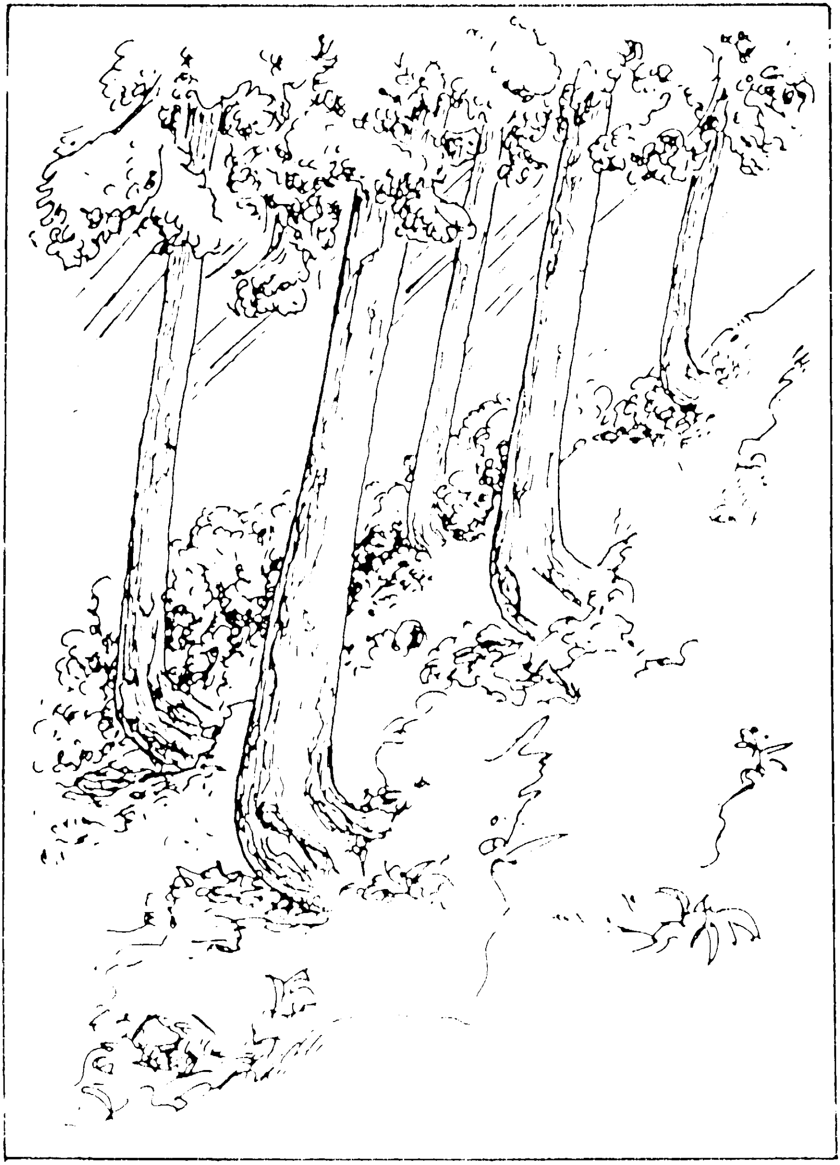


Table 5-1: Soil erodibility of soils derived from different parent materials.

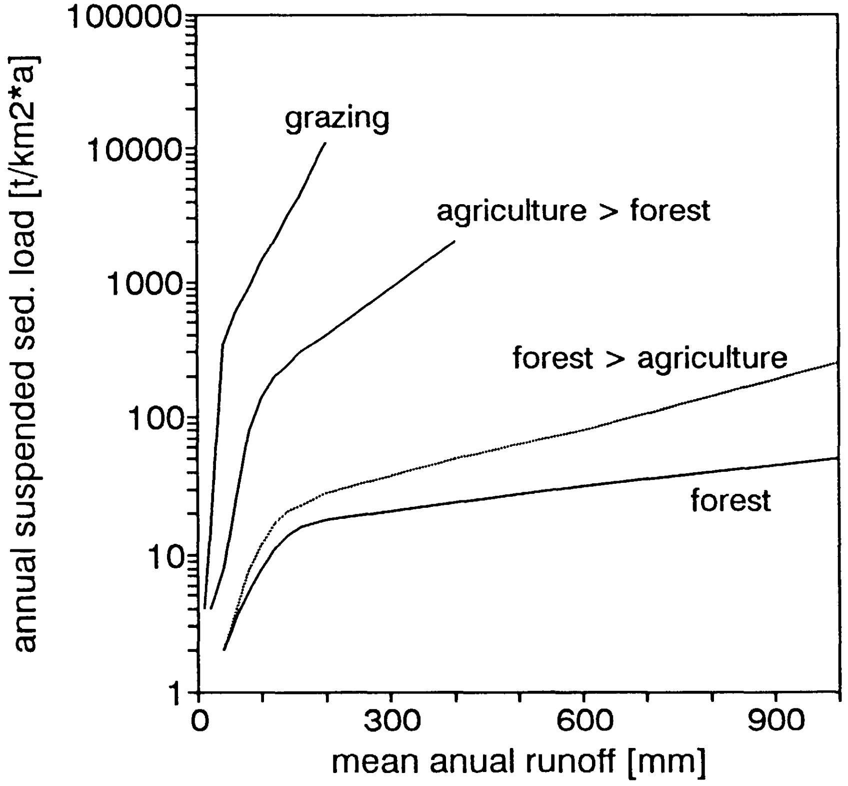
erodibility		
low	**medium**	**high**
basalt	gneiss	volcanic ash
gabbro	diorite	granite
shale	andesite	rhyolite
coarse/gravelly sand deposits		granodiorite
carbonate rocks		fine sand deposits
		silt stone
		loess

Soil classification as well gives rough indications for soil erodibility. With respect to USDA Soil Taxonomy erodibility increases in the order Oxisols < Ultisols < Alfisols, Vertisols, Mollisols < Aridisols (Chromec et al., 1989). Andisols were found highly variable (El-Swaify, 1990) and Vertisols proved more erodible than Inceptisols (El-Swaify & Dangler, 1982).

Erosion susceptibility decreases with increasing organic matter content which in turn increases with soil moisture and decreasing temperature. Therefore, a soil will have more organic matter in a cool highland climate and will be less erodible than a similar soil in the lowland.

A very evident indicator for soil erodibility is soil colour. Structural stability and erosion resistance of red hematitic soils is higher than of yellow goethitic soils. In other words, with decreasing hematite content, as seen from the redness rating (Torrent & Barrón, 1993), structure becomes weaker (Chauvel et al., 1976; Muller, 1977). Organic matter content is also roughly estimated by soil darkness (Munsell values).

Figure 5-7: Runoff and suspended sediment load of watersheds with different vegetation



A first impression of soil erosion can be gathered from the sediment concentration in the river water. Rivers coming out of forested watersheds carry very low amounts of sediments compared to cropped and grazed watersheds (Figure 5-7). An extreme example is seen from a plane approaching Madagascar. The high sediment load of the rivers leaves a red corona close to the estuaries and coast.

Finally, a very good indicator for erosion processes is population density. Agriculture creates soil erosion and agricultural systems are often not conservative. Thus, information about the population density combined with knowledge about cropping systems, quality of the soils and climate give already an idea of the erosion potential.

Further indicators like washed out roots and topsoil depth are sometimes already useful to quantify soil loss. They are therefore discussed in Chapter 6.3.3.

6 Assessment of soil erosion

Methods for soil erosion measurement depend on the scale applied and the accuracy needed. Measurements are carried out on plots of less than 1 m^2 to watersheds of several hundred km^2. The accuracy ranges from an estimate of the erosion dimension to measurements precise to the kg/ha. Choosing a measurement system, therefore, needs a clear definition of the problem to be investigated and the accuracy of answer needed.

6.1 Rainfall simulator studies

Rainfall simulators are used in the laboratory or in the field in order to apply storms of controlled length, intensity and drop size distribution to erosion plots. Today, a number of different rainfall simulators exist which apply permanent or intermittent rain from needles with drop-formers, small hoses or nozzles to plots of varying sizes. Plot size is limited by the size of the simulators and the availability of water in the field[10]. Simulators can be as large to fill a big truck or as small to be carried by hand (Crouch & Collison, 1989; Kamphorst, 1987). Largest and smallest plots of field simulators actually used in Germany and Switzerland are 42 and 0.38 m^2 (Auerswald et al., 1992b). A comprehensive review on rainfall simulators is given by Meyer (1988) and USDA (1979). A detailed description and discussion of simulators used in Germany and Switzerland was published by Auerswald et al. (1992a, b, c), Auerswald & Eicher (1992), Becher (1990) and Kainz et al. (1992).

Using rainfall simulators, soils can be tested fairly quick, under standardized conditions and independent of hazardous natural rainfall. The air-dry soil (simulations are advantageously carried out during the dry season) is exposed to several rains with varying duration and intensity. Intensity can be adjusted to the local conditions or to the international standard of 63.5 mm/h. The latter facilitates comparison with other studies. The standard treatment comprises a first storm of 1 hour. 24 hours later a second 30 min storm and after a 15 min break a third 30 min storm. This storm sequence represents rain on dry, moist and wet soil as it occurs under natural rain.

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[10] As a thumbrule about 1000 l of water is needed for a 60 min storm of 63.5 mm/h on a 10 m^2 plot if the intensity is measured before and after the storm.

Runoff and soil loss from moist and wet soil are generally larger compared to dry soil. In order to calculate a mean soil erodibility for all soil moisture conditions during the year, soil loss from dry, moist and wet soil is weighted in a ratio of 1 : 0.31 : 0.23 (Wischmeier et al.; 1971). This ratio proved valid for the climate in mainland USA. An attempt to adjust the ratio to other climates was made in Hawaii (Dangler & El-Swaify, 1976) by taking the number of dry and wet[11] months to weigh the storms on dry and wet soil. A storm on very wet soil was not carried out. Correct results were obtained in Cameroon by applying a ratio of 1 : 1 for dry and wet soil (Nill, 1993).

6.1.1 Laboratory studies with simulated rainfall

Laboratory tests are used especially for the study of single erosion processes like surface sealing, rill and interrill erosion, splash erosion, influence of mulch layers and different rain intensities. Relative differences in the erodibility of soils can also be evaluated. However, if quantitative information about soil loss is needed, the results from laboratory tests are better calibrated with to data from larger erosion plots under natural rainfall. In laboratory tests only a part of the soil profile (generally the surface soil) is used and the soil is disturbed in its natural structure. Therefore, results on runoff and soil loss can only be compared to in situ soils if the runoff volume is determined by the surface layer (= rapidly sealing soils). If runoff is especially determined by less permeable subsurface horizons or the degree of presaturation of the soil, laboratory test are of limited use. This is often the case for well structured soils rich in oxides, clay and organic matter.

The advantage of laboratory tests are the controlled conditions of slope angle, water temperature and quality (some tests are carried out with distilled water), rain intensity and antecedent soil moisture. The small plots can easily be handled which facilitates repetitions. The comparatively small amount of soil needed allows the collection of very different soils distant from one another.

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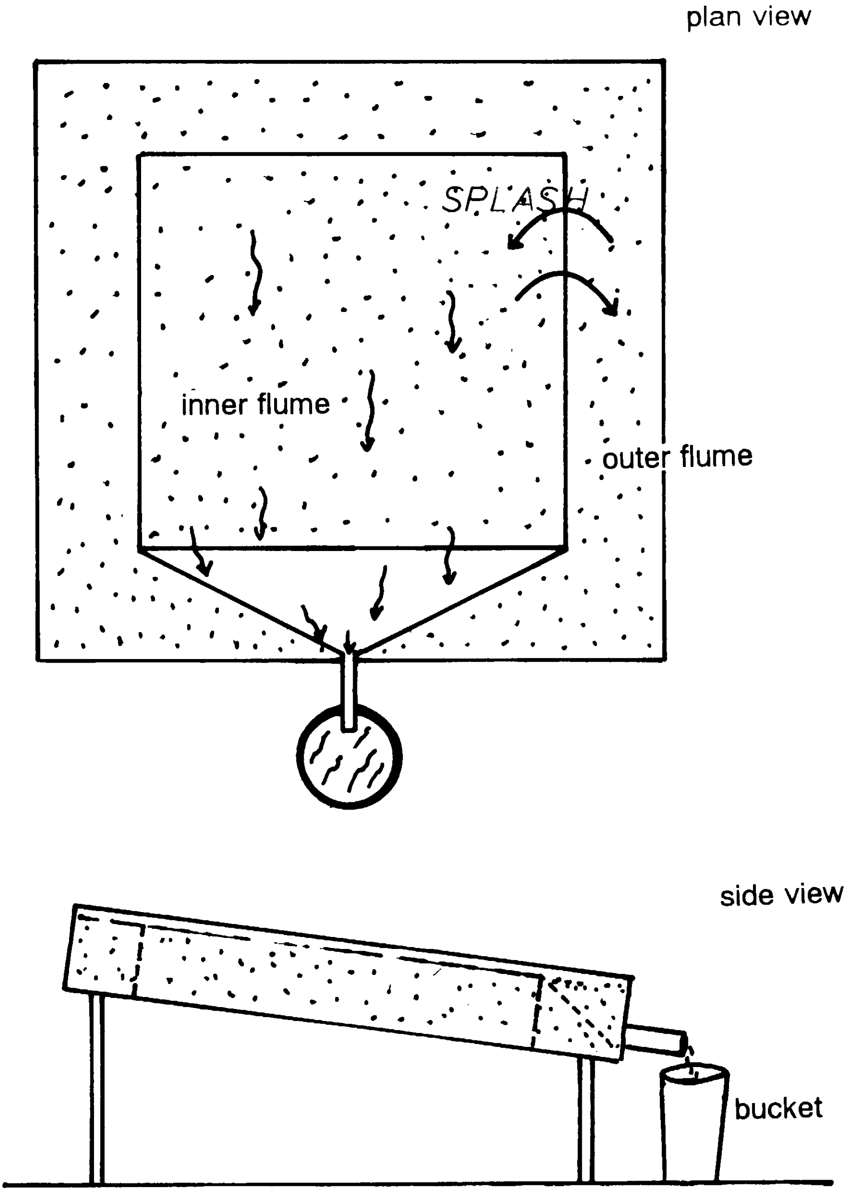
[11] A wet month was characterized by the median rainfall exceeding class A pan evaporation for the month.

Figure 611-1: Schematic diagramm of a flume used for laboratory rainfall simulation



For the tests, a layer of soil is packed into a flume about 10 cm deep where it is compacted to its natural bulk density for which a roller can be used. A large number of different flumes and rainfall simulators are used. Therefore only some general features will be given here. A flume is a wooden or metal box with an inner and outer area (Figure 611-1). The inner area is connected to an outlet which delivers runoff and sediment into a container. The outer area is also exposed to the artificial rain. The idea of an outer area is that the amount of splash which leaves the inner measurement plot is replaced by the amount splash from the outer plot entering into the measurement plot. The bottom of the flume is perforated in order to allow percolation of the infiltrating rain. The flume can be adjusted to several slope angles. Some flumes are also variable in their length.

6.1.2 Field studies with simulated rainfall

Field studies with rainfall simulators are more tiresome and expensive than laboratory studies. The whole equipment and the necessary crew must be transported to the site. If water is not available in the vicinity it needs to be carried from several kilometers away and stocked beside the experimental site. Test conditions are not as controllable as in the laboratory. Antecedent moisture, slope, water quality and temperature can not be standardized. On the other hand, the soil stays rather undisturbed and the whole soil profile is tested instead of a single soil layer. For determining soil erodibility, the plot and a 50 cm wide strip around the plot are tilled to maize seedbed conditions before the test. The tilled strip around the plot serves for the same purpose as the outer area of the laboratory flume. As the soil does not need to be transported, the plot size is generally larger in field studies compared to laboratory tests. Generally the field simulators need to be calibrated on runoff plots with known erodibility.

Field simulators also allow the testing of the effect of various factors on erosion such as vegetation cover during different growth stages and seasonal variation in structural stability. Use of field simulators also gives most realistic infiltration data as it reflects closely the influence of natural rain. In order to reflect the variation in soils and treatments two to four repetitions are carried out in most studies.

Figure 612-1: Mobile rainfall simulator unit in the field. 1: simulator; 2: manometer; 3: spraying nozzle; 4: supply hose; 5: outlet hose; 6: 300 l tanks; 7: electric pump; 8: electronic control system; 9: 5000 l tank; 10: 1 l sampling bottles; 11: 5 l beaker; 12: outlet; 13: dissembled simulator; 14: 120 l barrels for water transport

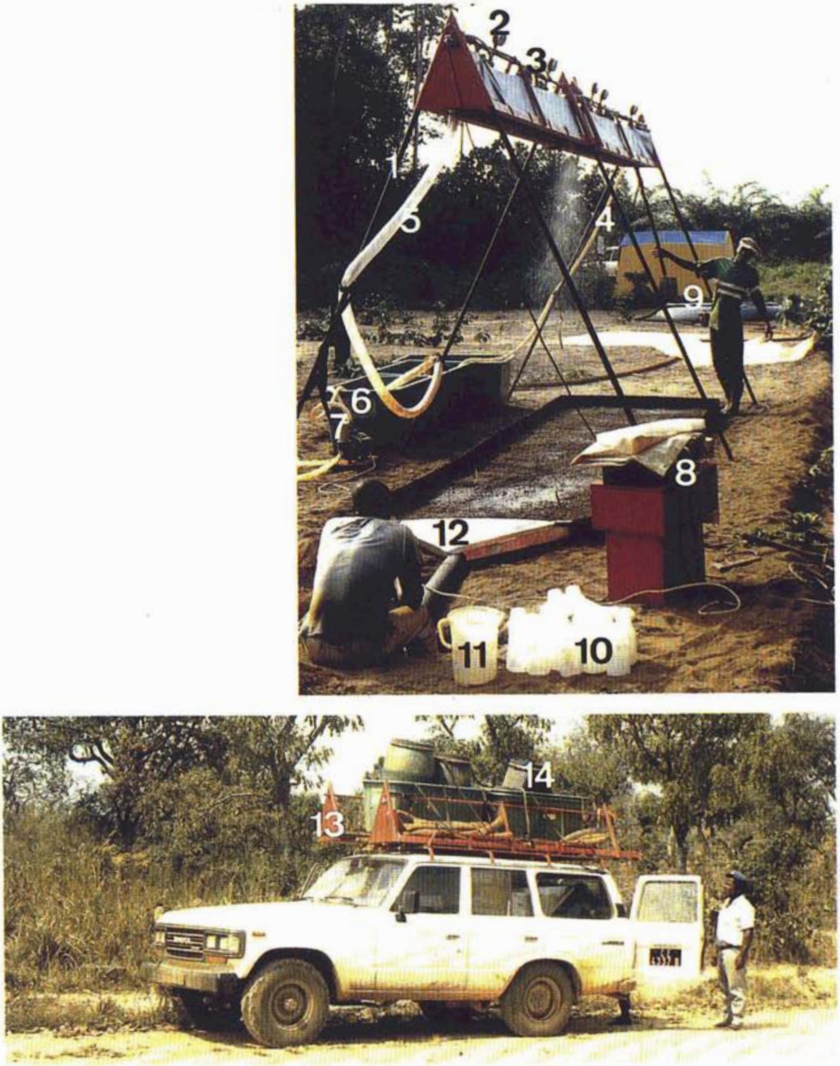
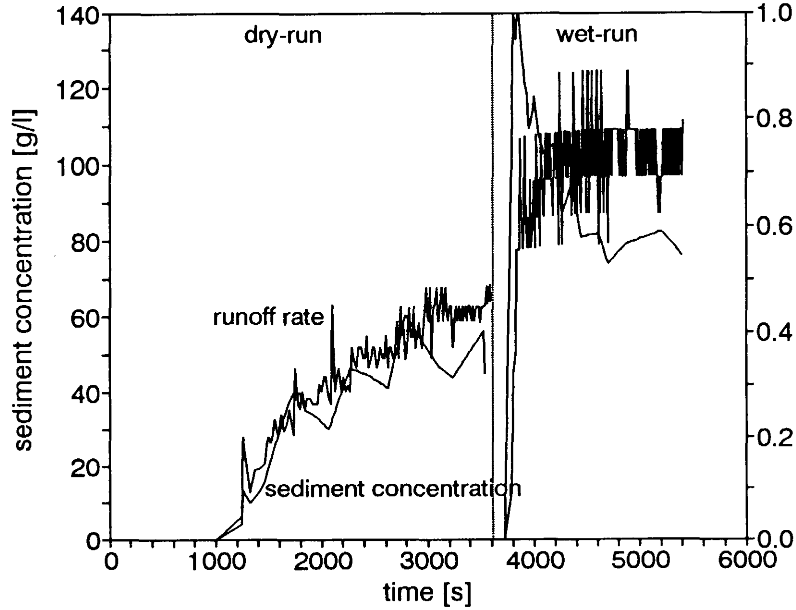


Figure 612-2: Runoff/soil loss diagramm for a 60 min dry- and a 30 min wetrun



The plots are bordered by metal sheets which are driven into the ground to 10–15 cm depth. At the bottom end a metal triangle is put into the soil which collects the runoff into a tube and finally into a graduated bucket (Figure 612-1). Standard reported data are:

- ▷ antecedent soil moisture before the rain
- ▷ surface roughness
- ▷ start of rain (time = 0)
- ▷ time for the first runoff
- ▷ time for every litre of runoff and runoff samples depending on the volume (e.g. 1st, 2nd, 5th, 7th, 10th, 15th, 20th, 30th litre, etc.) for sediment determination.

- ▷ end of rain and end of runoff
- ▷ initial and final rain intensity

With these data runoff/soil loss diagrams can be set-up which demonstrate the erosion process (Figure 612-2).

6.2 Runoff plots

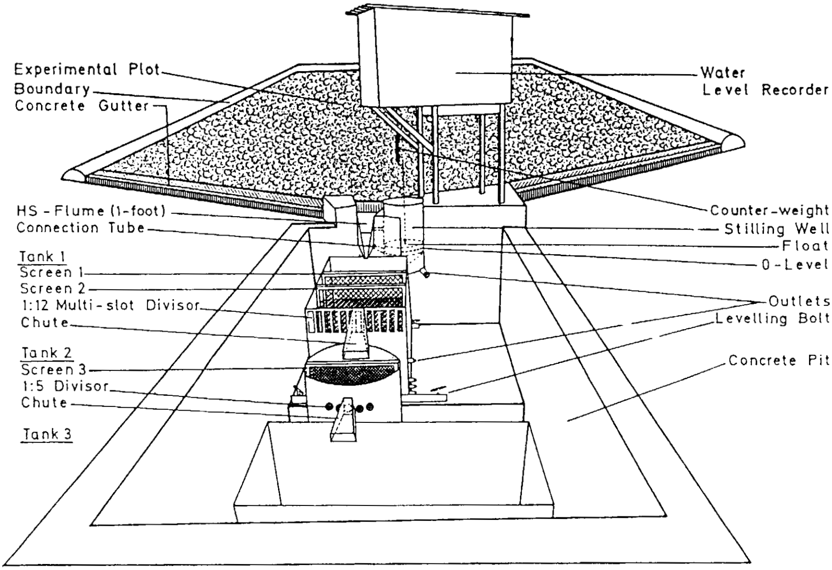
Measurements of soil erosion were originally conducted on runoff plots under natural rainfall. A standard plot of 22.1 m length, 1.87 m wide on a uniform slope of 9% was taken as 'unit' plot. It served as reference in comparative studies. The 'unit' plot was tilled up- and down-slope to maize seedbed conditions. Seals were regularly destroyed by further tillage (Wischmeier & Smith, 1978). Thus, all conditions were set to attain maximum soil loss. For soil erodibility measurements, a period of at least 2 years under barefallow was recommended to exclude all influences of the former vegetation.

Today, experiments are carried out on plots of different dimensions and on different slopes. However, these plots can be corrected to 'unit' plot conditions with the Universal Soil Loss Equation (USLE). Nevertheless, a minimum length of 9–10 m is recommended for erosion plots. Calculation is facilitated if the surface area is equal to an even fraction of an hectare (e.g. 50, 100, 500 or 1000 m^2) (Sheng, 1990). The plots should be large enough to contain a representative unit of a cropping system or treatment. Runoff plots range between < 100 m^2 to about 1 ha. On larger plots different slopes and soils as well as deposition within the plot create a more and more complex situation which is difficult to interpret. Additionally, it becomes difficult to control and measure the large amount of water and sediment.

The runoff plots are bordered (metal sheets, bricks, earthen ridges planted to grass) in order to prevent outside runoff from entering the plot. Runoff and sediment are collected by a drainage ditch at the bottom of the plots which leads to an outlet. Here, the volume and sediment can be measured by a divider tank system (Figure 62-1) or a Coshocton wheel. A steady measurement of the runoff rate is possible by using a standard flume and a waterlevel recorder.

The tank system consists of a large tank which can collect all runoff. If the expected runoff volume is too large, a system of several interconnected tanks or barrels is needed. If the first tank is filled the overflow is separated into a large aliquot (e.g. 90%) which spills into an outflow ditch and a small aliquot (e.g. 10%) which enters the second tank and so on. Most of the sediment, especially the coarser material, is deposited in the first tank whereas suspended soil particles will be found in the second tank. All tanks should be provided with an underground outlet to facilitate water evacuation.

Figure 62-1: Divider tank system for the measurement of runoff and soil loss (Sabel-Koschella, 1988)



Coshocton wheels are installed in the waterspill underneath a flume. The water falls onto the wheel thereby making it rotate. A slot in the wheel which is connected to a barrel passes underneath the spilling water taking each time a small aliquot of runoff. Coshocton wheels can be purchased for about 1500 to 2000 US$. Their advantage is that they can be installed in several places, while cemented tanks become worthless after the measurement in one place.

6.3 Erosion measurement within existing fields

If less measurement accuracy is needed, there are a number of simple devices which can be used to estimate soil loss.

6.3.1 Erosion nails

Erosion nails also called erosion pins can be hammered into the soil until a defined length (e.g. 20 cm) stays out above the soil surface. If this length is reduced or enlarged, sedimentation or erosion has occurred i.e. the soil surface has increased or decreased. The nails are placed along the slope of a field with an interspace of some meters and a lateral displacement of 10 to 20 cm (Figure 631-1) in order to avoid any interference on runoff from one nail to the nail below (Zöbisch, 1986). Length measurement of the nails must be carried out with high precision. An error of 1 mm in length means an error of 10–15 t/ha if bulk density is supposed to be between 1.0 and 1.5 g/cm^3. Therefore, a metal plate 5 cm in diameter is slipped onto the nails to compensate for random roughness of the soil surface. The length is measured with a slide calliper precise to 0.01 mm (Figure 631-2). The mean length of all nails is compared to the mean initial length. The soil loss can than be calculated by the missing soil height if the soils bulk density is known.

As the measurement error can be appreciable, this method is especially suitable for measurements over a period of several years or for sites with a high erosion potential.

Figure 631-1: Set-up of erosion nails on a slope

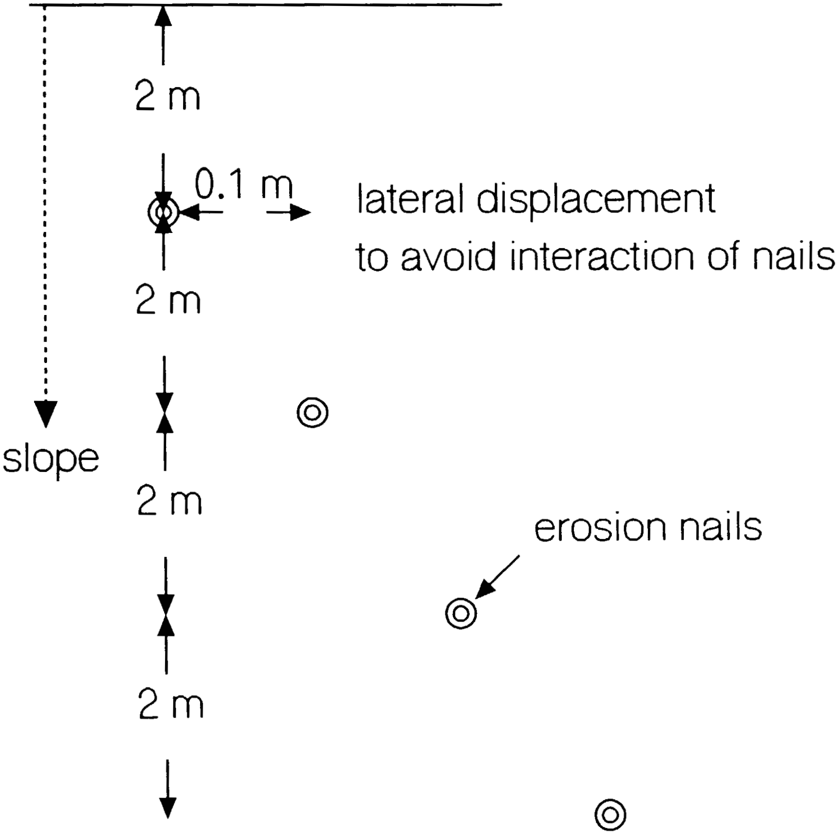
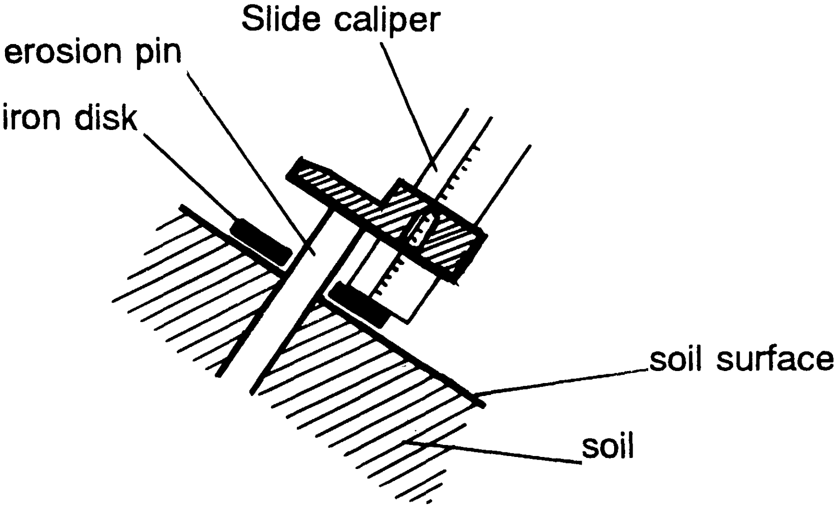


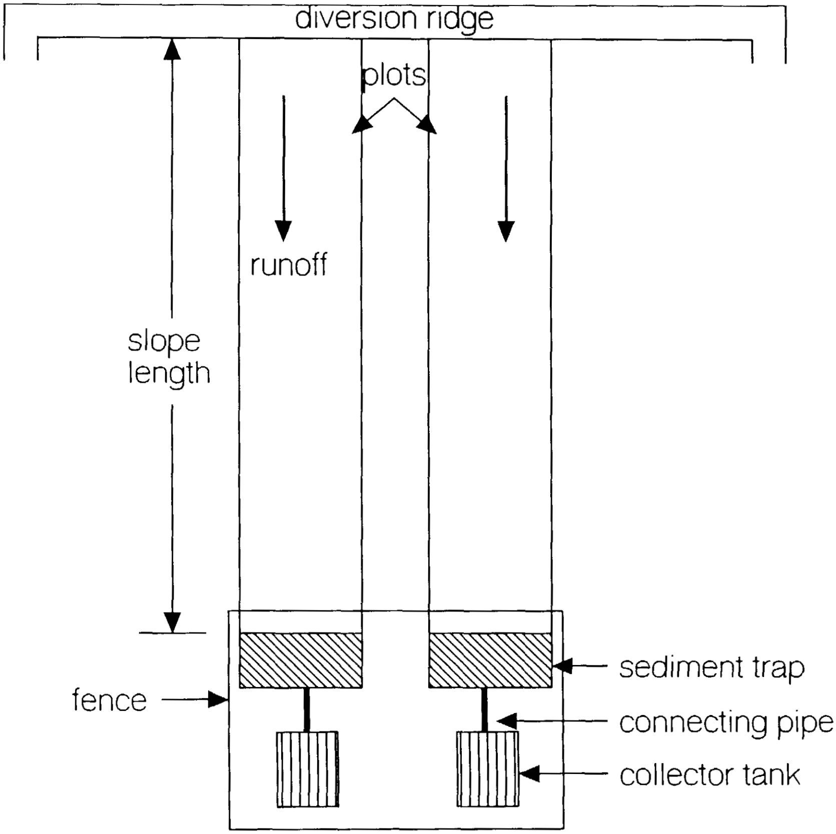
Figure 631-2: Measurement of nail height with a slide calliper



6.3.2 Sediment traps

Sediment traps are simple and cheap devices which permit the measurement of runoff and soil loss. They were extensively used in measurements in Kenya (Zöbisch, 1986). The traps consist of a 50 x 50 cm metal box closed on three sides by a 5 cm high rim. A 10 cm long extension of the bottom is left at the open front part. This extension can be pushed into the soil in order to allow runoff to freely enter the far end of the box which is installed at a slight angle. The box is covered by a lid ;to avoid direct access of rain water. At the far end a funnel is attached to the trap which is connected to a 30 l reservoir where runoff and sediment are collected.

Figure 632-1: *Sediment trap for measurement of runoff and soil loss*



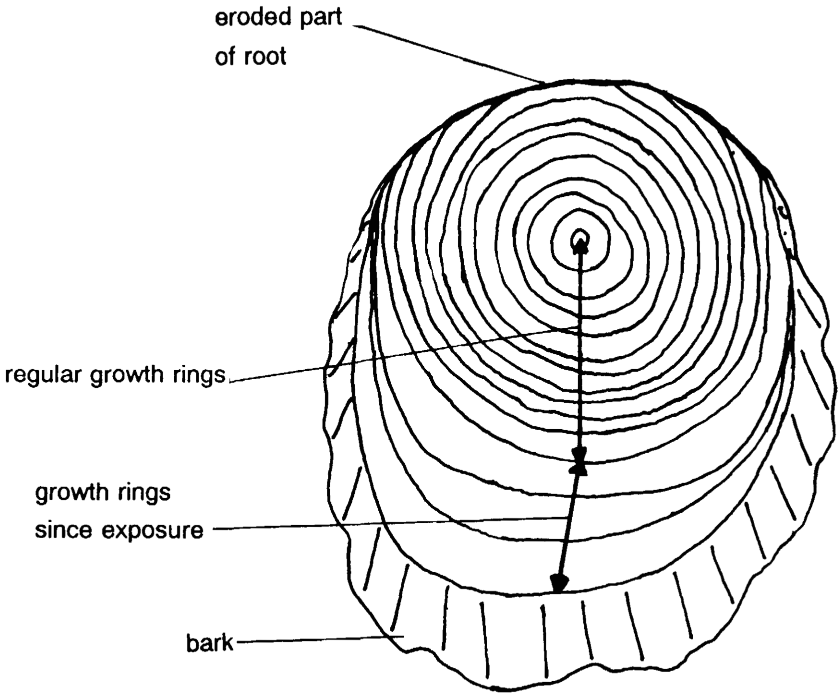
The sediment traps are installed in places with homogenous slope. A conversion ditch 10 m in front of the traps diverts runoff from further up-slope. The catchment area of 5 m^2 for the sediment traps is given by the width of the traps (50 cm) and the slope length (10 m). It is assumed that runoff which enters the area laterally equals the runoff volume which leaves laterally. A sketch of a sediment trap system is given in Figure 632-1.

A system with this design collects about 6 mm of runoff. It needs to be emptied after each rain. For larger storms either the reservoir must be bigger or the catchment area reduced.

6.3.3 Diverse techniques

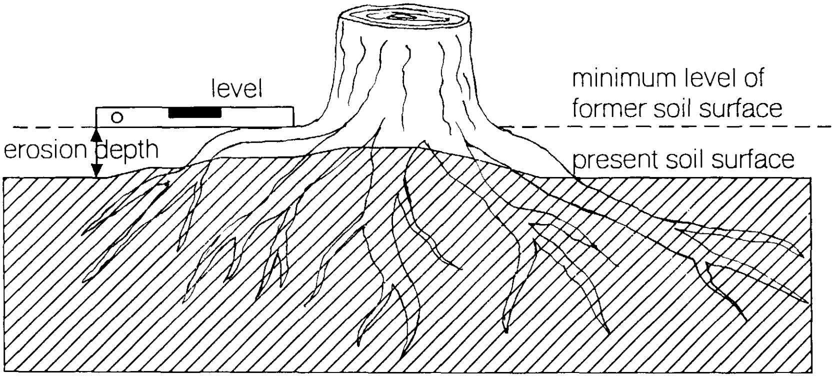
Root growth of many trees is evidently inhibited on the exposed root parts as the bark and cambium are damaged. This was found for Pinus aristata (La Marche, 1968), Pinus edulis, Juniperus scopulorum and J. osteosperma (Carrara & Carroll, 1979). Soil loss is calculated as the depth since exposure of the upper root surface which is observed on the growth rings
(Figure 633-1).

Figure 633-1: Calculating the time since exposure of tree roots by the growth rings of root sections



Dunne et al. (1978) used a similar approach in Kenya by measuring the height of the mounds underneath Acacia drepanolobium, A. tortilis, Sericomopsis pallida, Olea africana and Acocanthera species (Figure 633-2). These tree species were chosen because they do not develop any superficial roots. However, caution must be given that the mounds were not formed by water and wind erosion, termites or the trees themselves. The age of the trees was given by a regression between number of growth rings and diameter of the stem. Acacia drepanalobium is reported to develop a physiological mark on the stem at the level of the original soil surface (a bulge, branching or change of bark colour). An indicator for very erodible sodic soils is Colophospermum mopane (Stocking, 1988).

Figure 633-2: Measuring the height of the former soil surface by the use of exposed tree roots



Some methods can only be used very site-specifically. Rhoton et al. (1991) used the gravel concentration of the surface soil in order to calculate the eroded depth of a soil with rather homogeneous gravel content.

6.4 Sediment yield from river basins

Suspended sediment yield of rivers is calculated by measuring the cross section of rivers, the waterlevel, the discharge and the sediment concentration. Sediment yield, however, only gives a rudimentary estimate of the soil loss from fields within the basin. Several factors bias the result:

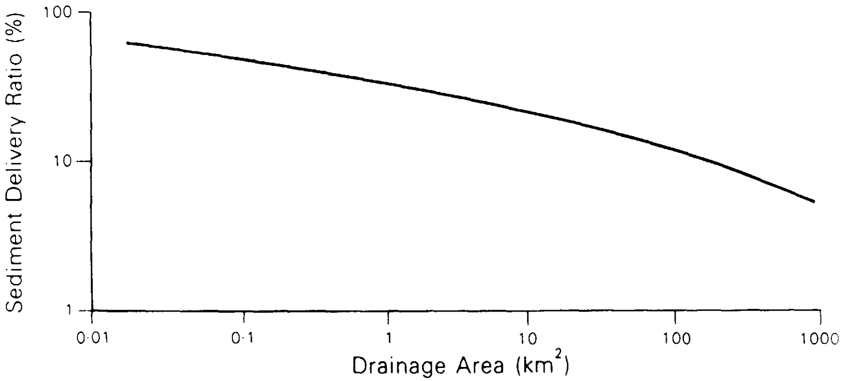
- Sediment yield measurements generally only cover the suspended sediment load. The bedload which is carried close to the river bottom is neglected. The bedload of African rivers accounts frequently between 5 and 10 % of the suspended load (Walling, 1984).
- The soil lost within a watershed is not entirely transported into the river. Sedimentation occurs on foot-slopes, depressions and well vegetated parts within the watershed. The sediment delivery ratio (SDR) which gives the suspended sediment load of the river relative to the total soil loss in the watershed varies with watershed size (Figure 64-1). The SDR from large watersheds is smaller than from small watersheds as the mean gradient declines and sedimentation increases with increasing watershed size.
- The soil lost from fields in the watershed can be subject to several cycles of deposition and remobilization until it reaches the river outlet. Thus, measured suspended sediment load may reflect soil erosion of former periods.
- Suspended sediment is not only derived from sheet erosion within the watershed but may also stem from gully erosion, landslides, channel and streambank erosion.

Table 64-1: Annual suspended sediment load of African rivers as compared to FAO soil loss estimates (Walling, 1988)

river	country	basin area [km^2]	suspended sediment load [t/(ha*a)]	FAO soil loss estimate [t/(ha*a)]
Watari	Nigeria	1450	4.8	10–50
Bunsuru	Nigeria	5900	4.4	10–50
Senegal	Mali	157400	0.2	10–50
Faleme	Mali	15000	0.4	10–50
Hammam	Algeria	485	2.0	10–50
Kebir Ouest	Algeria	1130	0.9	10–50
Mesanu	Ethiopia	150	16.8	50–200

The difference between suspended sediment loads of rivers and estimated soil erosion rates from the respective fields is demonstrated in Table 64-1. Suspended sediment load is generally an order of magnitude lower than the estimated total soil loss.

Figure 64-1: *Relationship between watershed drainage area and sediment delivery ratio as used by the U.S. Soil Conservation Service for the central and eastern USA (from Walling, 1988)*



7 Soil loss prediction with the Universal Soil Loss Equation

Erosion has already been noticed in ancient times. Plato already described the disastrous effects of the denudation of the hills around ancient Athens more than 2000 years ago (in: Herkendell & Koch, 1991). However, more attention to the problem was only given by the 1920s when the menacing extent of soil loss in the US became aware (Bennett & Chapline, 1928; Lyon & Buckman, 1922). As a consequence the US Soil Conservation Service was created in 1935. Soon it became insufficient to notice, describe and measure soil erosion. For a deeper comprehension of erosion and its assessment under varying conditions, it was important to understand the basic processes.

The development of mathematical models started with the equation of Zingg (1940) which related soil loss to slope length and gradient. Smith (1941) included factors for the influence of crops and conservation practices on soil loss. The addition of a rainfall factor resulted in the Musgrave equation (Musgrave, 1947). Finally data collection and analysis of 10,000 plot years from 49 locations led to the 'Universal Soil Loss Equation (USLE)' (Wischmeier & Smith, 1978) which, today, is still the basic tool for soil conservation in the US and other countries.

The USLE is an empirical model with widespread use in land use planning, extension and the design of cropping systems and conservation practices. It allows to estimate soil loss under varying climatic, topographic and management conditions on different soils with a set of relatively simple parameters. The basic idea was to measure maximum possible soil loss of a specific soil on a control plot with standard size, gradient and treatment, – the 'unit' plot. The 'unit' plot was 22.1 m long on a 9% slope. Soil loss as caused by gradients, slope lengths and management conditions different from the standard conditions was examined relative to maximum soil loss on the control plot which was achieved by barefallow tilled up- and down-slope to maize seedbed conditions. The equation is expressed as:

$$A = R * K * L * S * C * P \qquad (18)$$

with A mean, longterm annual soil loss [t/ha*a]
R erosivity of rain [N/h]

K erodibility of a soil, i.e. its susceptibility to erosion [t*h/N*ha]
L slope length factor [-]
S slope steepness factor [-]
C management factor [-]
P support practice factor [-]

Soil loss (A) gives the mean annual soil loss in t/ha on a longterm basis. Soil loss of a specific year may differ considerably from year to year. Rainfall erosivity (R) is calculated from rainfall charts for single erosive rains during a period of 22 years and represents the mean annual erosivity for this period. Soil erodibility (K) indicates a soil's susceptibility to the erosive forces and gives the amount of soil loss per unit erosivity. K was defined constant for a specific soil. L, S, C and P are expressed as ratios of soil loss on a given plot to soil loss on the unit plot. For example, an L factor of 2.1for a 100 m long slope of 9% means that this slope will suffer 2.1 times the soil loss of the 22.1 m long unit plot if all other conditions (climate, soil, management etc.) are alike. A C factor of 0.2 for a crop signifies that soil loss under this crop is only one fifth of the barefallowed unit plot provided that all other factors remain constant.

The model parameters were calculated from a defined set of natural and management conditions in the US. Therefore, it was not surprising that the application of the USLE has led to contradictory results under tropical conditions (Lal, 1980; Mtakwa et al., 1987; Ngatunga et al., 1984; Roose, 1977; Vanelslande et al., 1984). Part of the differences were however caused by treatments very different from the one's defined by Wischmeier & Smith (1978). Recent data show, that the USLE can be directly applied to a wide range of tropical soils and corrections can be made for most other soils (Nill, 1993). The most urgent need exists now in obtaining reliable data on tropical cropping systems.

Today, several deterministic models exist which try to consider the numerous, complicated processes which determine erosion. Mostly they need a large amount of information on climate, soils and management. Often they are not tested under differing conditions. Compared to these models, the USLE convinces by its simplicity, the large data base which was used for its development and its widespread application. Although empirical in principle, it still includes all important factors which influence soil loss. Its parameters, possibilities and limitations will be outlined in the following chapters.

The USLE was designed to predict longterm annual soil loss from a given slope under specified land use and management conditions (Wischmeier, 1976). It can be used for watersheds, if these are subdivided into smaller units where the USLE factors apply. Using mean gradients, erodibilities and slope lengths for the whole watershed may cause important errors in the estimate. Soil loss, as estimated by the USLE should rather be regarded as best available estimate than as absolute data. Soil loss from a specific event can not be calculated with the USLE. Even annual soil loss of a specific year may vary largely from longterm mean annual soil loss. The USLE does not account for deposition of sediment along field borders, ridges or on foot slopes and can not predict gully erosion.

Beside the USLE, a second important prediction model is applied in southern Africa. The 'Soil Loss Estimator for Southern Africa (SLEMSA)' (Elwell, 1980a) predicts mean annual soil loss (Z) on a given slope by:

$$Z = K * X * C \qquad (19)$$

with	K	mean annual soil loss from a 4.5 % slope, 30 m long under conventional tilled bare soil
	X	adjustment factor for different slope lengths and -gradients
	C	adjustment factor for the influence of crop cover derived from the annual energy distribution curve and growth curves of crops

An appreciable database was collected for this model. For further details refer to Elwell (1980b), Elwell (1984) and Elwell & Stocking (1976).

7.1 The erosivity of rain (R factor)

Wischmeier & Smith (1958) found that soil loss increased linearly with a storm's total kinetic energy (E) times its maximum 30 minute intensity (I_{30}):

$$R = \sum_{j=1}^{m} (E * I_{30}) \; [N/h] \qquad (20)$$

with
- R longterm mean annual erosivity [N/h][12]
- E kinetic energy of a storm j [kJ/m2]
- I_{30} maximum storm intensity of storm j during 30 min [mm/h] for $I_{30} > 63.5$ mm/h: $I_{30} = 63.5$ mm/h[13]
- m number of erosive storms j per year [-]

The energy of a storm is calculated by:

$$E = \sum_{j=1}^{n} (11.89 + 8.73 \log I_i) * Pi * 10\text{-}3 \; [kJ/m^2] \qquad (21)$$

with
- I_i intensity for storm interval i [mm/h] for $0.05 < I < 76.2$ mm/h; for $I > 76.2$ mm/h $I = 76.2$ mm/h[14]
- P_i rainfall volume during interval i [mm]
- n number of storm intervals i with equal intensity [-]

R is calculated from raingage charts. Each storm is divided in i intervals of constant intensity (I). For each interval intensity, volume and energy are calculated. The total storm energy is the sum of energy of all intervals. An example is given in Figure 71-1:

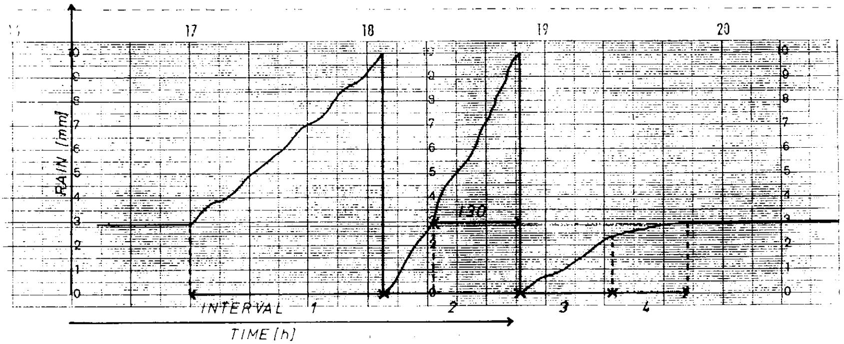
---

[12] R is often given in US units as [hundreds foot tons * in/ac ph] or as [foot tons * in/ac ph]. Multiply by 1.735 or 0.01735, respectively, to receive [N/h]. 1[N/h] = 10 [MJ * mm/ha * h]

[13] I_{30} was limited to 63.5 mm/h because correlation coefficients between erosivety and soil loss improved by introducing this threshold (Wischmeier & Smith, 1978)

[14] The maximum intensity was limited to 76.2 mm/h because drop diameters do not increase any more for very high intensities (cf. Chapter 4.1)

Figure 71-1: Strip chart of a 20 mm storm registered with a self-recording rain gage with a paper feed rate of 60 mm/h



A 20 mm storm was registered by a raingage with a paperspeed of 60 mm/h and a cylinder which emptied automatically after each 10 mm of rain (= vertical drop of the line). The storm started at 17.00 hour and lasted until 19.48 hour. It was divided into 4 intervals of approximately equal intensity (= slope of the ascending curve). Energy is computed as follows:

interval	duration [min]	rain volume [mm]	intensity [mm/h]	energy [kJ/m2]
1	64	7	6.6	0.13
2	47	10	12.8	0.22
3	31	2.4	4.7	0.04
4	26	0.6	1.4	00.008
1–4	168	20	7.1	0.4

The maximum rain volume during 30 min was 7.8 mm in interval 2. Thus, I_{30} equals 15.6 mm/h and $R = E * I_{30} = 0.4 * 15.6 = 6.2$ N/h.

Only 'erosive' storms are used in the calculation. For the US, they were defined as storms with at least 12.5 mm (1/2 inch) of rain or, if less, a maximum 30 min intensity of at least 12.5 mm/h (Wischmeier & Smith, In Germany, the limit for erosive storms was set to 10 mm height or 10 mm/h as maximum 30 min intensity (Schwertmann et al., 1987). The 10 mm threshold also proved to be valid for stations in Cameroon, Nigeria and Kenya (Nill, 1993; Ulsaker & Kilewe, 1984; Wilkinson, 1975) and was used for all further computations. Storms separated by less than 6 hours are considered as one storm (Wischmeier & Smith, 1978).

The tedious procedure for the energy calculation is easier done by computer and digitizing board[15]. Providing erosivity data on a nationwide basis is an important task for the national meteorological services.

In practice, the calculation of reliable R factors faces several constraints. Ideally, the calculation is based on daily rainfall records over 22 years (Wischmeier & Smith, 1978). However, in most countries it is already very satisfying if 10 to 15 years of complete data are available. The obligatory subdivision of individual storms into intervals of similar intensity and the recognition of the maximum 30 min intensity demands self-recording raingages with high resolution. Very often these requirements are not met and several estimation procedures and indices have been developed in different countries in order to replace the R factor (cf. Chapter 4.1).

Determination of the R factor:

Erosivity for many locations in Africa must be estimated from available data of different origin:

- In some countries erosivity is calculated for single sites.
- In other countries regressions exist which may be extrapolated to the surroundings.
- For some countries national or regional erosivity maps (iso-erodent maps) are available.

For countries where no erosivity data are available EI_{30} must be derived from rain data or rainfall distribution maps.

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[15] A softwarc programm for digitizing and analyzing rainfall charts is available from:
Dr. W. Martin, Bayerisches Geologisches Landesamt, Heßstr. 128, 80797 München, Germany.

The quality of the obtained erosivity values will be more reliable for sites or areas where EI_{30} was directly calculated from rain data (provided that the measurement period was sufficiently long). If regressions are used, the reliability decreases with increasing difference in climate and increasing distance from the stations of which the regressions were derived. National erosivity maps generally will be more precise than regional maps. For estimates of erosivity from rain data or maps, several regressions can be applied (Table 12-1Annex).

For the Sahel countries Roose's regression is recommended (Roose, 1977). The regression of Bresch (1993) was developed from 18 stations in Cameroon with 700 to 4000 mm/a. Its use is proposed for the semi-humid to humid parts of West and Central Africa. The equations for Zambia (Pauwelyn et al., 1988) and Zimbabwe (Stocking & Elwell, 1976) are based on a large and well described data base and are recommended for areas of southern Africa with comparable climate. For the highland areas of East Africa, the regression for Rwanda (Durand, 1983) and Kenya (Moore, 1979) can be used.

If regressions for near by neighbour countries are available, the user may decide whether the climate can be compared to these countries and whether these regressions may provide reasonable estimates.

In order to obtain EI_{30} for a particular location, look for the country in Table 71-1 and check if the site or a site nearby is listed. Table 71-1 indicates the reference tables in the Annex where you can find the EI_{30} values. If the site is not listed, look up a national or regional erosivity or rainfall map as indicated in Table 71-1[16].

A given rain falling on low slopes (between 0.2 and 4%) is not as erosive as the same rain on steeper slopes due to the formation of a protective water mulch. Correction of erosivity on low slopes demands the erosivity of the 10 year storm ($EI_{30}/10$)[17]. $EI_{30}/10$ was found to be more suited than mean annual erosivity as runoff depth is especially determined by the intensity of

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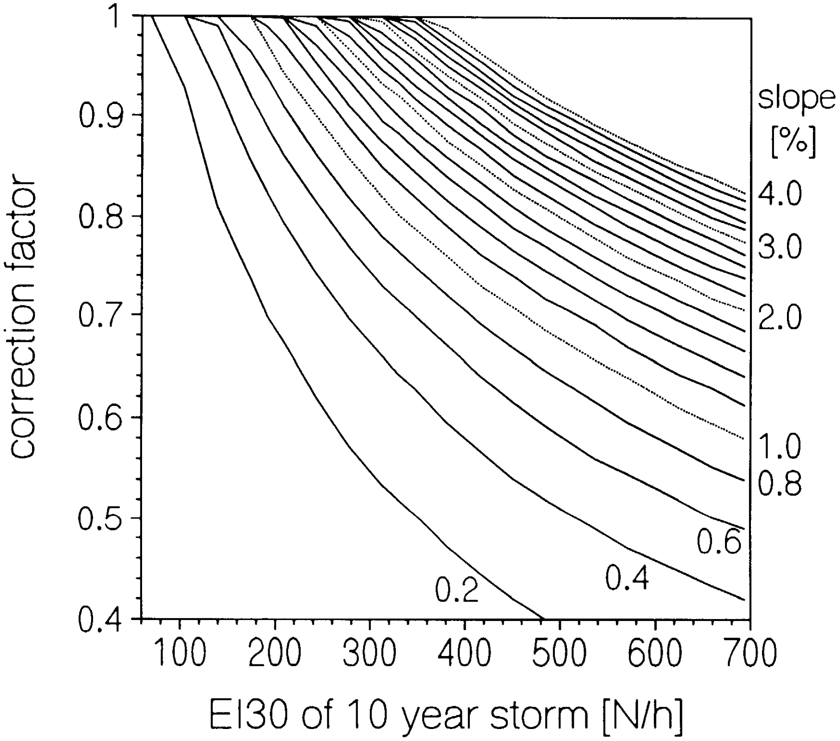
[16] Daily rain data for all station in Benin, Burkina Faso, Cameroon, Central African Repuplic, Chad, Congo, Gabon, Ivory Coast, Mali, Niger, Senegal and Togo are available from the Comité Interafrican d'Etudes Hydrauliques (CIEH), B.P. 369, Ouagadougou, Burkina Faso in two series. Serie I: Stations established until 1965. Serie II: 1965 – 1980.

[17] An estimation method for $EI_{30}/10$ is described in Annex 1.7.

individual storms (Renard et al., 1992). With $EI_{30}/10$ a correction factor can be read from Figure 71-2. Enter the chart vertically from the x-axis with the $EI_{30}/10$ of the site. Choose the gradient of the slope and read the corrected erosivity value by moving horizontally to the y-axis.

Figure 71-2: *Nomograph for the correction of erosivity for the effect of water mulch on slopes between 0.2 and 4 % (Foster, personal communication)*



If hail is a frequent event as in some mountain areas, the annual erosivity should be corrected by estimating the percentage of annual precipitation as hail. This percentage of the annual erosivity must be multiplied by 2.5 (Hurni, 1980) and added to the remaining annual erosivity.

Example:

It is estimated that 20 % of the annual rain falls during hailstorms in an area with a mean annual erosivity of 800 N/h. 20 % of 800 N/h corresponds to 160 N/h. Multiplied by 2.5 = 400 N/h. Thus, the annual erosivity corrected for hail is: 640 N/h (= 80 %) + 400 N/h = 1040 N/h.

Table 71-1: Available erosivity and rain data for single sites, countries and regions (see Annex 1.6 for the rain distribution and volume of single sites)

country	site	EI_{30} [N/h]				rain volume [mm]
		sites	regression map	national map	regional map	national
	Annex	1.1	1.2	1.3	1.4	1.5
Algeria					X	
	Gourari (Isser basin)	X				
	Heriz (Isser basin)	X				
	Madjoudj (Isser basin)	X				
	Sidi Mohamed Cherif (Isser basin)	X				
Angola						X
Benin					X	
Botswana						
Burkina Faso					X	
	Bobo-Dioulasso	X	X			
	Dori	X	X			
	Fada-N'Gourma	X				
	Farako-Ba	X				
	Gampela near Ouagadougou	X				
	Gaoua	X				
	Gonsé near Ouagadougou	X	X			
	Mogtedo	X				
	Niangoloko	X				
	Ouagadougou	X				
	Ouahigouya	X				
	Saria (Meteo)	X				
Burundi				X		
	Mashitsi (Giheta)	X				

Table 71-1: continue

country	site	EI_{30} [N/h]				rain volume [mm]
		sites	regression map	national map	regional map	national map
Cameroon				X	X	
	Bafia	X				
	Bamenda	X				
	Bangangte	X				
	Batouri	X				
	Dibamba	X				
	Douala	X				
	Dschang	X				
	Garoua	X				
	Maroua	X				
	Meiganga	X				
	Nachtigal	X				
	Ngaoundéré	X				
	Nkoundja	X				
	Penka Michel (Bansoa)	X				
	Poli	X				
	Yaoundé	X				
	Yoko	X				
Central African Republic					X	
Chad					X	
	Deli	X				
Congo					X	
Egypt					X	
Equatorial Guinea					X	X
Ethiopia					X	X
Gabon					X	
Gambia					X	
Ghana					X	X
Guinea					X	
Guinea-Bissau						X
Ivory Coast					X	X
	Abidjan	X				
	Azaguié	X				
	Bouaké	X				

Table 71-1: continue

country	site	EI$_{30}$ [N/h]				rain volume [mm]
		sites	regression map	national map	regional map	national map
Ivory Coast						
	Divo	X				
	Korhogo	X				
Kenya					X	
	Eldoret	X				
	Katumani (Machakos)	X				
	Kisumu	X				
	Kitale	X				
	Lodwar	X				
	Malindi	X				
	Mombasa	X				
	Nairobi (Kabete)	X				
	Nakuru	X				
	Nanyuki	X				
	Narok	X				
	Voi	X				
	Lesotho	X				
	Liberia	X	X			
	Libya	X				
Madagascar					X	
	Befandriana	X				
	MalawiMali	X				
Morocco				X	X	
Mauretania					X	
Mocambique					X	
Niger					X	
	Allokoto	X	X			
Nigeria					X	X
	Alore	X				
	Calabar	X				
	Enugu	X				
	Ibadan	X	X			
	Ikom	X				
	Nsukka	X				

Table 71-1: continue

country	site	EI_{30} [N/h]				rain volume [mm]
		sites	regression map	national map	regional map	national map
Nigeria	Onitsha	X				
	Owerri	X				
	Port- Harcourt	X				
	Umudike	X				
Rwanda			X			X
	Butare	X				
	Gakuta	X				
	Gisenyi	X				
	Kamembe	X				
	Kigali (airport)	X				
	Ruhengeri	X				
Sao Tome and Principe						X
Senegal					X	
	Bambey	X				
	Séfa	X				
Sierra Leone					X	X
Somalia					X	
South Africa				X		
Sudan					X	X
Tanzania			X			
Togo					X	
Tunisia					X	X
Uganda			X			
Zaire					X	
Zambia			X	X		
	Chipata	X	X			
	Kabompo	X	X			
	Kabwe	X	X			
	Kafua Polder	X	X			
	Kasama	X	X			
	Mwinilunga	X	X			
	Ndola	X	X			
	Sesheke	X	X			

Table 71-1: continue

country	site	EI_{30} [N/h]				rain volume [mm]
		sites	regression map	national map	regional map	national map
Zimbabwe			X	X		
	Beibridge	X				
	Chipinga	X				
	Chisumbanje	X				
	Delt	X				
	Eastern District		X			
	Enkeldoorn	X				
	Fort Victoria	X				
	Gokwe	X				
	Highveld		X			
	Inyanga	X				
	Karoi	X				
	Lowveld		X			
	Lupane	X				
	Middleveld		X			
	Salisbury	X				
	Tjolotjo	X				
	Tuli	X				
Regional:						
Sahel			X	X		

7.2 Soil erodibility (K factor)

The soil erodibility factor K of the USLE expresses a soil's susceptibility to erosion. It is defined as '... a quantitative value experimentally determined. For a particular site, it is the rate of soil loss per erosivity unit as measured on a 'unit plot'. A 'unit' plot is 72.6ft long, with a uniform lengthwise slope of 9%, in continuous fallow, tilled up- and down-slope.' (Wischmeier & Smith, 1978). Crusts on the soil which form during rains have to be regularly destroyed by further tillage. In order to exclude influences of the previous vegetation, the unit plot is kept under barefallow for at least 2 years before determining erodibility. It is assumed, that by then soil loss is primarily a function of inherent soil properties and increases linearly with the rainfall erosivity. Erodibility is considered to be a specific constant for a soil and is calculated by:

$$K = \frac{A}{R \cdot L \cdot S \cdot C \cdot P} \quad [t \cdot h/N \cdot ha] \qquad (22)$$

On a unit plot L, S, C and P equal 1 and the equation can be written as:

$$K = \frac{A}{R} \quad [t \cdot h/N \cdot ha] \qquad (23)$$

This basic concept of erodibility can also be applied to tropical soils. As shown in Figure 72-1a, erodibility initially increased after clearing of the vegetation. After 1000 to 2000 N/h (which corresponded to 2–3 years in the example) a steady erodibility value was approximated. However, on some soils erodibility may still increase or decrease after some years of barefallow. Erodibility of the soil in Figure 72-1b, for example, started to decrease slightly after 4600 N/h. This is the case if a surface horizon is partly or completely eroded and tillage mixes the underlying horizon with a lower erodibility more and more into the initial surface horizon. Tropical soils mostly have surface horizons of less than 15 cm depth. Partial or complete truncation

Figure 72-1: *Change of soil erodibility with cumulative erosivity on an Ultisol from Cameroon (a) and an Alfisol from Nigeria (b)*

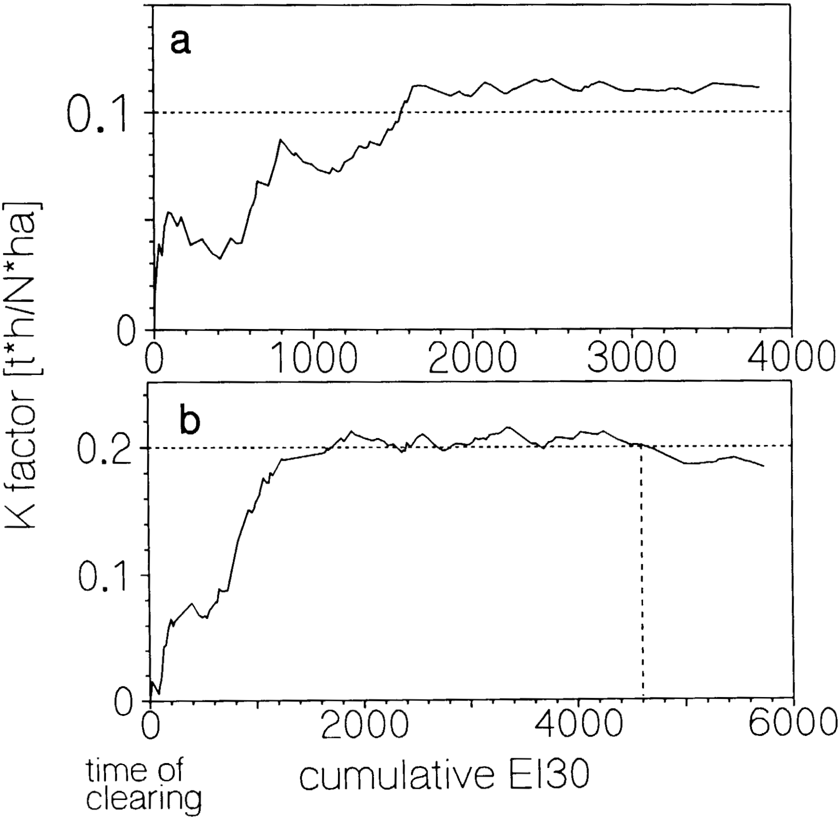


Table 72-1: *Total soil loss in 1 year and corresponding erosion depth on some Cameroonian soils under barefallow*

soil	**soil loss**	
	[t/ha*a]	**[cm/a]**
Andisol over basalt	698	5.8
Kandiudalf on gneiss	293	2.4
Tropohumult on gneiss	269	2.2
Tropudult on gneiss	225	1.8

of a barefallow soil is possible under tropical rain within a few years as shown by annual erosion depths of some Cameroonian soils (Table 72-1).

A decrease in erodibility occurs if the surface soil or subsoil contains coarser particles like quartz or iron oxide gravels. With the selective removal of the fine-earth, the gravel is enriched on the soil surface and protects the soil. Soil loss estimates for gravel-covered soil need, therefore, to be corrected for the protective influence of the cover. An increase in erodibility takes place if an unstable subsoil (e.g. with high sodicity) is more and more incorporated into the surface soil.

Measuring erodibility is time consuming and expensive. Wischmeier & Smith (1978), therefore, came up with an equation to calculate erodibility from simple soil properties which are measured routinely:

$$K = 2.77 * 10^{-6} * M^{1.14} * (12\text{-}OM) + 0.043 * (SC\text{-}2) + 0.033 * (4\text{-}PC) \tag{24}$$

where

$$M\ [-] = (si + ffS) * (100\text{-}cl) \tag{25}$$

with	cl	clay [%]
	si	silt [%][18]
	ffS	very fine sand (0.05-0.1 mm) [%]
	OM	organic matter [%]
	SC	structure class [-]
	PC	permeability class [-]

The equation shows that soil erodibility increases with increasing silt plus very fine sand content of the soil. It decreases with increasing clay and organic matter content.

Structure class of a soil (Table 72-2) does not refer to the actual structure of the soil surface of a field but to structure after 2 years of barefallow. Therefore, some experience is needed in order to assign a structure class to a soil. Soils with an unstable structure develop coarse fragments after prolonged barefallow periods whereas stable soils maintain an aggregated surface. The coarser the final structure, the higher the structure class and erodibility.

---

[18] very fine sand ffS: 100 – 50 µm equivalent diameter
silt: 50 – 2 µm –"–
clay: ≤ 2 µm –"–

Table 72-2: Definition of structure classes for use in the USLE (as modified by Schwertmann et al., 1987)

structure class	**structure**	**mean aggregate size [mm]**
1	very fine crumb	< 1
2	fine crumb	1–2
3	medium to coarse crumb	2–10
4	blocky, platy or massive	> 10

The permeability of a soil describes its infiltration capacity and ability to conduct water. Permeability classes (Table 72-3) must be determined for all horizons down to 80 cm depth. For each horizon a permeability class is chosen. The permeability class of the soil is determined by averaging the permeability classes of all horizons.

If the horizon with the lowest permeability is within the upper 40 cm, its permeability is counted twice before averaging. If the least permeable horizon is found within the upper 20 cm, it determines the permeability class of the soil.

Table 72-3: Definition of permeability classes as used in the USLE (as modified by Schwertmann et al., 1987)

permeability class	**permeability**	**hydraulic conductivity [cm/d]**
1	very low	< 1
2	low	1–10
3	medium	10–40
4	high	40–100
5	very high	100–300
6	extremely high	>300

For field use, the permeability of a soil can be estimated by using information on biological activity or structure in the profile description. An example is given in Table 72-4. However, use of such data needs experience and should only be considered carefully.

Table 72-4: Determination of permeability class by using profile information

description	**permeability class**
very few pores	1
few pores	2
common pores	3
many pores/ porous	4
very porous	5
very high biological activity, very porous	6

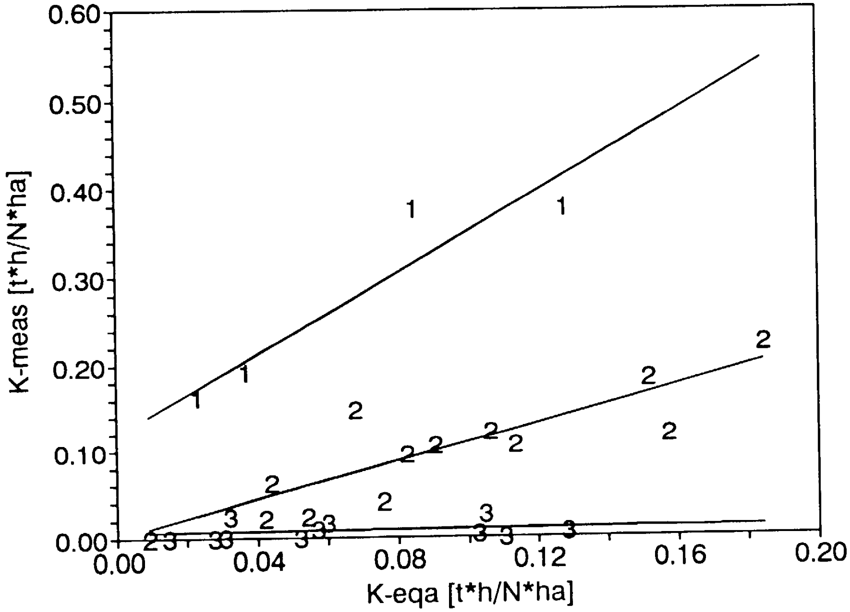


Figure 72-2: Comparison of calculated (K_{eqa}) and measured (K_{meas}) soil erodibility for 28 soils from Cameroon and Nigeria

Equation No. (24) was applied to soils with < 65 % sand and < 35 % clay (Wischmeier et al., 1971). K factors for soils beyond these limits need to be determined from a nomograph. However, a recent investigation indicated no quality loss if erodibility was calculated by the above equation for soils beyond these textural properties (Nill, 1993).

Erodibility measurements on 28 tropical soils from Cameroon and Nigeria showed that equation (24) can not be applied to all tropical soils but needs correction factors for 3 different soil groups (Figure 72-2). For part of the soils (group 1), erodibility as calculated by equation (24) underestimated the measured erodibility whereas group 3 was clearly overestimated. For group 2 (about half of the soils), calculated erodibility agreed well with measured erodibility.

A discriminant analysis can distinguish between unknown soils by using two discriminant functions[19]. 89 % of all soils were correctly classed by using:

- bulk density of 5-10 cm depth [g/cm^3]; measured one day after the soil had been tilled with a hand hoe to seedbed conditions of maize
- silt content of the surface soil [%]
- organic matter content of surface soil [%]
- pH in water of the surface soil; measured in 1 : 2.5 soil/water suspension after 18 h
- amount of air-dry aggregates of the surface soil (0-5 cm) with 0.6–0.2 mm diameter [%] measured by dry-sieving

Wrong classification only becomes dangerous if a soil's erodibility is underestimated. If it is overestimated, too much conservation efforts may be the result which means an exaggerated input of labour and money but no virtual danger.

All soils with a very high erodibility (group 1) were correctly classed. 9 % of low erodible soils (group 3) were classed into group 2 and would receive more conservation than necessary. 17 % of the medium to high erodible soils (group 2) were assigned to group 3 and would receive insufficient conservation.

Based on the two discriminant functions, Fisher's Linear Discriminant Functions were derived which facilitate classification. They were:

---

[19] function 1 = 12.03*BD(5-10) + 0.169*si + 0.265*OM – 1.62*pH – 0.066*agg(06–02) – 5.62
eigenvalue = 1.08, Wilks' Lambda = 0.19 sign. = 0.0001

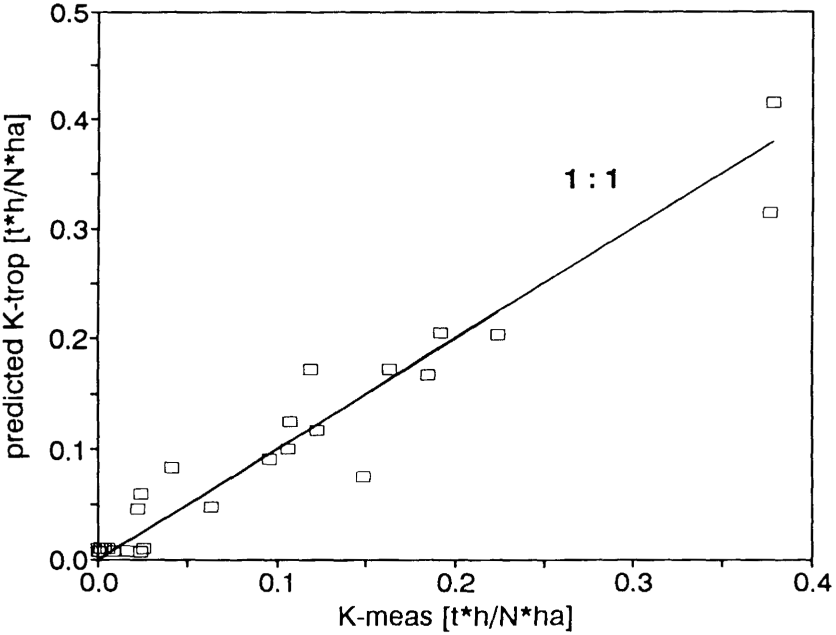
function 2 = 0.25*OM + 0.085*agg(06–02) + 0.0958*si +3.18*BD(5–10 + 0.717*pH – 9.37

eigenvalue = 1.08, Wilks' Lambda = 0.48 sign. = 0.0028

with BD(5–10) bulk density in 0 – 5 cm [g/cm^3]
si silt [%]
OM organic matter [%]
agg(06–02) dry sieved aggregates with 0.6 to 0.2 m diameter [%]

The group centroids for function 1 and 2, respectively, were –2.6 and 0.93 for group 1, 0.938 and 0.77 for group 2 and –0.76 and –1.18 for group 3.

Figure 72-3: *Measured (K-meas) and predicted (K-trop) erodibilities after application of discriminant functions*



$$\begin{aligned}\mathbf{group\ 1} &= 1.118 \ast si + 90.5 \ast BD(5\text{–}10) + 0.416\ OM \\ &\quad + 13.4 \ast pH + 0.724 \ast agg(06\text{–}02) - 100.6 \qquad (26)\end{aligned}$$

$$\begin{aligned}\mathbf{group\ 2} &= 1.7 \ast si + 134.7 \ast BD(5\text{–}10) + 1.395\ OM \\ &\quad + 7.577 \ast pH + 0.478 \ast agg(06\text{–}02) - 114.4 \qquad (27)\end{aligned}$$

$$\begin{aligned}\mathbf{group\ 3} &= 1.343 \ast si + 114.2 \ast BD(5\text{–}10) + 1.617 \ast OM \\ &\quad + 7.816 \ast pH + 0.378 \ast agg(06\text{–}02) - 90.5 \qquad (28\end{aligned}$$

In order to assign a soil to one of the groups, the three functions must be solved. The soil belongs into the group whose function yields the highest value. Once the group is selected, the erodibility of the soils (K–trop [t * h/N * ha]) can be calculated by the following regressions:

$$\textbf{group 1:} \quad \mathbf{K_{trop} = 2.3 * K_{eqa} + 0.12} \tag{29}$$

$$r^2 = 0.87^{*}, n = 4$$

$$\textbf{group 2:} \quad \mathbf{K_{trop} = 1.1 * K_{eqa}} \tag{30}$$

$$r^2 = 0.74^{**}, n = 13$$

$$\textbf{group 3:} \quad \mathbf{K_{trop} = 0.03 * K_{eqa} + 0.006} \tag{31}$$

$$r^2 = 0.02 \text{ n.s.}, n = 11$$

Applying the three regressions to the set of tropical soils mentioned above, explained 92% of the variation in measured soil erodibility (Figure 72-3). The third regression was not significant. However, soils in group 3 have very low erodibilities (maximum K_{meas} = 0.026) and prediction errors may be tolerated.

How can the typical soils for groups 1 to 3 be characterized? Table 72-5 shows average properties for the groups. Group 1 contains soils with more sand, less clay and a higher amount of aggregates in the size fraction of 0.6 to 0.2 mm and have a slightly higher pH than soils in group 2 and 3. Bulk density is lower than in group 2. The surface soil of group 1 readily seals. Their low bulk density and high amount of transportable material enables high soil loss rates. They are characterized by an early occurring runoff, high runoff rate and coefficient. The agronomically very important volcanic ash soils belong to this group. An alternative equation to calculate erodibility was developed by El-Swaify & Dangler (1977) for a group of seven residual soils and five volcanic ash soils from Hawaii[20]:

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[20] dimension for K: [ton * acre * hour/ hundreds of acre * foot tons * inches]; in order to arrive at [t * h/N * ha] multiply with 1.3.

Table 72-5: Average runoff, soil loss and soil properties for the three erodibility groups (values with different letters are significantly different at the 0.05 level);

parameter	**means for:**		
	group 1	**group 2**	**group 3**
sand [%]	52^{a}	43^{a}	31^{a}
very fine sand [%]	2.8^{a}	3.1^{a}	3.0^{a}
silt [%]	16^{a}	18^{a}	17^{a}
clay [%]	32^{a}	40^{a}	52^{b}
organic matter [%]	4.2^{a}	3.8^{a}	6.3^{a}
pH	5.3^{a}	5.1^{a}	5.0^{a}
bulk density (5-10 cm) [g/cm³]	0.87^{ac}	1.06^{ab}	0.87^{c}
bulk density (0-10 cm) [g/cm³]	0.88^{ac}	0.97^{ab}	0.79
aggregates (0.6-0.2 mm) [%]	39^{a}	25^{b}	22^{b}
Kmeas [t*h/N*ha]	0.2775^{a}	0.0969^{b}	0.0077^{c}
start runoff [s]	860a	1349^{a}	3873b
mean runoff rate [l/min*m²]	3.1^{a}	2.2^{a}	0.3^{b}
maximum runoff rate [l/min*m²]	5.2^{a}	4.3^{a}	0.8
runoff coefficient [% of rain]	32^{a}	23^{a}	3b
soil loss [t/ha]	8.9^{a}	2.9^{a}	0.1^{c}
mean soil loss rate [g/l*min]	33^{a}	23^{a}	3^{b}
maximum soil loss rate [g/l*min]	49^{a}	36^{a}	6^{a}

$$\begin{aligned} K = {} & -0.0397 + 0.00311 \cdot \mathrm{LT}\,250\mu + 0.00043 \cdot \mathrm{MH} \\ & + 0.00185 \cdot \mathrm{BS} + 0.00258 \cdot \mathrm{si} - 0.00823 \cdot \mathrm{sa} \end{aligned} \tag{32}$$

with LT250 m percentage of soil which passes a 0.25 mm sieve by wet-sieving
MH (sand > 0.1 mm) · (silt + very fine sand)
BS base saturation in 1 n NH_4oAc at pH 7
si percent silt
sa sand > 0.1 mm

Soils in group 3, as the other extreme, tend to be more clayey and richer in organic matter than soils in group 1 and 2. Bulk density is slightly lower than in group 2 and there are less aggregates of 0.6 to 0.2 mm diameter. These soils hardly seal and runoff starts very late if rain falls on dry soil. Soil loss under natural rain occurs especially after sequences of several storms which presaturate these soils. Their runoff-soil loss behaviour is not determined by surface sealing but by the permeability of the profile. The poor relationship between surface soil and profile properties explains the insignificant regression in Figure 72-2 for this group. Drop impact and storm have little influence on soil loss. As runoff in group 3 requires a presaturation of the soil, occasional rains during the dry season are of no danger. Especially clayey, iron oxide rich soils from basic parent rock are found in this group.

Soils in group 2 tend to have more silt and very fine sand, along with medium clay and sand contents (Table 72-5). The organic matter content is lower than in the other groups and bulk density higher. Their surface seals as in group 1 but sealing and runoff occurs later during a rain resulting in lower mean runoff and soil loss. This is indicated by smaller differences of maximum runoff and soil loss rates of group 1 and group 2 soils compared to mean rates. It can be assumed that maximum runoff is reached at the end of a storm for soils in group 2. Group 2 had 71% of the mean runoff rate of soils in group 1 but reached 83% of the maximum runoff rate of group 1. The values for mean and maximum soil loss were 70 and 74%, respectively. Thus, with increasing rain volume the difference in runoff and soil loss between group 1 and 2 became smaller. However, mean and maximum soil loss rate did not differ as much as mean and maximum runoff rate. This suggests that runoff increased more than soil loss. Typic soils in group 2 are formed from metamorphic basement rocks.

Soil taxonomy gives some, though not very safe, indications. Oxisols frequently are to be found in group 3 although some occur in group 2 as well. Ultisols, Inceptisols and Alfisols are especially found in group 2. However, some soils in group 2 also have low erodibilities (Figure 72-2) and rather stable structure.

Determination of the K factor:

1. Calculate K_{eqa} according to equation (24). Silt, clay, very fine sand and organic matter content are taken from soil analysis of the surface soil.

   Structure class is chosen from Table 72-2. If doubts exist which class to choose, erodibility can be calculated for two different classes in order to receive the range in soil loss.

   Permeability is calculated as explained on page 96 and shown in the following example:

soil 1:				**soil 2:**			
horizon	**depth [cm]**	**permea-bility**	**permea-bility class**	**horizon**	**depth [cm]**	**permea-bility**	**permea bility class**
A	0-10	very high	6	A	0-10	very high	5
Bt1	10-50	medium	3	A/B	10-25	high	4
Bt2	50-150	medium	3	Bt1	25-60	low	2 X 2
				BC	60-150	medium	3
mean permeability of soil:			4	mean permeability of soil:			3.2

In soil 1, the lowest permeability corresponds to the deepest horizon within 80 cm depth and permeability class of the soil is calculated as mean permeability of all horizons to 80 cm depth. In soil 2, horizon Bt1 has the lowest permeability and lies within 40 cm depth. Therefore, it is counted twice (sum of all classes/number of horizons = 16/5 = 3.2).

2. In order to decide into which erodibility group a soil belongs, equations (26) to (28) must be solved. The group with the highest result is assigned to the soil.

3. Erodibility (K_{trop}) is calculated for group 1 and 2 soils from equation (29) and (30), respectively, or can be read from Table 72-6. The regression for group 3 soils (equation (31)) was not significant. It is recommended to use the maximum erodibility $K_{meas} = 0.026$ found for group 3 soils. As 30 % of the group 3 soils had erodibilities between 0.01 and 0.026 and 70 % of the soils erodibilities < 0.01, most of the group 3 soils are overestimated by this procedure.

Table 72-6: Conversion of K_{equ} to K_{trop} for soils in group 1 and 2 (derived from equations (29) and (30))

K_{equ}	K_{trop}		K_{equ}	K_{trop}	
	group 1	group 2		group 1	group 2
0.001	0.122	0.001	0.31	0.83	0.34
0.002	0.125	0.002	0.32	0.86	0.35
0.003	0.127	0.003	0.33	0.88	0.36
0.004	0.129	0.004	0.34	0.90	0.37
0.005	0.132	0.006	0.35	0.93	0.39
0.006	0.134	0.007	0.36	0.95	0.40
0.007	0.136	0.008	0.37	0.97	0.41
0.008	0.138	0.009	0.38	0.99	0.42
0.009	0.141	0.010	0.39	1.00	0.43
0.01	0.14	0.01	0.40	1.00	0.44
0.02	0.17	0.02	0.41	1.00	0.45
0.03	0.19	0.03	0.42	1.00	0.46
0.04	0.21	0.04	0.43	1.00	0.47
0.05	0.24	0.06	0.44	1.00	0.48
0.06	0.26	0.07	0.45	1.00	0.50
0.07	0.28	0.08	0.46	1.00	0.51
0.08	0.30	0.09	0.47	1.00	0.52
0.09	0.33	0.10	0.48	1.00	0.53
0.10	0.35	0.11	0.49	1.00	0.54
0.11	0.37	0.12	0.50	1.00	0.55
0.12	0.40	0.13	0.51	1.00	0.56
0.13	0.42	0.14	0.52	1.00	0.57
0.14	0.44	0.15	0.53	1.00	0.58
0.15	0.47	0.17	0.54	1.00	0.59
0.16	0.49	0.18	0.55	1.00	0.61
0.17	0.51	0.19	0.56	1.00	0.62
0.18	0.53	0.20	0.57	1.00	0.63
0.19	0.56	0.21	0.58	1.00	0.64
0.20	0.58	0.22	0.59	1.00	0.65
0.21	0.60	0.23	0.60	1.00	0.66
0.22	0.63	0.24	0.61	1.00	0.67
0.23	0.65	0.25	0.62	1.00	0.68
0.24	0.67	0.26	0.63	1.00	0.69
0.25	0.70	0.28	0.64	1.00	0.70
0.26	0.72	0.29	0.65	1.00	0.72
0.27	0.74	0.30	0.66	1.00	0.73
0.28	0.76	0.31	0.67	1.00	0.74
0.29	0.79	0.32	0.68	1.00	0.75
0.30	0.81	0.33	0.69	1.00	0.76

If the analytical data for the solution of the discriminant functions are not available the experience that volcanic ash soils (Andisols) are often in group 1, soils from acid basement rocks are frequently in group 2 whereas soils from basalt and other basic parent rock are often in group 3 can be used for a crude soil loss estimate.

7.3 The topographic factor (LS factor)

Soil erosion is favoured with increasing slope length and -gradient[21] (cf. Chapter 4.3). The slope length factor (L) gives soil loss on a given slope length relative to soil loss on the USLE unit plot. The factor for gradient (S) gives the ratio of soil loss on any given slope to that of a 9% slope. The combined topographic factor (L*S) allows to adjust soil loss on a given slope length, gradient and slope form to that of the control plot. It is calculated by (Wischmeier & Smith, 1978):

$$LS = \left(\frac{l}{22.1}\right)^m * (65.41 * \sin^2\alpha + 4.56 * \sin\alpha + 0.065)\ [-] \qquad (33)$$

with l slope length [m]
m slope length exponent [-]
a gradient [°]

or

$$LS = \left(\frac{l}{22.1}\right)^m * s/9 * \sqrt{(s/9)}\ [-] \qquad (34)$$

with s gradient [%]

The slope length exponent (m) depends on the gradient and is smaller for low slopes than for steep slopes (Table 73-1).

---

[21] Gradient can be measured by inclinometers or specially equipped compasses. A very simple device to measure slope - length and - gradient is illustrated in Annex 2.1.

Table 73-1: Slope length exponent (m) for different gradients

gradient [%]	**m**
<= 0. 5	0. 15
0.6–1.0	0.20
1.1–3. 4	0.30
3.5–4.9	0.40
>= 5	0.5

On low slopes, m becomes smaller because low obstacles as rills and clods (surface roughness) produced by tillage slow down runoff. Thus, more water stays on the field for a longer time and water depth on the field increases. Time for infiltration is longer and at least part of the soil surface is protected against drop impact by a water layer. LS factors can directly be read from Figure 73-1. In order to adjust for less splash erosion on low slopes and the protective water layer, an additional correction of the annual erosivity is proposed on low slopes in the successor model of the USLE, – the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1992). This correction factor can be obtained from Figure 71-2.

An exponent m < 1 shows that soil loss increases to a smaller extent than slope length. Nevertheless, in contrast to erosivity, soil erodibility, and slope-gradient, slope length can be influenced easily by man and is an important parameter for soil loss reduction. Slope length in the USLE is defined as the distance from the point where runoff begins to the point where deposition occurs or where runoff enters a well-defined channel (Wischmeier & Smith, 1978). As demonstrated in Figure 73-2, the lower slope end may be presented by a small ditch or ridge along a field border, a road ditch or a drainage channel. In case of small rivers, the slope end generally does not correspond to the river border because deposition generally starts earlier. The upper slope end can be formed by the watershed boundary or by ridges, channels or deposition zones which limit a slope above. In general, the definition of an upper slope limit is met if no runoff from slope segments above enters the slope.

Figure 73-1: Diagram for the determination of LS factors

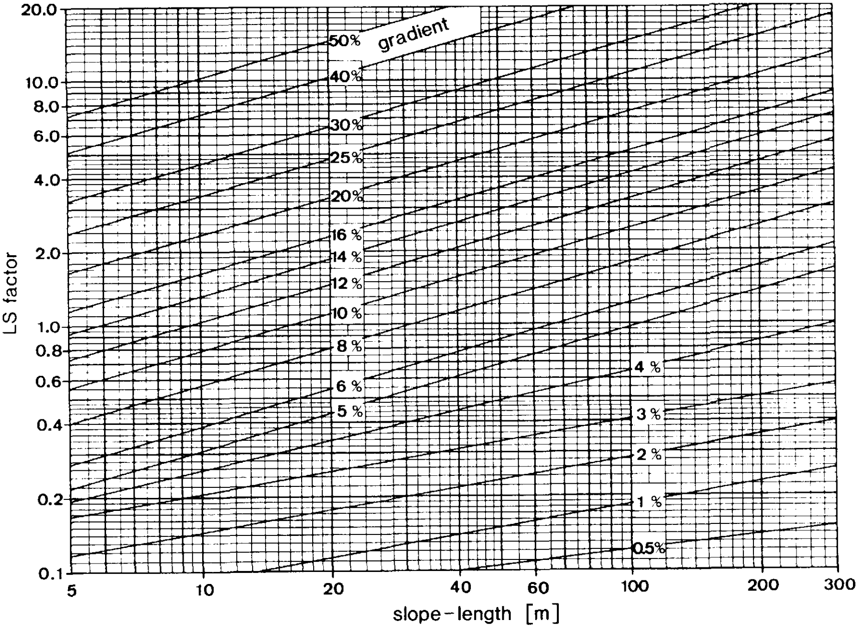
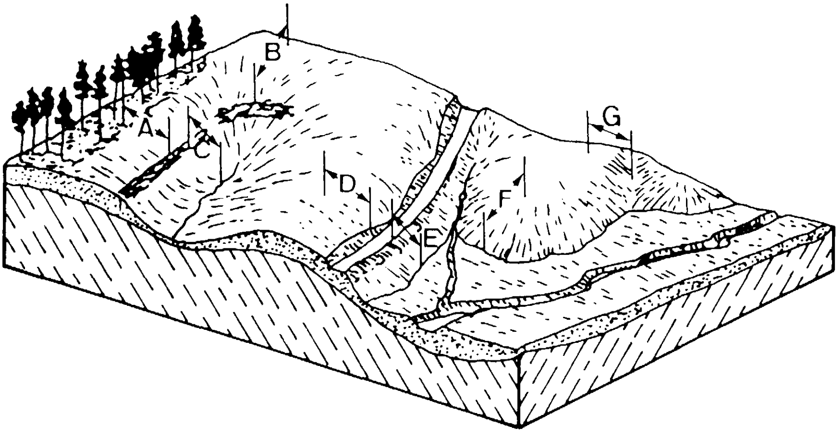


Figure 73-2: Examples for the determination of erosive slope-length (after Dissmeyer & Foster (1980) as modified by Schwertmann et al. (1987)



Runoff volume and velocity increase along the slope. This causes an increase of soil loss per unit area with increasing distance down-slope. In order to calculate soil loss on a segment of the slope, the slope is divided into a small number of segments i with equal length and approximately equal gradient. The segment on top of the slope corresponds to i = 1. The ratio of soil loss on each segment to soil loss of the total slope can be described by:

$$A_i = \frac{i^{(m+1)} - (i-1)^{(m+1)}}{N^{(m+1)}} \quad [-] \tag{35}$$

with	A_i	relative soil loss of segment i [-]
	i	segment number
	N	number of segments with equal length
	m	slope length exponent

On a uniform slope of 6% (m = 0.5), for example, which was divided into 3 segments of equal length, the upper segment would provide 19%, the middle and lower segment 35 and 46% of the total soil loss on the slope. Results of equation 35 for different slope exponents and segment numbers are given in Table 73-2.

As soil loss is not equally distributed along a slope, slope form as well determines soil loss. On a concave slope, the up- and mid-slope parts are steeper than the foot-slope whereas on a convex slope the foot-slope has a higher gradient. The large runoff volume which arrives down-slope meets a low gradient on the concave but a high gradient on the convex slope. Submitting the same average gradient, soil loss on convex slopes is, therefore, more severe than on concave slopes.

Table 73-2: Soil loss of slope segments with equal length on uniform slopes relative to soil loss of total slope for different number of segments and different slope exponents (based on equation (35))

number of segments	segment number	slope exponent				
		m=0.5	**m=0.4**	**m=0.3**	**m=0.2**	**m=0.15**
2	1	0.35	0.38	0.41	0.44	0.45
	2	0.65	0.62	0.59	0.56	0.55
3	1	0.19	0.21	0.24	0.27	0.28
	2	0.35	0.35	0.35	0.35	0.34
	3	0.46	0.43	0.41	0.39	0.37
4	1	0.13	0.14	0.16	0.19	0.20
	2	0.23	0.24	0.24	0.25	0.25
	3	0.30	0.29	0.28	0.27	0.27
	4	0.35	0.33	0.31	0.29	0.28
5	1	0.09	0.11	0.12	0.14	0.16
	2	0.16	0.17	0.18	0.19	0.19
	3	0.21	0.21	0.21	0.21	0.21
	4	0.25	0.24	0.23	0.22	0.22
	5	0.28	0.27	0.25	0.23	0.23

Determination of the LS factor:

Read the LS factor for uniform slopes from Figure 73-1[22]. In order to correct soil loss for the effect of slope form, an irregular slope is divided into a small number of equal length segments with approximately uniform gradient. LS values for each segment are chosen from Figure 73-1 by using the slope length of the entire slope and the gradient of the segment. The so derived LS values are weighted by multiplying them with the values from Table 73-2. Summation of the products gives the LS factor for the whole slope.

Example:

A 60 m long convex slope is divided into three 20 m long segments with uniform gradient of 10, 15 and 20% for the up-, mid- and down-slope segment (segments 1,2 and 3 in Table 73-3), respectively. The LS factor for each segment is chosen from Figure 73-1 by using a slope length of 60 m and the gradient of each segment (column 3, Table 73-3):

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[22] A conversion table from degrees to percent is given in Annex 2.2.

Table 73-3: Example for the consideration of an irregular slope with changes in soil erodibility in the USLE

1	2	3	4	5	6	7
segment	**gradient**	**LS factor**	**weighting factor**	**corrected LS factor**	**K factor**	**corrected KLS factor**
1	10	1.92	0.19	0.37	0.02	0.007
2	15	3.53	0.35	1.24	0.13	0.16
3	20	5.43	0.46	2.50	0.21	0.53
			sum:	4.11		0.70

These LS factors are weighted by the values from Table 73-2 for a slope ≥ 5 % ($m = 0.5$) and 3 segments (column 4 in Table 73-3). The products of all segments (column 5) are summed up and give the LS factor (= 4.11) for the slope. This means that on a soil on this slope, soil loss would be 4.11 times the soil loss of the same soil on a 22.1 m long slope of 9 %.

Soil erodibility changes on a slope can be considered by the same procedure. Soil erodibility for each segment (column 6) is multiplied with the weighted LS factors for the segments (column 5) which gives a KLS factor for the slope of 0.7 (column 7).

Changes of the crop and management factor are dealt alike as long as no deposition is induced by the changes.

The slope length factor also allows the calculation of a maximum length if the maximum tolerable soil loss (T) is known:

$$LS = \frac{T}{R * K * C * P} \quad [-] \tag{36}$$

If LS is known, the maximum length can be chosen from Figure 73-1. A tolerable LS value of 2 on a 10% slope, for example, yields a maximum slope length of 65 m in order to keep soil loss within the tolerable limits.

7.4 The cover and management

The cover and management factor C of the USLE gives the ratio of soil loss on a cropped plot to soil loss on a barefallow control plot of identical size, slope length, gradient and soil. In contrast to the barefallow control plot where soil loss per unit erosivity (= erodibility) is supposed to be a constant (see Chapter 7.2), soil loss on a cropped plot is subject to changes over the year which depend on crop growth and management. After planting, the growing canopy increasingly protects the soil surface while litter from senescent parts falls to the ground and forms a mulch layer. The weeds in the crop stand develop additional canopy cover and act as mulch after weeding, if left in the field. The protection of the soil surface depends on the amount and quality of coverage. Both are crop and management specific.

However, an uncovered soil surface is only endangered if erosive storms occur. Therefore, in order to calculate the influence of crop cover on soil loss, the distribution of erosivity during the year must also be considered. As the annual erosivity distribution is site specific, the same cropping system will cause different soil loss at different locations because of different distribution of erosive rains. The mean annual erosivity distribution is then assigned to the different crop stages (Table 74-1).

Table 74-1: Crop stages as defined for the USLE (Wischmeier & Smith, 1978)

crop stage	description
F – SB	rough fallow (F) after primary tillage (coarse tilth) to seedbed (SB) preparation (= secondary tillage; fine tilth)
SB – 10	after seedbed preparation until 10 % canopy cover of the crop (seedbed to germination)
10–50	10 % canopy cover until 50% cover (establishment)
50–75	50 % to 75 % canopy cover (development)
75 – H	75 % canopy cover to harvest
H – F	harvest to next plowing or seeding

For each crop stage (i) a soil loss ratio (SLR) is calculated as soil loss of the cropped plot ($Acrop_i$) relative to soil loss of the control plot ($Abare_i$) during the same period:

$$SLR_i = \frac{Acrop_i}{Abare_i} \quad [-] \tag{37}$$

The soil loss ratios indicate the degree of soil protection by a specific crop stage. They are independent of site specific climate.

In order to avoid short term soil loss variations, the longterm mean soil loss of the barefallow is used instead of the actually measured soil loss. It is calculated by:

$$Abare_i = R_i * K \text{ (t/ha)} \tag{38}$$

with		
	K	soil erodibility [t*h/N*ha]
	R_i	mean erosivity during crop stage i [N/h]

The term (R_i * K) gives the mean soil loss of the barefallow control plot during crop stage i. In order to reflect the site specific erosivity distribution, the erosivity during crop stage i relative to the annual erosivity is calculated:

$$Rrel_i = \frac{R_i}{R} \quad [-] \tag{39}$$

with		
	$Rrel_i$	proportion of annual R (relative erosivity) during crop stage i [N/h]
	R	mean annual erosivity [N/h]

The soil loss ratios for each crop stage of a rotation are multiplied by the corresponding Rreli's. Summation of the products and subsequent division by the duration of the rotation results in an average annual C factor:

$$C = \frac{\sum_{j=1}^{t} \sum_{j=1}^{n} (Rrel_i * SLR_i)_j}{t} \quad [-] \tag{40}$$

with		
	n	number of crop stages i per year j
	t	duration of the rotation [a]

An example for the calculation of a groundnut – maize rotation is given in Table 74-2. Mean planting date of groundnut and maize was 15th March and 5th August, respectively.

Table 74-2: Calculation of the C factor for a groundnut (1st growing season) – maize (2nd season) system as measured for 1 year in Douala

column	**1**	**2**	**3**	**4**	**5**	**6**
	crop stage	**duration [d]**	**cumul. erosivity [relative to mean annual]**	**relative erosivity ($Rrel_i$) [-]**	**soil loss ratio (SLR) [-]**	**column 4 * 5 (C_i)**
ground-nut	SB – 10	16	0.06	0.01	1.52	0.02
	10–50	28	0.12	0.07	0.63	0.04
	50–75	7	0.14	0.02	0.02	0.00
	75 – H	37	0.24	0.10	0.07	0.00
	H – SB	55	0.54	0.29	0.03	0.00
	SB – SB	143		0.49		0.06
maize	SB – 10	31	0.68	0.14	0.56	0.08
	10–50	19	0.79	0.11	0.51	0.06
	50–75	8	0.84	0.06	0.32	0.02
	75 – H	44	0.99	0.15	0.05	0.01
	H – SB	120	1.05	0.05	0.00	0.00
	SB – SB	222		0.51		0.17
	Total	365		1		0.23

The crop stage duration is taken from the growth curves of the various crops (Annex 3.3). The $Rrel_i$'s (column 4) are obtained from the mean annual distribution of erosivity (Table 74-3). Alternatively, the erosivity distribution can be estimated by calculating the relative <u>rainfall</u> distribution[23].
The C factor is calculated by summation of the product of the relative erosivity (column 3) times the soil loss ratio (column 4) for each crop stage (column 5).

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[23] Estimation of the erosivity distribution from rainfall distribution for 18 stations in Cameroon resulted in a mean and maximum error of 1.3 and 12.6%, respectively (Bresch, 1993).

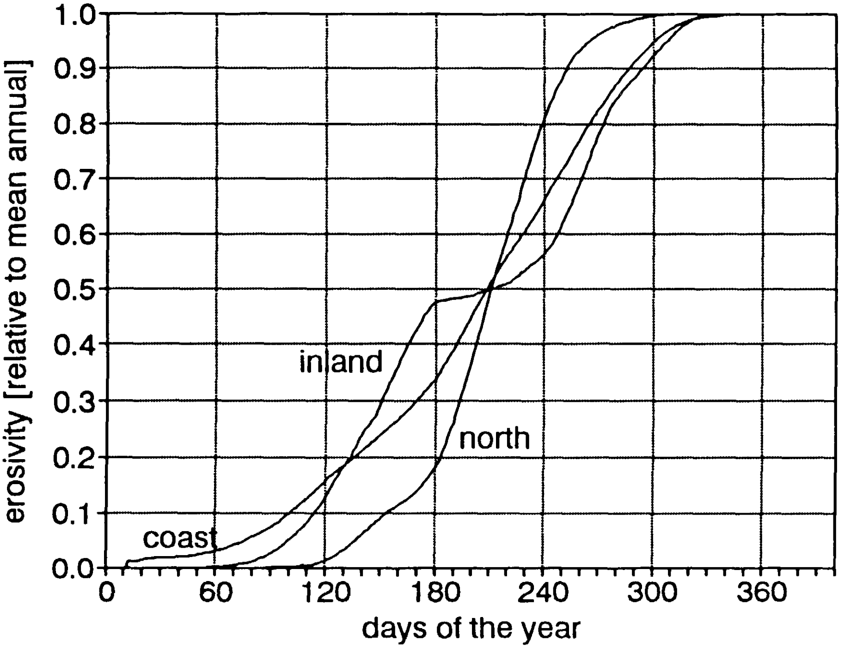
High contribution to the C factor results from crop stages where little surface cover coincides with high erosivity: This was the case for crop stage SB – 10 of maize which received 14 % of the annual erosivity ($Rrel_i$ = 0.14) in Table 74-2 in a state of little cover. 35 % of the annual soil loss (column 6 in Table 74-2: 0.08/0.23) occurred during this period. The soil loss ratios are generally high during the initial crop stages when cover is poor. An SLR > 1for crop stage SB – 10 of groundnut (SLR = 1.52) signifies that soil loss on the cropped plot exceeded the mean soil loss of the barefallow plot during this crop stage. This was due to compaction of the cultivated plot during the planting operation and sealing by early rains. On the barefallow plot, seals after a rain are raked (per definition) and no planting takes place.

The duration of the crop stages shows the faster growth of groundnut which needed 88 days from seedbed (SB) to harvest (H) compared to 102 days for maize. Groundnut in the example received 49 % of the annual erosivity (sum RRi of groundnut (SB to SB) = 0.49) compared to 51% for maize (sum RRi (SB to SB) = 0.51). The contribution of groundnut to the C factor was 0.06 (SB to SB) which corresponds to 26 % compared to 74 % (0.17) for maize. Thus, in the example, groundnut was more protective for the soil than maize. Protection measures (e.g. mulch) would thus be more effectively applied during maize cultivation.

Table 74-3: Annual erosivity distribution for Douala/Cameroon

day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	32 0.02	60 0.03	91 0.08	121 0.16	152 0.24	182 0.35	213 0.54	244 0.68	274 0.85	305 0.96	335 1.00
2	0.00	33 0.02	61 0.03	92 0.08	122 0.16	153 0.24	183 0.35	214 0.54	245 0.68	275 0.85	306 0.97	336 1.00
3	0.00	34 0.02	62 0.03	93 0.08	123 0.16	154 0.25	184 0.36	215 0.54	246 0.69	276 0.85	307 0.97	337 1.00
4	0.00	35 0.02	63 0.03	94 0.09	124 0.17	155 0.25	185 0.36	216 0.54	247 0.69	277 0.86	308 0.97	338 1.00
5	0.00	36 0.02	64 0.03	95 0.09	125 0.18	156 0.25	186 0.36	217 0.55	248 0.71	278 0.86	309 0.97	339 1.00
6	0.00	37 0.02	65 0.04	96 0.09	126 0.18	157 0.26	187 0.36	218 0.55	249 0.71	279 0.87	310 0.98	340 1.00
7	0.00	38 0.02	66 0.04	97 0.09	127 0.18	158 0.26	188 0.37	219 0.55	250 0.72	280 0.87	311 0.98	341 1.00
8	0.00	39 0.02	67 0.04	98 0.09	128 0.18	159 0.26	189 0.37	220 0.56	251 0.73	281 0.88	312 0.99	342 1.00
9	0.01	40 0.02	68 0.04	99 0.09	129 0.19	160 0.26	190 0.38	221 0.56	252 0.74	282 0.88	313 0.99	343 1.00
10	0.01	41 0.02	69 0.04	100 0.09	130 0.19	161 0.28	191 0.39	222 0.57	253 0.75	283 0.88	314 0.99	344 1.00
11	0.01	42 0.02	70 0.04	101 0.10	131 0.19	162 0.28	192 0.39	223 0.58	254 0.75	284 0.89	315 0.99	345 1.00
12	0.01	43 0.02	71 0.04	102 0.10	132 0.20	163 0.28	193 0.40	224 0.58	255 0.76	285 0.90	316 0.99	346 1.00
13	0.01	44 0.02	72 0.04	103 0.10	133 0.20	164 0.28	194 0.41	225 0.58	256 0.76	286 0.90	317 0.99	347 1.00
14	0.02	45 0.02	73 0.05	104 0.10	134 0.20	165 0.29	195 0.41	226 0.59	257 0.77	287 0.90	318 0.99	348 1.00
15	0.02	46 0.02	74 0.05	105 0.10	135 0.20	166 0.29	196 0.42	227 0.59	258 0.77	288 0.90	319 0.99	349 1.00
16	0.02	47 0.02	75 0.05	106 0.11	136 0.20	167 0.29	197 0.44	228 0.60	259 0.77	289 0.91	320 0.99	350 1.00
17	0.02	48 0.02	76 0.05	107 0.12	137 0.20	168 0.29	198 0. 44	229 0.60	260 0.77	290 0.92	321 0.99	351 1.00
18	0.02	49 0.02	77 0.05	108 0.12	138 0.21	169 0.29	199 0.45	230 0.61	261 0.78	291 0.92	322 0.99	352 1.00
19	0.02	50 0.02	78 0.05	109 0.13	139 0.21	170 0.30	200 0.45	231 0.62	262 0.78	292 0.93	323 0.99	353 1.00
20	0.02	51 0.02	79 0.06	110 0.13	140 0.21	171 0.31	201 0.46	232 0.62	263 0.79	293 0.93	324 0.99	354 1.00
21	0.02	52 0.02	80 0.06	111 0.13	141 0.21	172 0.31	202 0.47	233 0.62	264 0.79	294 0.93	325 0.99	355 1.00
22	0.02	53 0.02	81 0.06	112 0.14	142 0.21	173 0.31	203 0.47	234 0.63	265 0.79	295 0.93	326 0.99	356 1.00
23	0.02	54 0.02	82 0.05	113 0.14	143 0.21	174 0.31	204 0.48	235 0.64	266 0.81	296 0.93	327 0.99	357 1.00
24	0.02	55 0.03	83 0.06	114 0.14	144 0.22	175 0.32	205 0.48	236 0.64	267 0.81	297 0.94	328 0.99	358 1.00
25	0.02	56 0.03	84 0.06	115 0.14	145 0.23	176 0.32	206 0.49	237 0.65	268 0.82	298 0.95	329 0.99	359 1.00
26	0.02	57 0.03	8 0.06	116 0.15	146 0.23	177 0.32	207 0.51	238 0.66	269 0.83	299 0.95	330 1.00	360 1.00
27	0.02	58 0.03	86 0.06	117 0.15	147 0.23	178 0.33	208 0.51	239 0.66	270 0.84	300 0.95	331 1.00	361 1.00
28	0.02	59 0.03	87 0.06	118 0.16	148 0.23	179 0.33	209 0.52	240 0.66	271 0.84	301 0.95	332 1.00	362 1.00
29	0.02		88 0.06	119 0.16	149 0.24	180 0.33	210 0.52	241 0.66	272 0.85	302 0.96	333 1.00	363 1.00
30	0.02		89 0.07	120 0.16	150 0.24	181 0.34	211 0.52	242 0.67	273 0.85	303 0.96	334 1.00	364 1.00
31	0.02		90 0.07		151 0.24		212 0.53	243 0.67		304 0.96		365 1.00

Figure 74-1: Mean annual erosivity distribution for coastal, inland and northern Cameroon (day 1 corresponds to the 3rd erosive rain in each year) (Bresch, 1993)



The difference of erosivity distributions is shown by the three sites from Cameroon in Figure 74-1. On the coast (Douala), the very humid ocean climate has rather uniformly distributed erosivity during 9 months. The dry season lasts about 3 months. The inland of southern Cameroon (Yaoundé) has two distinct rainy seasons separated by a dry spell whereas in the north (Maroua) nearly all erosivity is concentrated in a few months.

To establish soil loss ratios for different crops and management systems needs field measurements which are costly and time consuming. Soil loss ratios for the major crops[24] in the USA have been experimentally determined for a range of management options[25].

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[24] maize, soybeans, cottons small grain, sorghum, wheat, ryegrass, potatoes, pasture, range and idle land and forest

[25] plow, notill, chisel plow, contour tillage, stripcrop, ridging, with and without mulch or residues

In order to calculate soil loss for further crops and systems, Wischmeier (1975) proposed to divide the influence of the cropping system into subfactors. He defined a subfactor for:

1. the influence of the canopy cover (c1)
2. the influence of mulch or of vegetation close to the soil surface (c2)
3. tillage and residual effects of the former vegetation (c3)

The C factor is calculated as the product of all 3 subfactors:

$$C = c1 * c2 * c3 \qquad (41)$$

For tropical countries, the subfactor method is especially valuable because for many crops no experimentally determined data are available. A further complication is the large variety of small holder systems which are difficult to compare to American standards (e.g. hand tillage, mixed cropping, heaping and bedding etc.).

Data for the subfactor calculation also are often not available but can rather easily be collected. The procedure for subfactor determination is subsequently explained.

Subfactor c1

The influence of canopy is calculated by (Foster, 1982):

$$c1 = 1 - CC_e * e^{-0.34*He} \quad [-] \qquad (42)$$

with CC_e effective canopy coverage [-]
H_e effective canopy height [m]

The canopy height effects the velocity of drops falling off the leaves and thereby the energy of the drop impact on the soil. As drops may be formed by lower and higher leaves on a plant and drops from higher leaves may be intercepted by the leaves below, the effective canopy height is used which represents an average value. For practical considerations, H_e is estimated as:

$$H_e = 0.6 * H_{max} \quad [m] \qquad (43)$$

with H_{max} mean height of the uppermost horizontal leaf of the plants in a crop stand [m]

The second variable in equation No. (42) – canopy cover – enters also as effective canopy cover. Drops which fall from the canopy may not directly hit the soil surface but may fall on mulch material underneath without causing soil loss. As a cover from mulch is more protective than from canopy, the effect of mulch is considered to 100% whereas only the canopy cover with no mulch underneath, i.e. the effective canopy cover (CCe), is taken into account. It is calculated by:

$$CC_e\ [-] = CC * (1\text{-}MC) \quad [-] \qquad (44)$$

with CC canopy cover [-]
MC mulch cover [-]

If canopy cover is 80%, for example, with a mulch cover of 20%, the effective canopy cover is 0.8 * (1–0.2) = 0.64.

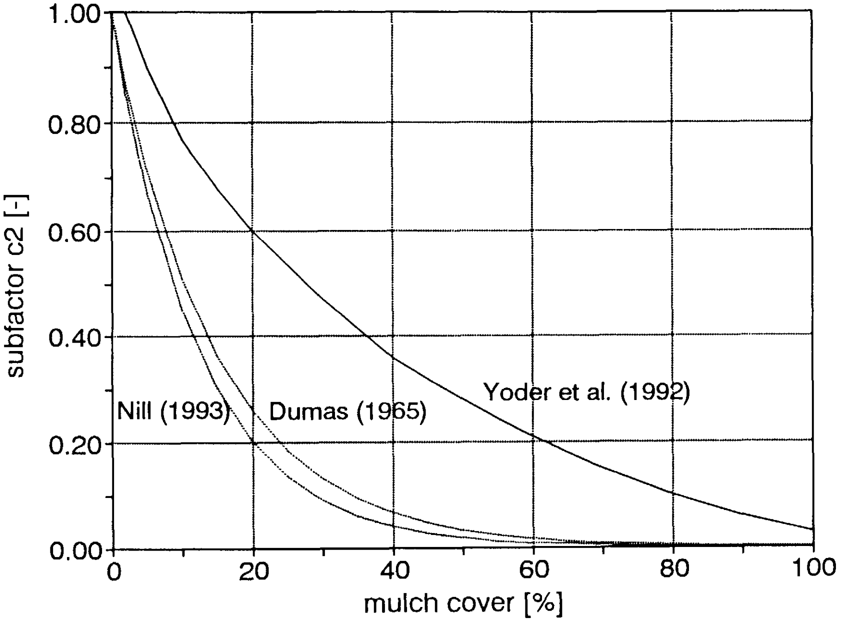
Subfactor c2

The influence of mulch cover (c2) can be calculated by (Yoder et al., 1992):

$$c2 = e^{-0.035 * MC} \quad [-] \qquad (45)$$

Equation No. (45), which reflects the curve used by Wischmeier & Smith (1978) gives a conservative estimate of the mulch effect. Measurements by numerous other authors (Dumas, 1965; Kainz, 1989; Nill, 1993) revealed a higher efficiency (cf. Figure 74-2). Nevertheless, it is indicated to continue using equation No. (45) in order to arrive at a cautious estimate of soil loss reduction by mulch. Some simple methods for soil cover measurements are illustrated and explained in Annex 3.2.

Figure 74-2: Influence of mulch on soil loss as evaluated by different authors. Subfactor c2 gives the ratio of soil loss on a coveredplot to an uncovered plot.



Subfactor c3

Not much data are available to determine subfactor c3 for tropical agro-systems which accounts for the residual effect of the previous vegetation. Own measurements resulted in an average c3 of 0.8 for the 1st year after forest fallow and 0.4 after grass fallow (Table 74-4). A mean c3 of 0.67 for the first 2 years after grass fallow can be estimated from data of Kilewe & Mbuvi (1987) by the ratio of erodibility during the first 2 years and erodibility of the 3rd to 5th year. For practical purposes, the c3 values in Table 74-9a are proposed. The influence of the grass fallow residues comes very close to the residual effects described by Wischmeier & Smith (1978) for turned sod. For the first year after plowed grassland they proposed 0.4, 0.45, 0.5 and 0.6 for crop stages SB – 50, 50–75, 75 – H and H – SB, respectively. The same crop stages during the second year were weighted by 0.8, 0.85, 0.9 and 0.95.

Figure 74-3: Subfactor c1 as influenced by effective canopy cover and crop height (after Foster, 1982 and Wischmeier, 1975)

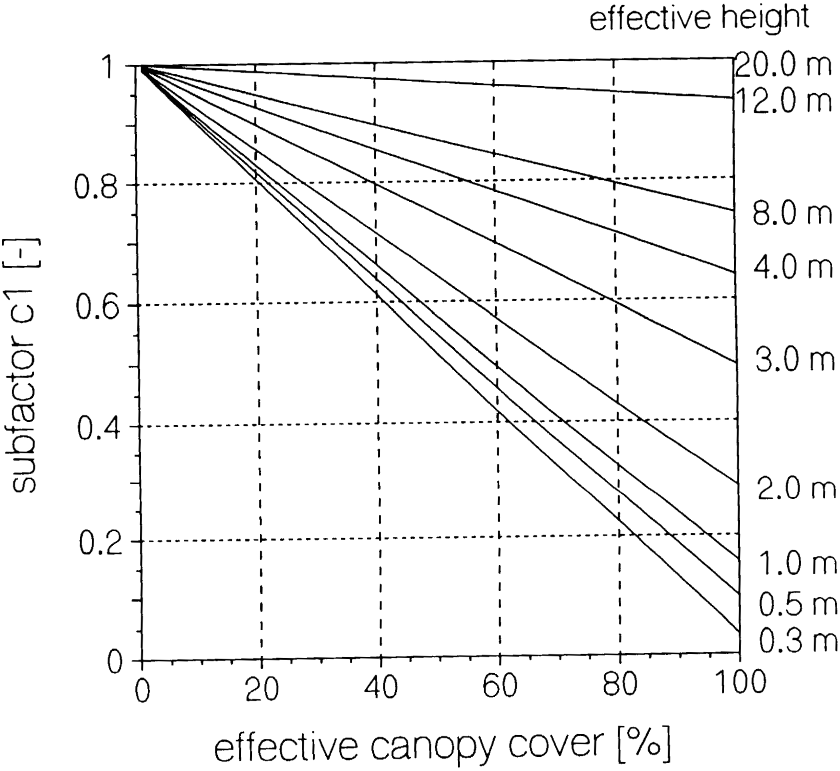


Table 74-4: Residual effects (c3) of savannah and forest fallows as estimated by the coefficient of erodibility during the first year of bare-fallow (K_{first}) *and the finally determined K factor after several years of bare-fallow (K)*

fallow type	K_{first}	K factor	c3
	[t*h/N*ha]		[-]
forest	0.0105	0.0135	0.78
- ,, -	0.0886	0.1100	0.81
grass	0.0115	0.0236	0.49
- ,, -	0.0660	0.2000	0.33
- ,, -	0.1620	0.3450	0.47

At the moment, not enough data are available to calculate SLRs for the multitude of tropical cropping systems. Nevertheless, soil loss can be estimated by the available data. In most experiments published in literature, soil loss was measured on a cropped plot and compared to soil loss on an adjacent control plot. Such data supply soil loss values for single cropping seasons or years without considering different crop stages. C factors which have a high variability due to a low number of repetitions can be calculated from such data. However, some crops have been tested in several experiments and by comparing and averaging the results some reasonable trends can be observed.

Such annual C factors from different locations include an unknown, site specific variation caused by the erosivity distribution which can not be accounted for. By using them in different sites, the same soil loss will be predicted irrespective of the site specific erosivity distribution.

To estimate the error caused by ignoring the erosivity distribution, C factors were calculated for a mixed cropping system measured in Cameroon by using erosivity distribution curves from sites with an annual erosivity between 750 and 3231 N/h and mono- and bimodal rain distribution. The maximum difference was small (16%) (Table 74-5) (Petri, 1992). Furthermore, the limited ecological range of most crops will also contribute to keep the difference within certain limits because very large differences in climate are generally also accompanied by a change in crops.

The system rain – canopy cover – soil loss can be regarded as self-stabilizing within certain limits. More rain after seeding or germination will enable faster and more growth provided that water is a limiting growth factor as it is in many regions at the onset of the rain. Such an auto-regulation also favours similar annual C factors despite site specific differences in temporal rain distribution. However, some crops can be found in very contrasting climatic zones. Groundnut and maize, e.g., are as well planted in the rainforest as in much drier environments. In this case it is safer to choose a C factor which was measured in a climate comparable to the site for which calculations shall be carried out.

Table 74-5: Annual C factor calculated for a mixed cropping system with the erosivity distribution of sites from different climatic zones (Petri, 1992)

site	**mean annual rain [mm]**	**mean annual erosivity [N/h]**	**C factor**		**ecological zone**
			[-]	**[% of mean]**	
Douala	3970	3231	0.23	92	humid rainforest
Bamenda	2470	1395	0.26	104	humid highland
Bafia	1470	818	0.29	116	humid savannah
Yaoundé	1610	942	0.23	92	savannah/ forest transition
Batouri	1560	750	0.25	100	- „ -
mean				0.25	100

Determination of the C factor

As previously described, C factors can be derived from available experimental data or be calculated by using subfactors.

I. Derivation of C factors from experimental data

Choose a table from Tables 74-8 to 74-18 according to the main crop and look for a similar management system as your own in the descriptions:

Tables 74-8 to 74-18 contain average values derived from the detailed data in Annex 3.4 (= source refers to the lines in the Annex tables). The detailed C factors given in Annex 3.4 are not advised for unexperienced users. They were included for people who seek more information and in order to allow control and improvement of the data-base and the derived values in the user section[26]. If you doubt about what to choose, take an average value.

With some routine, corrections for differences between described and own system can be applied. If, for example, your crop is especially well developed, a smaller C factor should be chosen within the range given as 'extremes'.

If a notill option is not included in one of the management systems, the C factor for the clean tilled variant can be taken and multiplied by one of the values in Table 74-6 which were derived from data in Table 34-8Annex:

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[26] If you have literature available on the subject which is not included in the tables of Annex 4.4, the authors would be grateful for indications or a copy.

Table 74-6: Average C factor for notill

no.	notill system	C factor		literature (lines in Table 34-8Annex)
		mean	extremes	
1	without residues	0.65	0.45 to 0.81	mean of no. 1 to 7
2	with residues	0.22	0.1 to 0.41	mean of no. 8 to 12

If a certain mulch cover is maintained in your system, you can choose the C factor for the system without mulch and correct it by multiplying with a mulch factor (c2) from Table 74-7.

If two crops are planted during the year, two C factors must be chosen from the tables. In order to arrive at an annual C factor, the two C factors and the periods between the two cropping seasons must be weighted according to the erosivity which they receive.

Example:

A rotation consists of groundnut which is planted during the first rainy season and is followed by plowed maize. In the dry spell between the two cropping seasons, the field is left to the natural weeds. The C factors for each crop and period are multiplied by the relative amount of erosivity which falls during the respective period i.e. 30 % of the annual erosivity falls during groundnut cultivation, the dry season receives 10 %, maize 50 % and the 2nd dry season another 10 % of the annual erosivity. The sum of all products gives the annual C factor of 0.35:

period	C factor for single periods	relative erosivity	product
groundnut	0.39	0.3	0.117
dry season	0.19	0.1	0.019
maize	0.39	0.5	0.195
dry season	0.19	0.1	0.019
total		**1.0**	**0.350**

In order to judge a system, not only the cultivation period is regarded but the whole rotation which includes the fallow period. If in the above example the groundnut-maize year is followed by two years of grass fallow, the annual C factor is (0.35 + 0.19 (Table 74-9a, line 2) + 0.004 (Table 74-9a, line 3))/3 = 0.18.

II. Derivation of C factors by subfactors

The C factor can be calculated from subfactors by:

$$C = c1 * c2 * c3 \quad (-) \tag{46}$$

with subfactor:	c1	influence of canopy cover
	c2	influence of mulch cover
	c3	residual influence of former vegetation

In order to derive c1 to c3, the following information is needed:

1. the canopy cover curve and the canopy height to calculate subfactor c1 (equation No. (42))
2. the mulch cover curve for subfactor c2 (equation No. (45))
3. the residual influence of the former vegetation
4. the relative distribution of the annual erosivity

The influence of notill can additionally be considered by multiplying with the notill subfactors in Table 74-6.

▷ 1. The canopy curve is either determined by measuring canopy coverage for the system (methods in Annex 3.2) or by using the typical growth curves given in Annex 3.3. However, it should be kept in mind that the variability included in the mean growth curves due to growing conditions and cultivars may be appreciable. Calculations and measurements can be carried out for crop stage periods (Table 74-1) or with a finer resolution i.e. 10 day or weekly intervals. The effective canopy coverage is calculated by equation No. 44. The canopy height can be measured or estimated from experience and is used to calculate the effective height by equation No. (43). With the effective height and the effective cover subfactor c1 can be read from Figure 74-3.

▷ 2. Mulch coverage is determined from the mulch cover curve which shows mulch cover in the cropping system during the year. Subfactor c2 can be directly read from Table 74-7.

Table 74-7: Subfactor c2 for the effect of mulch cover (based on Wischmeier & Smith, 1978)

mulch coverage [%]	**subfactor c2 [-]**	**mulch coverage [%]**	**subfactor c2 [-]**
0	1.00	50	0.28
2	1.00	55	0.25
5	0.90	60	0.21
10	0.77	65	0.18
15	0.68	70	0.15
20	0.60	75	0.13
25	0.54	80	0.10
30	0.47	85	0.08
35	042	90	0.06
40	0.36	95	0.05
45	0.32	100	0.03

▷ 3. Use c3 from Table 74-9a.

▷ 4. Calculate the mean relative erosivity distribution from as many years as available (as in Table 74-3). If no erosivity data are available, use the relative rainfall distribution. Generally, mean curves are calculated by averaging weekly or 10 day intervals for as many years as possible.

Table 74-8: Average C factors for forest, bush and grass vegetation (fallows, pasture) and subfactors for their residual effects

no.	fallow	C factor		literature (lines in Table 34-1Annex)
		mean	extremes	
1	dense forest	0.0002	-	1
2	grass or bush vegetation 1st year or poorly developed*1	0.19	0.09 to 0.29	mean of 3, 5, 16, 22
3	well established grass or bush vegetation	0.004	0.002 to 0.007	mean of 2, 15, 17, 21, 23, 24
4	time between cropping cycles with residues of former crop left (maize residues, groundnut, mungbean)	0.05	0.01 to 0.09	mean of 6 and 7
		0.27	0.25 to 0.28	mean of 8 and 9
	residual effects			
5	1st year after clearing of bush fallow	0.8	0.78 to 0.81	11
6	2nd year after clearing of – .. -	0.9	-	12
7	1st year after clearing of grass fallow	0.4	0.33 to 0.49	13
8	2nd year after clearing of – .. -	0.7	-	14

[*1] The C factor for the 1st year can alternatively be determined by measuring the time until 10%, 20%, 40% and 60% canopy cover and the amount of erosivity for the same periods of time. From the Table 74-7 the mean soil loss ratio can be determined for coverages 0-10% (= 0.89), 10-20% (= 0.69), 20-40% (0.48) and 40-60% (= 0.29) cover. A SLR of 0.004 (line 3) can be used for >60% cover and the following years. These mean SLR's are weighted for the amount of erosivity in the same periods of time relative to the annual erosivity. An example is shown in Table 74-9b

Table 74-9: Example of an alternative method for the determination of a C factor for the 1st year of grass, cover crops and bush fallows

cover/period **[%]**	**duration during period** **[d]**	**erosivity** **[N/h] / [-]**	**SLR** **[-]**	**weighted SL (SLR*relative erosivity)** **[-]**
tillage/seedbed	0		0	—
10	12	150 / 0.103	0.89	0.092
20	6	120 / 0.083	0.69	0.057
40	15	140 / 0.097	0.48	0.047
60	18	220 / 0.152	0.29	0.044
>60	314	820 / 0.566	0.004	0.00 23
sum	365	1450 / 1		0.24

The C factor for the 1st year is the sum of the weighted SLR's (0.24).

Table 74-10: Averaged C factors for banana

no.	**description**	**C factor**		**literature**
		mean	**extremes**	**(lines in Table 34-2Annex)**
1	leaves placed around trunks and on contour; spacing 5 x 3 m on contour Alternatively for a young plantation (1st year)	0.56	0.14 to 1.08	1
2	as above but spacing 2 x 3 m	0.16	0.04 to 0.3	2
3	as above but spacing 3 x 3 m	0.30	0.08 to 0.58	3
4	as above but spacing 4 x 3 m	0.42	0.1 to 0.83	4
5	with complete mulch cover	0.00061	0.0003 to 0.0009	mean of 5 & 6

For other spacings/ densities between 5 x 3 m (= 660 plants/ha) and 2 x 3 m (= 1650 plants/ha) C can be taken from Figure 74-4.

Figure 74-4: C factor for different banana densities

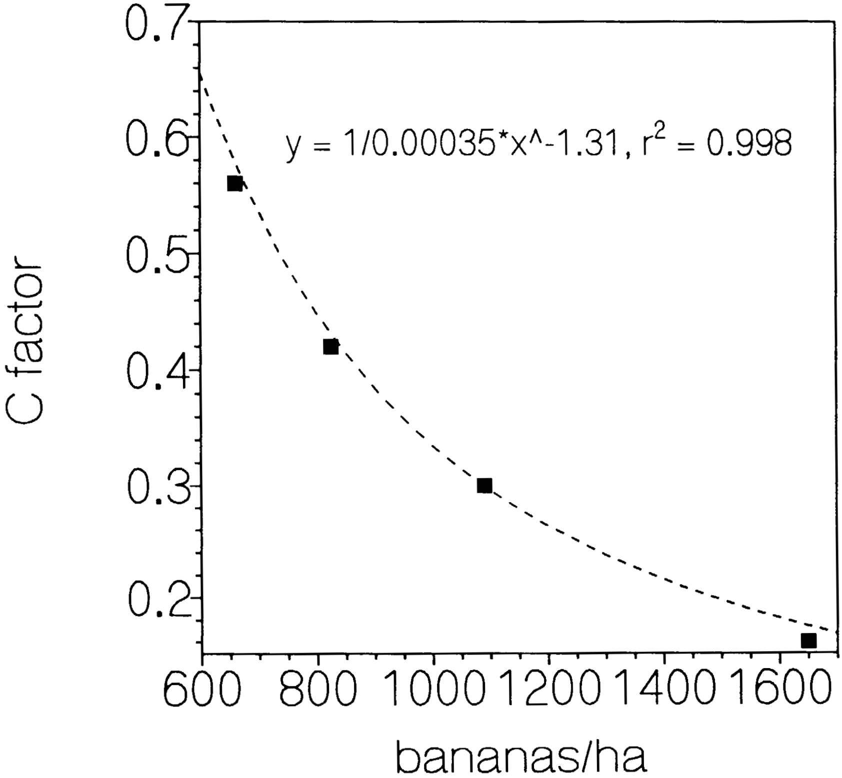

Table 74-11: Average C factors for pineapple

no.	**pineapple**	**description**	**C factor**		**literature (lines in Table 34-3Annex)**
			mean	**extremes**	
1		planted along slope: density 45000 plants/ha; 1st year (9% slope)	0.73	-	1*1
	subfactors				
2		for every 15 000 plants added to the	0.75	0.71 to 0.78	calculated from 1 to
3		45000 plants/ha above multiply 0.73 by			
3	intercrop	intercropping with upright growing plant (comparable to cowpea)	0.84	0.79 to 0.93	calculated from 1 to 3 and 10 to 12*2
4	- " -	intercropping with creeping plant (comparable to melon)	0.5	0.44 to 0.53	calculated from 1 to 3 and 11 to 13

*1 calculated from no. 1; corrected for effect of contour on 9 % slope (0.6)
*2 (no.4/no.1 + no. 5/no. 2 + no. 6/no. 3)/3

Example: pineapple planted along slope at a density of 75 000 plants/ha intercropped with groundnut: (no.1 * no.2 * no.2 * no.3); C = 0.73 * 0.75 * 0.75 * 0.84 = 0.35. If the plants are planted on a 9 % slope on contour, the C factor has to be multiplied additionally by 0.6 (= 0.21)

Table 74-12: Averaged C factors for cassava

no.	cassava	description	C factor		literature
			mean	extremes	(line in Table 34-4Annex)
1	monocrop	planted on level ground[*1]	0.36	0.12 to 0.56	mean of no. 1–5
2	intercrop	on level ground; intercropped with maize, rice, cowpea, soya, phaseolus or cocoyam	0.18	0.02 to 0.59	mean of no. 16 to 18 and 20 to 26
	subfactor				
3		for intercropping with maize	0.63	0.57 to 0.69	no. 27

[*1] level ground = no mounds or ridges were formed

Table 74-13: C factors for miscellaneous perennial crops

no.	crop	description	C factor		measurement period	country	location	literature
			mean	extremes		[a]		
1	coffee . oilpalm, cocoa	with well developed cover crop	0.002	0 .00007 to 0.0036		Ivory Coast	Adiopodoumé	Roose (1975, p. 30/31)
2	coffee, oilpalm, cocoa	with badly developed cover crop	—	0.036 to 1	—	— .. —	— .. —	
3	coffee		0.02	—				Lewis (1986 in: Young, 1989, p. 33)
4	oilpalm	mature stand; 9% slope	0.03	—	3	—		Maene & Chong (1979 in: Sulaiman et al., 1983)
5	sugarcane		0.39—		—	Malaysia-		Sulaiman et al. 1983

Table 74-14: Averaged C factors for groundnut

no.	groundnut	description	C factor		literature (lines in Table 34-5Annex)
			mean	extremes	
1	monocrop	on level ground; on contour	0.34	0.21 to 0.59	mean of no. 1–8
2	intercrop	with cowpea or pigeon pea	0.53*1	0.50 to 0.57	mean of no. 10 and 11

*1 The higher C factor for intercropped groundnut does not seem very reasonable. As long as there is no further evidence, it is proposed to use the value for monocropped groundnut also for the intercropped system

Table 74-15: Averaged C factors for maize

no.	**treatment**	**description**	**C factor**		**literature (lines in Table 34-5Annex)**
			mean	**extremes**	
1	plow	without residues: along slope	0.39	0.16 to 0.82	no. 1 – 11
2	- „ -	with maize residues surficially incorporated	0.06	0.026 to 0.084	no. 13 and 14
3	- „ -	with cowpea residues surficially incorporated; can also be used for residues of groundnut, soya and crops with similar growth and biomass	0.18	-	no. 15 to 16
4	- „ -	with mulch	0.004	0.0029 to 0.004	no. 35 and 36
5	- „ -	intercropped with Lotus corniculatus, Trifolium hortum or beans	0.35	0.29 to 0.4	no. 17 and 19
6	notill	without residues	0.11	0.044 to 0.24	no. 20 to 26
7	- „ -	with residues	0.02	0.001 to 0.041	no. 27–32
8	reduced tillage	plowing without harrowing	0.03	0.02 to 0.04	no. 33 and 34
9	ridge	contour ridge, 3% slope	0.054	-	no. 39
10	- „ -	contour ridge, 8% slope	0.026	-	no. 40
11	tied-ridge/notill	25 cm high contour ridges with 1% lateral slope; ties at intervals of 1.5 m and app. 15 cm high	0.011	0.004 to 0.018	no. 42 and 43

Table 74-16: C factors for millet and sorghum

no.	crop treatment	description	C factor		measure-ment period [a]	country	location	literature
			mean	extremes				
	millet							
1		accord ing to yield level	—	0.4 to 0.9	—	—		Roose (1975, p. 40)
2	mulch	tractor-plowing and hand-rotovator on 2% slope; Pennisetum glaucum planted at 60 x 25 cm plus 4 t/ha dry millet straw; 42-16-48 kg/ha NPK	0.052	0.055 to 0.049	2	Ghana	Nyankpala	Bonsu (1980, p. 250/51)
3	intercrop	tillage and fertilizer as above; groundnut planted at 60 x 20 cm and intercropped with millet without straw	0.076	0.055 to 0.098	2	— " —	— " —	— " —
4	intercrop	traditionally intercropped with sorghum and bambara nut	0.137	0.105 to 0.169	2	— " —	— " —	— " —
5	ridge	millet mono-crop (spacing, tillage and fertilizer as above) on ridges across slope	0.079	0.055 to 0.1	2	— " —	— " —	— " —
6	reduced tillage (minimumtill)	millet mono-crop, tractor -plowed, no harrowing	0.113	0.104 to 0.123	2	— " —	— " —	— " —

Table 74-16: continue

no.	crop treatment	description	C factor		measure-ment period [a]	country	location	literature
			mean	extremes				
	sorghum							
7	plow	—	0.242	—	—	Indonesia	—	Abdurachman et al. (1984)
8	plow	according to yield level	—	0.4 to 0.9	—	—	—	Roose (1975, p. 40)
9	contour	planted on contour on 4 out of 8 different Indonesian soil types	0.27	—	1	Indonesia	—	Keersebilck (1990, p. 570)
10	—	—	0.4	—	—	—	—	Lewis (1986 in: Young, 1989, p. 33)

Table 74-17: C factors for upland rice

no.	crop treatment	description	C factor		measurement period [a]	country	location	literature
			mean	extremes				
1	plow	intensive cropping	—	0.1 to 0.2	—	—	—	Roose (1975, p. 40)
2	— " —	planted on contour on 4 out of 8 different Indonesian soil types	0.58	—	1	Indonesia	—	Keersebilck (1990, p. 570)
3	— " —		0.561	—	—	— " —	—	Abdurachman et al. (1984)
4	— " —	hand hoe tillage; 5.5% slope:	0.135	—	6	Brazil	Brasilia	Leprun et al. (1986, p. 228)
5	— " —	with 4 t/ha straw mulch	0.096	—	—	Indonesia	—	Abdurachman et al. (1984)
6	— " —	with residue mulch in a rotation of rice – maize	0.347	—	—	— " —	—	— " —
7	— " —	as above but without residue mulch	0.496	—	—	— " —	—	— " —
8	— " —	in a rotation of rice – sorghum	0.345	—	—	— " —	—	— " —
9	— " —	in a rotation of rice – soya	0.417	—	—	— " —	—	— " —

Table 74-18: Averaged C factors for miscellaneous crops

no.	**crop**	**description**	**C factor**		**literature lines in Table 34-7Annex**
			mean	**extremes**	
1	Bambara nut	plowed; 3.5% slope; spacing 30 x 30 cm	0.43	—	no. 1
2	beans	data from mung bean, red bean and jack bean	0.27	0.47 to 0.16	no. 2 to 6
3	cabbage	planted as monocrop on contour on 4 out of 8 different Indonesian soil types	0.6	—	no. 7
4	chili		0.33	—	no. 8
5	cotton	planted along slope	0.29	—	no. 9
6	— " —	2nd cycle	0.5		no. 11
7	cowpea	plowed; without residues	0.24	0.21 to 0.27	no. 12 and 13
8	— " —	plus residues of former maize; planted along slope	0.06	0.002 to 0.28	no. 14 to 17
9	— " —	notill, plus residues of former maize, planted along slope	0.005	0.0004 to 0.02	no. 18 to 20
10	Irish potatoe	—	0.22	—	no. 21
11	lemon grass		0.434	—	no. 22
12	papaya	without cover crop	2.1	—	no. 23
13	soya		0.26	0.1 to 0.4	no. 24 to 27
14	— " —	notill without residues	0.103	—	no. 28
15	sweet potatoes	—	0.23	—	no. 29
16	tobacco	2nd cycle	0.5	—	no. 30 and 31
17	wheat-soya	rotation on 12% slope, wheat residues burned; soya residues incorporated	0.113	—	no. 32
18	— " —	as above but all residues surficially incorporated	0.05	—	no. 33
19	— " —	rotation as above but with notil	0.04	—	no. 34
20	wheat-maize	as above, conventionally tilled, residues incorporated	0.1	—	no. 35
21	— " —	as above but notill (residues maintained)	0.014	—	no. 36
22	yam	on heaps	0.23	0.16 to 0.8	no. 38
23	— " —	on heaps; intercropped; with residue mulch	0.07	0.04 to 0.09	no. 39

7.5 The effect of protective methods – Support practice factor (P)

Protection measures must be adjusted to the possibilities and resources of each farmer. For nearly each individual situation a set of suitable physical and biological methods can assure sufficient soil protection.

7.5.1 Contouring, contour-ridging, tied-ridging

Generally speaking contouring means that all tillage operations and planting are carried out across the slope. Contour tillage and planting with mechanical tools leaves a roughness of the soil surface that is oriented across the slope. This may be considered as micro-ridges on contour. Such a formed surface redirects and retards the surface runoff. The efficiency depends on the degree of roughness (ridge height), the side slope of the tillage marks and the gradient of the overall slope. There is no clear limit between contouring and contour-ridges or bunds. The latter could be regarded as extreme roughness. Contouring in its original sense occurs under mechanized tillage with crops planted in rows. In handtilled systems only planting can strictly be achieved on contour. Tillage with the handhoe is generally moving up-slope. The blade of the hoe is placed on contour but no continuous roughness is created. There is no information whether the roughness left by the handhoe marks can be compared to contour tillage.

Contouring reaches its maximum protectiveness on slopes between 3 and 8% (Table 751-1). It is less efficient on slopes below 3% where runoff velocity is slow and a protective water mulch forms. On slopes above 8%, the protectiveness declines as the water storage capacity of the ridges becomes smaller with increasing gradient. For slopes > 25%, no protection is reached. P factors which were calculated from recent soil loss studies (Table 41-1Annex) support the values in Table 751-1:

Table 751-1: P factor for contouring (Wischmeier & Smith, 1978)

slope [%]	P factor for contouring	maximum slope length [m]*1
1 – 2	0.6	122
3 – 8	0.5	91
9–12	0.6	61
13 – 16	0.7	24
17–20	0.8	18
21 – 25	0.9	15
>25	1.0	13

*1 The maximum slope length may be increased by 25% if residue cover after planting regularly exceeds 50%

A P factor of 1 for slopes > 25% was based on the assumption that a typical 15 cm high ridge in mechanized systems retains no more water on a slope of 25% (Foster et al., 1992). If the storage capacity of the ridges is large enough to prevent overflow, maximum slope lengths need not to be applied. As the effectiveness of contour ridges depends on their storage capacity, it must also depend on storm size. In locations with frequent large storms, contouring is less effective than in locations with smaller storms. Therefore, the 10 year storm volume is chosen for ridge design purposes (Foster et al., 1992). If the furrows can only carry the maximum 2 year storm, length limits are applicable (Wischmeier & Smith, 1978).

The procedure to estimate the influence of ridges applied by the USLE gives a rough estimate and does not allow to distinguish between different ridge heights. Ridges, however, play an important role in tropical agro-systems. A more refined estimation is possible by using the P factors in Figure 751-1 used in the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1992). The curves were calculated on the basis of a 10 year storm of 86 to 190 mm, hydrologic soil group C[27] and clean tillage for row

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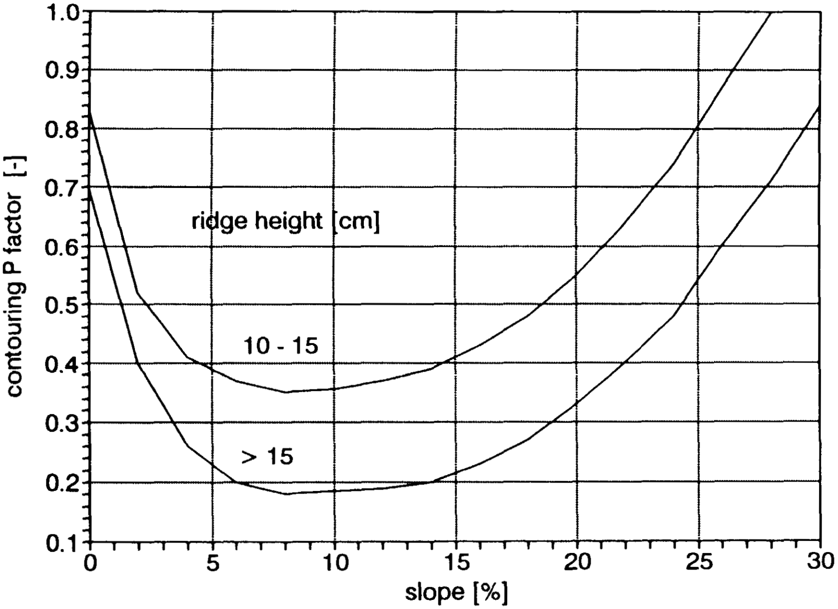
[27] hydrologic soil group C includes soils with low infiltration rates when wet, mostly with impending layers or moderatly fine texture (USDA, 1972: SCS National Engineering Handbook)

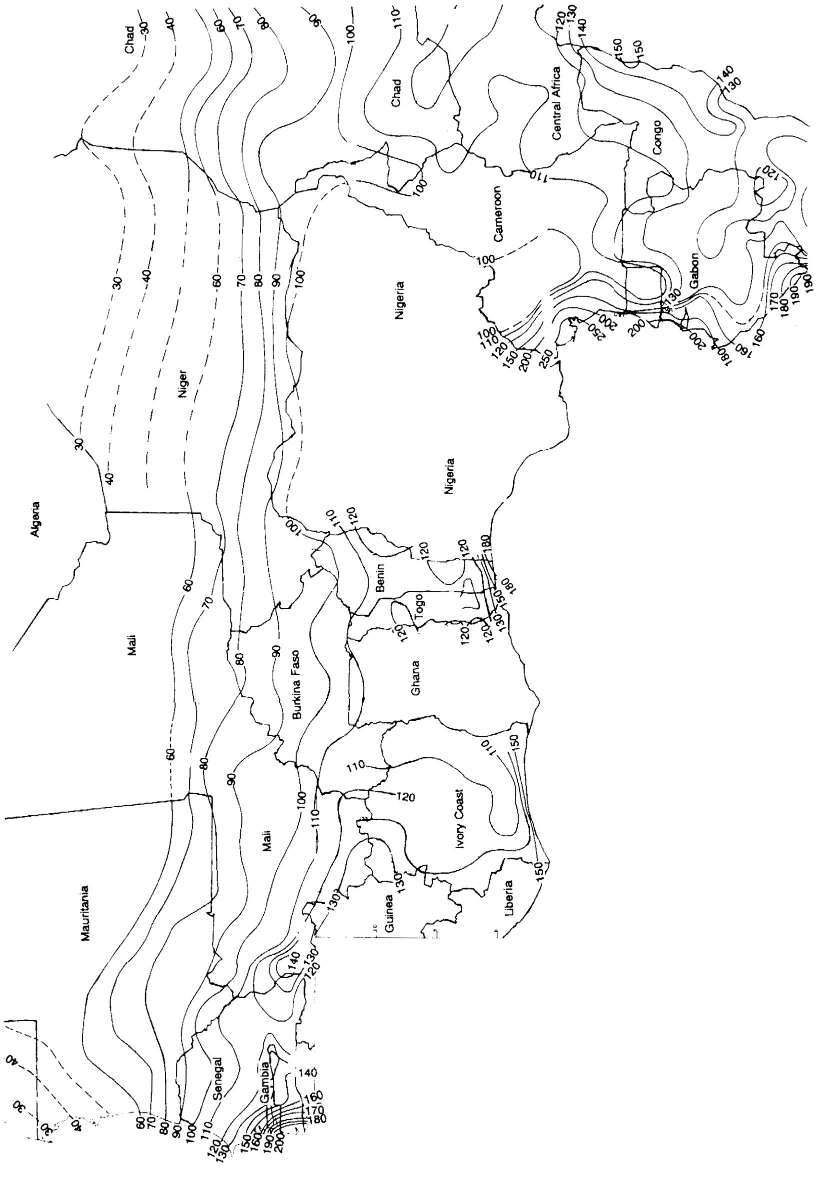
Figure 751-1: P factors for different ridge heights for areas with 10 year storms between 86 and 190 mm and hydrologic soil group C (Foster et al., 1992)



crops with no cover and minimum roughness (cover-management condition 6). In West Africa such 10 year storms are found approximately in the belt between 16° northern latitude (north Senegal, north Burkina Faso) and the coast line (Figure 751-2). For other areas no information on the 10 year storm was found.

For areas with a lower 10 year storm volume (e.g. north of 16° latitude) the ridge efficiency will be underestimated by Figure 751-1, whereas for areas with higher 10 year storm volume an overestimation is possible. Regarding the soils, hydrologic soil group C may be applied to the Aridisols, Alfisols, Inceptisols and Vertisols of the semi-humid to semi-arid/ arid area. For the Ultisols and Oxisols of the humid to semi-humid areas the efficiency is underestimated by hydrologic soil group C.

Figure 751-2: Isohyetes for the 10 year storm volume (CIEH, 1985)



Contouring and contour ridges are mostly not exactly on contour. In practice, they have a side slope either accidentally or in order to evacuate excess water. For side slopes < 0.5%, all soil is deposited in the furrows (cf. Chapter 4.3). For steeper side slopes the efficiency of contour ridging is reduced. P factors corrected for side slope effects (Table 751-2) were calculated by (Foster et al., 1992):

$$P_g = P_o + (1 - P_o) * (s_f / s_l)^{0.5} \qquad (47)$$

with P_g P factor for off-grade contouring
P_o P factor for on-grade contouring
s_f grade along the furrows (sine of slope angle)
s_l steepness of the land (sine of slope angle)

Measured values for ridges are given in Table 41-2Annex, line 1 and 2. The table also indicates the disastrous effect of up- and down-slope ridges (P = 0.9 to 4.4). For practical purposes a P factor of 2 can be used for this practice.

Table 751-2: Correction of P factors for ridges with side slopes

slope [%]	**uncorrected P factor**	**corrected P factor** **side slope of furrows [%]**					
		0.5	**1.0**	**1.5**	**2.0**	**3.0**	**5.0**
4	1	1.00	1.00	1.00	1.00	1.00	1.00
	0.9	0.94	0.95	0.96	0.97	0.99	1.00
	0.8	0.87	0.90	0.93	0.95	0.98	1.00
	0.7	0.81	0.86	0.89	0.92	0.97	1.00
	0.6	0.75	0.81	0.85	0.89	0.96	1.00
	0.5	0.68	0.76	0.82	0.87	0.95	1.00
	0.4	0.62	0.71	0.78	0.84	0.94	1.00
	0.3	0.56	0.66	0.74	0.81	0.93	1.00
	0.2	0.49	0.62	0.71	0.79	0.92	1.00
	0.1	0.43	0.57	0.67	0.76	0.91	1.00
8	1	1.00	1.00	1.00	1.00	1.00	1.00
	0.9	0.93	0.94	0.94	0.95	0.96	0.98
	0.8	0.85	0.87	0.89	0.90	0.92	0.96
	0.7	0.78	0.81	0.83	0.85	0.88	0.94
	0.6	0.70	0.74	0.77	0.80	0.85	0.92
	0.5	0.63	0.68	0.72	0.75	0.81	0.90
	0.4	0.55	0.61	0.66	0.70	0.77	0.87
	0.3	0.48	0.55	0.60	0.65	0.73	0.85
	0.2	0.40	0.48	0.55	0.60	0.69	0.83
	0.1	0.33	0.42	0.49	0.55	0.65	0.81
12	1	1.00	1.00	1.00	1.00	1.00	1.00
	0.9	0.92	0.93	0.94	0.94	0.95	0.96
	0.8	0.84	0.86	0.87	0.88	0.90	0.93
	0.7	0.76	0.79	0.81	0.82	0.85	0.89
	0.6	0.68	0.72	0.74	0.76	0.80	0.86
	0.5	0.60	0.64	0.68	0.71	0.75	0.82
	0.4	0.52	0.57	0.61	0.65	0.70	0.79
	0.3	0.44	0.50	0.55	0.59	0.65	0.75
	0.2	0.36	0.43	0.48	0.53	0.60	0.72
	0.1	0.28	0.36	0.42	0.47	0.55	0.68
16	1	1.00	1.00	1.00	1.00	1.00	1.00
	0.9	0.92	0.93	0.93	0.94	0.94	0.96
	0.8	0.84	0.85	0.86	0.87	0.89	0.91
	0.7	0.75	0.78	0.79	0.81	0.83	0.87
	0.6	0.67	0.70	0.72	0.74	0.77	0.83
	0.5	0.59	0.63	0.65	0.68	0.72	0.78

Table 751-2, continue

slope [%]	uncorrected P factor	corrected P factor					
		side slope of furrows [%]					
		0.5	**1.0**	**1.5**	**2.0**	**3.0**	**5.0**
16	0.4	0.51	0.55	0.58	0.61	0.66	0.74
	0.3	0.42	0.48	0.52	0.55	0.61	0.69
	0.2	0.34	0.40	0.45	0.49	0.55	0.65
	0.1	0.26	0.33	0.38	0.42	0.49	0.61
20	1	1.00	1.00	1.00	1.00	1.00	1.00
	0.9	0.92	0.92	0.93	0.93	0.94	0.95
	0.8	0.83	0.85	0.86	0.86	0.88	0.90
	0.7	0.75	0.77	0.78	0.80	0.82	0.85
	0.6	0.66	0.69	0.71	0.73	0.76	0.80
	0.5	0.58	0.61	0.64	0.66	0.70	0.75
	0.4	0.50	0.54	0.57	0.59	0.63	0.70
	0.3	0.41	0.46	0.49	0.52	0.57	0.65
	0.2	0.33	0.38	0.42	0.46	0.51	0.60
	0.1	0.24	0.30	0.35	0.39	0.45	0.55
24	1	1.00	1.00	1.00	1.00	1.00	1.00
	0.9	0.91	0.92	0.93	0.93	0.94	0.95
	0.8	0.83	0.84	0.85	0.86	0.87	0.89
	0.7	0.74	0.76	0.78	0.79	0.81	0.84
	0.6	0.66	0.68	0.70	0.72	0.74	0.79
	0.5	0.57	0.60	0.63	0.65	0.68	0.73
	0.4	0.49	0.52	0.55	0.58	0.62	0.68
	0.3	0.40	0.44	0.48	0.51	0.55	0.62
	0.2	0.32	0.37	0.40	0.43	0.49	0.57
	0.1	0.23	0.29	0.33	0.36	0.42	0.52
28	1	1.00	1.00	1.00	1.00	1.00	1.00
	0.9	0.91	0.92	0.92	0.93	0.93	0.94
	0.8	0.83	0.84	0.85	0.85	0.87	0.89
	0.7	0.74	0.76	0.77	0.78	0.80	0.83
	0.6	0.65	0.68	0.69	0.71	0.73	0.77
	0.5	0.57	0.60	0.62	0.64	0.67	0.72
	0.4	0.48	0.52	0.54	0.56	0.60	0.66
	0.3	0.40	0.43	0.47	0.49	0.53	0.60
	0.2	0.31	0.35	0.39	0.42	0.47	0.54
	0.1	0.22	0.27	0.31	0.35	0.40	0.49

Determination of the P factor for contouring and contour ridging

Contouring and contour-ridging

a. For simple tillage and planting of row crops on the contour, use P factors in Table 751-1 according to the slope. If contouring and ridges were established with side slopes, enter Table 751-2 for correction.

Example:

For a contoured slope of 14% with a side slope of 3% a P factor of 0.7 was chosen from Table 751-1. The side slope effect is considered by entering Table 751-2 for a 12% and a 16% slope (P corrected = 0.85 and 0.83, respectively) and interpolating the two values to a 14% slope (P corrected = 0.84).

b. For ridges with a height of more than 10 cm, choose a P factor according to slope and minimum ridge height from Figure 751-1. Correct it for the effects of an eventual side slope as explained in a..

c. If ridges do not persist during the entire year but are mounted, for example, during the growing period of a crop and levelled during harvest, the P factor can not be fully credited. In this case only the soil loss ratios of those crop stages are multiplied with the P factor for ridges for which the ridges are intact. For the crop stage periods without ridges P equals 1.

Example:

Maize is planted on level ground on a 10% slope. When canopy cover reaches 10%, 15 cm high ridges are mounted with a 1% side slope. The term C x P factor is calculated like in Table 751-3.

Table 751-3: Calculation of the C x P factor for temporary established ridges

1	2	3	4	5	6
crop stage	**erosivity ratio**	**soil loss ratio**	**P factor**	**corrected P factor**	**C x P column 2 x 3 x 5**
SB – 10	0.02	0.56	1.00	1.00	0.011
10–50	0.07	0.51	0.36	0.57	0.020
50–75	0.06	0.32	0.36	0.57	0.011
75 – H	0.51	0.05	0.36	0.57	0.015
H – SB	0.36	0.05	1.00	1.00	0.018
SB – SB	1.00			Total:	0.075

The erosivity ratios were taken from Figure 74-1 from the 'north' curve assuming that crop stage SB – 10 started on the 130 day. The duration of the crop stage periods and the soil loss ratios were taken from Table 74-2 (column 2 and 5). A P factor of 0.36 corresponds to 15 cm ridges on a 10% slope (Figure 751-1). The corrected P factor is interpolated from Table 751-2 ((0.59 + 0.54)/2 = 0.57). The resulting C x P factor is 0.075 which compares to C x P = 0.063 if the ridges would be credited for during the entire cropping cycle.

Tied contour ridges

Values in literature for soil loss with tied contour ridges range between 0.21 and 0.035 on slopes between 4.5 and 7% (Table 41-2Annex). Ties between the ridges have no effect if the ridges are perfectly on contour. If the ridges have a side-slope, ties will stop or reduce the sideways evacuation of runoff. A reduction of the ridge efficiency due to side slope will therefore be much less. For practical purposes it is proposed to choose a P factor as for contour ridging from Figure 751-1 and to dismiss the correction for the side slope.

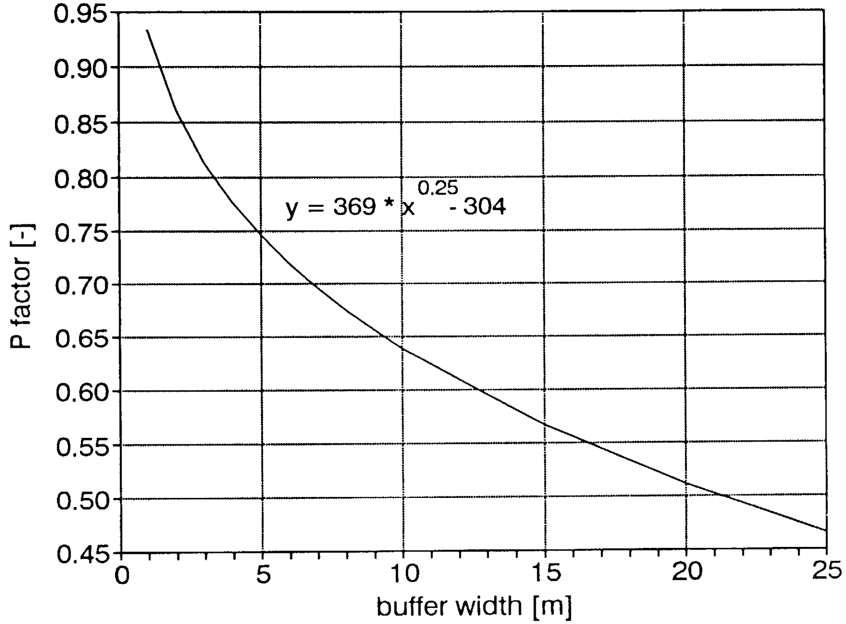
7.5.2 Bufferstrips

Bufferstrips are < 1 to several m large strips within fields mostly composed of quick growing species or natural vegetation. They are laid out on contour in order to decrease runoff velocity thereby causing deposition of suspended sediment. The efficiency of bufferstrips depends on the quality of the strip (strip widths, vegetation density), its age and its position on the slope. The runoff which arrives at the upper bufferstrip end has a certain transport capacity and sediment load. Runoff velocity and transport capacity are reduced in the bufferstrip by the higher hydraulic roughness and friction exerted by the vegetation. Additionally, part of the runoff will infiltrate within the strip which has generally a higher infiltration rate than the adjacent cropped soil. If the transport capacity becomes less than the sediment load, soil is deposited in the bufferstrip. However, if runoff leaves the strip on the lower end, it may regain speed and pick up new sediment from the cultivated strip underneath. Thus, the most favourable case is, if no runoff leaves the strip.

Planted bufferstrips generally do not reach their full protection efficiency during the first rainy season or the first year while the plants' root and canopy system is still establishing. P factors for the second year are, therefore, often lower than for the first year. There is also some evidence, that the efficiency of bufferstrips may decrease with increasing sedimentation in the strip (Barfield & Albrecht, 1982). This will depend on the growth habit of the strip vegetation (e.g. canopy or twig density close to the ground) and how fast the vegetation can grow up and cope with a heavy sediment load. If large amounts of sediment arrive at the bufferstrip, a small terrace will form within a couple of years.

A special case of bufferstrip are the riparian bufferstrips along rivers which prevent sediment entry. However, they do not prevent soil loss from the slope above. An indication for the effectiveness of riparian bufferstrips with increasing strip width is given in Figure 752-1.

Figure 752-1: *P factors for riparian bufferstrips of different widths derivedfrom a 8 % slope with an annual sediment load of ca. 1 t/m buffer length (Schauder & Auerswald, 1992)*



Determination of P factors for bufferstrips

a. Bufferstrips

a. Systematic trials for the effect of bufferstrips are still deficient. Some P factors as calculated by the RUSLE are given in Table 752-1.

b. Further P factors can be taken from the experimentally determined P factors in Table 41-5Annex for comparable situations.

Table 752-1: *P factors for bufferstrips as calculated by the RUSLE (Foster etal., 1992)*

percent of slope covered by strip	position of strip*1	P factor
20% in 2 strips	0.4–0.5 and 0.9–1.0	0.67
10% in 2 strips	0.35–0.40 and 0.65–0.70	0.71
10% in 1 strip	0.4–0.5	0.75

*1 for example 0.4–0.5 means that the strip starts after 40% of the slope length downslope and ends after half of the slope length

b. Riparian bufferstrips

P factors for riparian bufferstrips can be chosen from Figure 752-1.

7.5.3 Contour bunds and heaps

Results from trials indicate the different efficiency of stone-bunds and earthen bunds. Runoff occurring on the uppermost side of a field picks up velocity and sediment. Arriving at the first bund it is completely stopped by an earthen bund or slowed down by a stone bund. The sediment is deposited in front of the bund. Using earthen bunds, the process is repeated between first and second bund, second and third bund and so on. However, stone-bunds, which are permeable, allow a part of the water to pass the bund. This water regains velocity and transport capacity on the lower side of the bund and entrain new sediment in addition to the runoff produced on the lower side itself.

The efficiency of earthen bunds is thus much higher in the first year compared to stone-bunds (Table 41-4Annex). However, the data indicate that in the second year the effect of the two types becomes similar. The stone-bunds become less permeable due to sediment which progressively fills and clogs the inner space of the bunds. The earthen bunds apparently became less efficient due to holes which occur in the bund or to the lowering of the bund by raindrop impact or overtopping. The decreasing efficiency of the earthen bunds also make higher maintenance necessary compared to stone-bunds.

Determination of P factors for contour bunds and heaps

a. Stone-bunds and earthen bunds

The P factors in Table 41-4Annex can be used for first and subsequent years in comparable situations. As a bund can be compared to a ridge a similar slope influence on the efficiency of bunds is assumed. Therefore, it is proposed to multiply the available P factors with the ratio of the P factor for a 15 cm ridge (Figure 751-1) of a given slope to the P factor on a 3 % slope (Table 753-1). If maintenance is regularly carried out on earthen bunds each year, the P factor for the first year can also be used for subsequent years.

b. Heaps

Not many data are available for the specific effect of heaps on soil loss. The very variable influence is shown by the data in Table 41-3Annex. The influence of heaps depends on their arrangement on the slope (up and down-slope, on contour, in quintuples), their size and height which depend on slope and top soil depth (cf. Chapter 4.4). The data in Table 41-3Annex should only be used if the influence of mounds is not yet included in the C factor (e.g. for yam in Table 74-18 it is not necessary to use additionally a P factor for heaps).

Table 753-1: *Correction factor for bunds on different slopes*

slope [%]	ratio [-]	slope [%]	ratio [-]
0	2.12	16	0.70
1	1.67	17	0.76
2	1.21	18	0.82
3	1.00	19	0.91
4	0.79	20	1.00
5	0.70	21	1.11
6	0.61	22	1.21
7	0.58	23	1.33
8	0.55	24	1.45
9	0.55	25	1.64
10	0.56	26	1.82
11	0.57	27	1.98
12	0.58	28	2.15
13	0.59	29	2.27
14	0.61	30	2.55
15	0.65		

7.5.4 Ditches and terraces

Hillside and drainage ditches (cf. Figure 448-1) decrease soil loss by reducing the erosion effective slope length (L factor). Thus, the down-slope acceleration of runoff and its concentration is controlled. Slope length in the USLE is defined as that part of a slope where no major deposition is occurring.

In the case of drainage ditches, the sediment charged water spills freely into the ditch. The slope length is the distance between the lower side of a ditch to the upper side of the next ditch. For a Fanya Juu type terrace (cf. Figure 448-1), deposition begins in front of the excavated ridge and slope length is calculated from the lower end of the ditch to the area where deposition begins in front of the next terrace.

Terraces not only reduce slope length but also gradient which is considered in the LS factor. For sloping bench terraces (cf. Figure 449-2), the width of the bench is considered as slope length for soil loss prediction. The soil eroded from the bench reaches the toe drain where it is either deposited or washed off into the waterway and out of the field.

The soil deposited either in front of the Fanya Juu terraces, in the ditches or in the toe drains is not yet lost from the field. It can be regarded as distributed within the field. Excavation of the ditches will partly put it back on to the field. The amount of soil which is actually transported out of the field relative to the amount of soil eroded is called the sediment delivery ratio. It varies with the side-slope of the ditches (Foster & Highfill, 1983) from 0.1 for level ditches to 1for ditches with a side-slope of 1% (Table 754-1).

Table 754-1: Sediment delivery ratios (SDR) for side-slopes (Foster & Highfill, 1983)

terrace grade [%]	sediment delivery ratio
closed outlet*1	0.05*2
0	0.10
0.1	0.13
0.2	0.17
0.4	0.29
0.6	0.49
0.8	0.83
0.9	1.00
> 0.9*3	—

*1 including terraces with underground outlets

*2 from Wischmeier & Smith (1978); all other values from SDR = 0.1*e2.64g; g = side slope [%]

*3 net erosion may occur in the channels depending on flow hydraulics and erodibility of the channels; if channel erosion occurs SDR > 1

Determination of P factors for terraces

Calculate soil loss A = R*K*L*S*C*P for each terrace by using slope lengths as explained above. The gradient is either the slope-gradient in the case of hillside ditches or the bench gradient in the case of bench terraces.

P may be composed of a contouring factor if tillage and planting are carried out on contour (cf. Chapter 7.5.1) which needs to be multiplied by the sediment delivery ratio from Table 754-1.

Example:

A slope is divided into 10 reverse-sloped terraces 10 m wide and 100 m long with a bench gradient of 5% and a side-slope of 0.4%. The benches are cropped to cassava with maize arranged on contour. Further data (R = 500 N/h; K = 0.15; LS = 0.31 (from Figure 73-1); C = 0.21 (from Table 74-12)). P for contouring is 0.5 (from Table 751-1) and the sediment delivery ratio for a 0.4% side-slope is 0.29 (Table 754-1). Thus soil loss for this situation is A = 500 * 0.15 * 0.31 * 0.21 * 0.5 * 0.29 = 0.71 t/ha. Each terrace has 0.1 ha. All terraces together would thus loose 0.71 t.

7.6 Soil loss tolerance limits

Soil loss tolerance limits define the soil loss rates which are tolerable in order to maintain the soil's diverse functions during a specified time. The effect of soil loss depends strongly on the type of soil. Soil loss always implies a loss of nutrients and structural components (clay, organic matter) which are enriched in the sediment. The soil profile is shortened, rooting depth and water storage capacity decreased. On very deep, homogeneous soils, the damage will be less than on soils with unfavourable layers or solid rock close to the surface. Compared to less weathered soils of the temperate and semi-arid zones, loss of surface soil is more severe on highly weathered soils whose nutrient storage and availability depends largely on the organic matter of the surface soil while the subsoil fertility is low.

The yield decline associated with erosion depends also on the crop. Mbagwu et al. (1984) showed that removal of 5 cm of soil reduced maize yields by 95% on an Ultisol whereas on Alfisols mean yield decline was only 52%. Cowpea yields were only reduced by 63 and 22% on Ultisols and Alfisols, respectively. In own measurements, maize yields on an Ultisol were zero after four years of erosion had stripped off the surface soil. On an Alfisol, however, which had been exposed for 8 years, a poor yield was still possible.

Ideally, the soil loss rate should not exceed the soil formation rate of the parent material. Most reported annual weathering rates for tropical climates are below 500 kg/ha (Table 76-1) which is far below agricultural soil loss rates. The lost productivity is irrecoverable by external inputs. This is even more true for small scale farmers in developing countries which do not have the necessary inputs to mitigate soil damage.

Tolerance values also depend on the intended purpose of soil conservation. In general, the purpose for erosion control will be agricultural production. However, in flood prone areas water retention can be the more important goal whereas for the municipal authorities sediment damages on road ditches, waterways or in the public sewerage system may be decisive.

In order to formulate tolerance limits, a decision about a reasonable conservation time must be taken. This is more a political and social question than a scientific one. Can we tolerate a 50% yield decline in 50 years, 100 years, – or are we still responsible for the well-being of our ancestors in 500 or 1000 years? An answer to this question must be found in order to calculate a mean, annual tolerable soil loss.

Table 76-1: Rates of soil weathering

country	climate	parent material	annual weathering rate [kg/ha]	literature
Central Africa	sub-humid	granite	150-400	Owens (1974)
Puerto Rico	humid	limestone	15000	Kaye (1959)
Kenya	humid	--	150-300	Dunne et al. (1978)
Kenya	semi-arid	—	< 150	Dunne et al. (1978)
USA	arid	—	300	Kirkby (1980)

Tolerance values, – first developed in the USA, were based on estimates of a surface soil formation of 2.54 cm in 300 to 1000 years (Bennett, 1928). This estimate was later changed to 2.54 cm in 30 years which is about 11 t/ha*a (Pimentel et al., 1976). This was the basis for setting maximum annual soil loss rates in the USA to 11 t/ha. Thus, setting of this and all subsequent values was more based on expert judgement and practical considerations than on scientific data.

Tolerance values for tropical soils have not yet been formulated on an international level. However, some countries use tolerance values and propositions were made by some authors. A summary of existing values is given in Table 76-2.

Table 76-2: Tolerance limits proposed for tropical soils

applied for	**tolerance limit [t/ha*a]**	**literature**
tropical soils	15-25	Chin & Tan (1974)
clayey soils	11	Central African Federation after Hudson (1986)
sandy soils	9	— " —
sandy soils/Zimbabwe	5	Nyagumbo (1992)
shallow, erodible soils	2-5	Hudson (1986)
shallow highland soils	2.5	Lal (1980)
tropical soils	0.2-2	Lal (1983)
Ethiopia	2	Hurni (1980)

Annex 1 Rainfall and erosivity

Annex 1.1 Erosivity for single sites

Check if your site is included in Table 11-1Annex. Erosivity was directly calculated for these sites. Also verify if erosivity data are available from the meteorological services or research stations[28]. If your location is near to one of the sites in Table 11-1Annex and has the same annual rain volume, you may as well use the erosivity given in the table. If the rain volume of your site varies within 10% of a nearby station, you can extrapolate the erosivity value linearly. The error for stations between 400 and 4000 mm in Table 11-1Annex is supposed to be less than 6% (Figure 11-1Annex).

Example for extrapolation: The site in Table 11-1 Annex receives 1440 mm/a of rain with an erosivity of 1249 N/h. Your own site nearby has 1300 mm/a. EI_{30} *for your site can be calculated by (1249/1440)*1300 = 1128 N/h.*

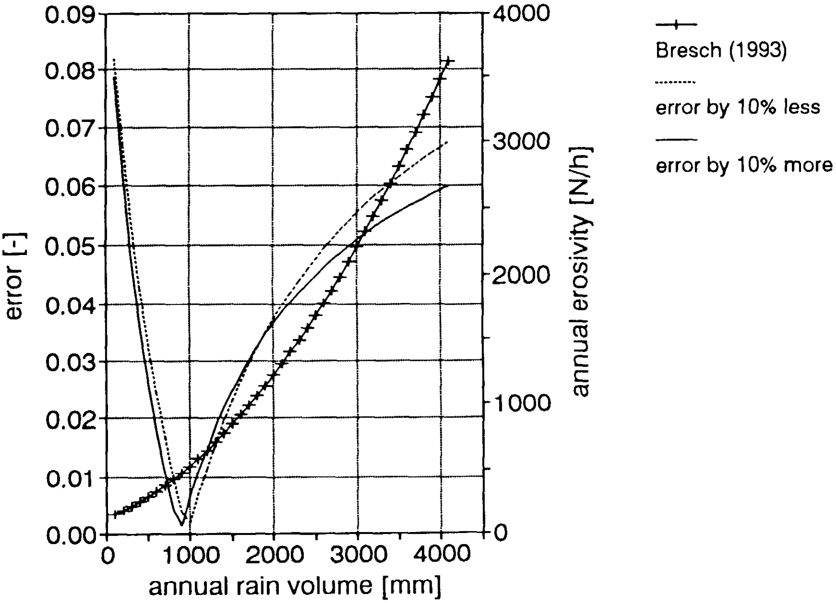


Figure 11-1 Annex: Error as caused by linear extrapolation of erosivity for 10% less/more rain than the stations listed in Table 11-1 Annex

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[28] If you find any data not yet included in the handbook, please inform the author about location, country, values (with units!), years of measurements and source.

Table 11-1 Annex: *Erosivity, rain volume, measurement period for single sites*

country	site	erosivity [N/h]	measurement period [a]	mean annual rain [mm]	literature
Algeria	Gourari	139	2	555	Mazour (1992)
– " –	Heriz	53	2	338	- „ -
– " –	Madjoudj	50	2	330	– " –
– " –	Sidi Mohamed Cherif	53	2	338	– " –
Burkina Faso	Bobo-Dioulasso	998	58	1150	Galabert & Millogo (1973)*2
– " –	Dori	468	47	540	– " –
– " –	Fada- N'Gourma	772	48	890	– " –
– " –	Farako-Ba	841	6	1083	– " –
– " –	Gaoua	1076	53	1240	– " –
– " –	Gonsé	599	5	709	Roose (1975)
– " –	Mogtedo	656	6	754	Galabert & Millogo (1973)*2
– " –	Niangoloko	1162	23	1340	– " –
– " –	Ouagadougou	763	21	880	– " –
– " –	Ouahigouya	607	49	700	– " –
– " –	Saria (Meteo)	729	30	840	– " –
Burundi	Mashitsi (Giheta)	499	2	1157	Stocking & Elwell (1976)
Cameroon	Bafia	818	2	1428	Bresch (1993)
– " –	Bamenda	1395	6	2315	– " –
– " –	Bangangte	569	1	1239	Nill (1993)
– " –	Batouri	750	11	1472	Bresch (1993)
– " –	Dibamba	1627	1	2220	Nill (1993)
– " –	Douala	3231	11	3566	Bresch (1993)
– " –	Dschang	1084	4	1970	Seguy (1971)*2
– " –	Garoua	469	8	924	Bresch (1993)
– " –	Maroua	546	12	752	– " –
– " –	Meiganga	858	10	1477	– " –
– " –	Nachtigal	1063	3	1320	Nill (1993)
– " –	Ngaoundéré	746	14	1485	Bresch (1993)
– " –	Nkoundja	1015	8	1901	– " –
– " –	Penka Michel (Bansoa)	777	4	1560	Nill (1993)
– " –	Poli	1326	4	1388	Bresch (1993)
" –	Yaoundé	942	13	1593	– " –
Cameroon	Yoko	667	8	1542	– " –
Chad	Deli	954	22	1100	Audry (1974)*2

Table 11-1 Annex, continue

country	site	erosivity [N/h]	measurement period [a]	mean annual rain [mm]	literature
Ivory Coast	Abidjan	2186	27	2100	Roose (1975)
– " –	Azaguié	1535	41	1770	– " –
– " –	Bouaké	902	60	1160	Roose & Bertrand (1971)*2
– " –	Divo	1457	29	1680	Roose & Jadin (1969)*2
– " –	Korhogo	1249	47	1440	Roose (1975)
Kenya	Eldoret	387	10	1226	Wenner (1977)*3
– " –	Kisumu	906	10	1186	– " –
– " –	Kitale	564	10	1169	– " –
– " –	Lodwar	113	10	232	– " –
– " –	Malindi	359	10	1101	– " –
– " –	Mombasa	297	10	1130	– " –
– " –	Nairobi (Kabete)	368 (?)	10	909	– " –
– " –	Nakuru	224	10	827	– " –
– " –	Nanyuki	210	10	752	– " –
– " –	Narok	267	10	869	– " –
– " –	Voi	283	10	516	– " –
Madagascar	Befandriana	2386	2	2030	CTFT (1973)*2
Niger	Allokoto I	99	6	437	Delwaulle (1973)
Nigeria	Calabar	2217		–	Armon (1984)*1
– " –	Enugu	1209		–	– " –
– " –	Ibadan	1009	3	–	Lal (1976b)
– " –	Ikom	1948		–	Armon (1984)*1
– " –	Nsukka	1281	12	–	Salako (1988)
– " –	Onitsha	1578		–	Armon (1984)*1
– " –	Owerri	1855	12	–	Salako (1988)
– " –	Port- Harcourt	1861	12	–	– " –
– " –	Umudike	1592	12	–	– " –
Rwanda	Butare	324	10	930	Ryumugabe & Berding (1992)
– " –	Gakuta	693	10	1409	– " –
– " –	Gisenyi	274	10	896	– " –
– " –	Kamembe	379	10	1230	– " –
– " –	Kigali (airport)	426	10	855	– " –
– " –	Ruhengeri	311	10	1135	– " –
Senegal	Bambey	564	47	650	Charreau & Nicou (1971)*2
– " –	Séfa	1136	54	1310	– " –

Table 11-1 Annex, continue

country	site	erosivity [N/h]	measurement period [a]	mean annual rain [mm]	literature
Zambia	Chipata	685	10	1036	Pauwelyn et al. (1988)
– " –	Kabompo	512	10	1062	– " –
– " –	Kabwe	560	10	934	– " –
– " –	Kafua Polder	525	10	779	– " –
– " –	Kasama	791	10	1217	– " –
– " –	Mwinilunga	842	10	1391	– " –
– " –	Ndola	798	10	1217	– " –
– " –	Seshcke	343	10	733	– " –
Zimbabwe	Beitbridge	40	10	295	Stocking & Elwell (1976)
– " –	Chipinga	134	20	1141	– " –
– " –	Chisumbanje	86	10	569	– " –
– " –	Dett	77	10	606	– " –
– " –	Enkeldoorn	83	10	615	– " –
– " –	Fort Victoria	85	25	625	– " –
– " –	Gokwe	112	10	752	– " –
– " –	Inyanga	102	10	869	– " –
– " –	Karoi	114	10	833	– " –
– " –	Lupane	71	10	540	– " –
– " –	Salisbury	117	25	812	– " –
– " –	Tjolotjo	48	5	529	– " –
– " –	Tuli	49	15	385	– " –

*1 in: Salako (1988)

*2 in: Roose (1975)

*3 in: Moore (1979)

Annex 1.2 Erosivity regressions

See if your own site is listed in *Table 12-1 Annex* or if it is close to a site listed there. There is no evidence as to how far these regressions can be used apart from the specific sites for which they were calculated. However, the quality of rain will generally not change in the same geographic area within some kilometers. A qualitatively similar rainfall is presumed which can differ in volume.

If regressions in *Table 12-1 Annex* are given for single storms, the mean annual EI_{30} is calculated by summation of the storm erosivity for several years. It is not possible to use these regressions with annual rain volumes.

Table 12-1 Annex: Regressions for the calculation of erosivity
(P_{ann} = mean annual rain volume [mm],
EI_{30} = mean annual erosivity; EI_{30i} = erosivity of a storm i;
P_i = rain volume of a storm i)

No.	country/ area	location	regression	remarks	literature
			EI_{30} [N/h]		
1	**Burkina Faso**	Bobo-Dioulasso	$EI_{30i} = 0.0158 * PI_{30i} - 1.24$	for single storms; regressions for No. 1 and 2 were very similar to equation No.3. Delwaulle therefore proposed to use No. 3 for the sahel region between 440 and 1160 mm	Galabert & Millogo (1973) in: Delwaulle (1973)
2	" -	Dori	see No. 1		– " –
3	– " -	Gampela and Gonsé near Ougadougou	$EI_{30i} = 0.0158 * PI_{30i} - 1.2$ $r^2 > 0.98$; n = 7 years of single storms	for single storms; both sites had very similar rain distribution and were evaluated together with Allokoto/Niger	Delwaulle (1973)
4	**Cameroon**	all	$EI_{30} = (11 + 0.012 * Pann)^2$ $r^2 = 0.91$	18 stations with 3 to 14 years each	Bresch (1993)

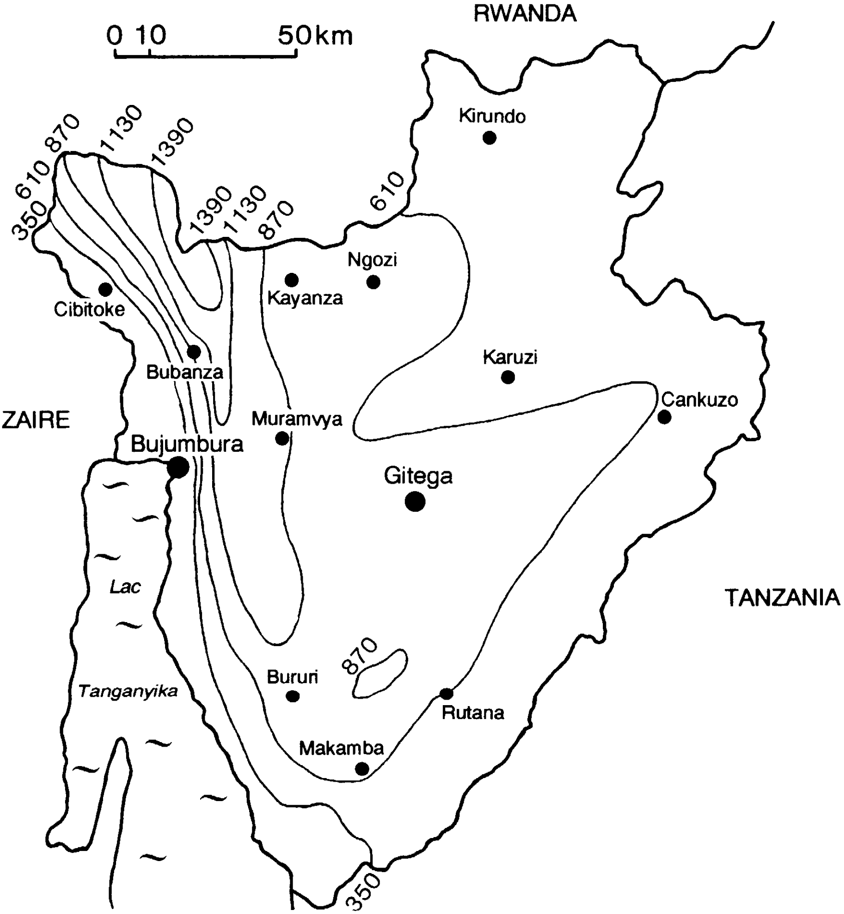
No.	country/ area	location	regression	remarks	literature
			EI_{30} [N/h]		
5	**Kenya**	coastal zone to 50 km inland	$EI_{30} = 1.149*Pann-840$	calculated for Lamu, Malindi, Mombasa, Dar es Salaam and Zanzibar[*1]	– " –
6	– " –	inland < 1250 m altitude	$EI_{30} = 0.571*Pann-80$	calculated for Lodwar, Makindi, Voi, Dodoma, Kigoma, Mwanza and Tabora[*1]	– " –
7	– " –	inland > 1250 m altitude	$EI_{30} = 0.269*Pann+113$	calculated for Eldoret, Equator, Kitale, Nairobi Airport, Dagoretti, Kabete and Wilson, Nakuru, Lyamungu and Mbeya[*1]	
8	– "	Uganda plateau	$EI_{30} = 0.833*Pann-396$	calculated for Kisumu, Entebbe, Foprt Portal, Gulu, Jinja, Kabale, Kampala, Kasese, Masindi, Mbarara and Tororo[*1]	
9	– " –	Katumani/ Machakos	$EI_{30i} = 0.9*P_i-97.4$ $r^2 = 0.9; n = 35$	regression for single storms based on 35 events	Ulsaker & Onstad (1984)
10	– " –	Katumani/ Machakos	$EI_{30i} = 0.0206PI_{30i}-3.9$ $r^2 = 0.99; n = 35$	– " –	– " –
11	**Niger**	Allokoto	$EI_{30i} = 0.0158*PI_{30i}-1.2$	see No. 3	Delwaulle (1973)
12	**Nigeria**	Alore	$EI_{30i} = (0.12+0.18P_i)^2$ $r^2 = 0.87; n = 240$	for single storms	Nill (1993)
13	– " –	Ibadan	$EI_{30i} = (1048*P_i-1059)*0.017$ $r^2 = 0.67$	for single storms; regression for storms of 3 years	Lal (1976b)
14	**Rwanda**	all	EI_{30} ca. (0.433*Pann)	based on 6 stations and 10 years	Ryumugabe & Berding (1992)
15	**Sahel**		$EI_{30} = 0.87 * Pann$		Roose (1977)
16	**Tanzania**	see No. 5 to 8	use regressions No. 5 to 8	see No. 5 to 8	Moore (1979)
17	**Uganda**	Uganda pla-	use regression No. 8	see No. 8	– " –

No. country/ area	location	regression EI_{30} [N/h]	remarks	literature
18 **Zambia**	all	$EI_{30i} = 0.0236*P^{1.91}$ $r^2 = 0.71, n = 2348$	for single storms	Pauwelyn et al. (1988)
19 – " –	Chipata	$EI_{30i} = 0.0256P_i^{1.95}$ $r^2 = 0.74, n = 292$	– " –	– " –
20 – " –	Kabompo	$EI_{30i} = 0.0234*P_i^{1.98}$ $r^2 = 0.72, n = 248$	– "	– " –
21 – " –	Kabwe	$EI_{30i} = 0.0235*P_i^{1.87}$ $r^2 = 0.67, n = 261$	– " –	– " –
22 – " –	Kafue Polder	$EI_{30i} = 0.0253*P_i^{1.82}$ $r^2 = 0.74, n = 213$	- "	"
23 – " –	Kasama	$EI_{30i} = 0.0217*P_i^{1.96}$ $r^2 = 0.71, n = 349$	– "	" –
24 "	Mwinilunga	$EI_{30i} = 0.0229*P_i^{1.96}$ $r^2 = 0.72, n = 392$	– " –	"
25 – " –	Ndola	$EI_{30i} = 0.0226*P_i^{1.88}$ $r^2 = 0.72, n = 378$	– " –	– "
26 – " –	Sesheke	$EI_{30i} = 0.0248*P_i^{1.85}$ $r^2 = 0.67, n = 215$	" –	– " –
27 **Zimbabwe**	all	$EI_{30} = 0.215*Pann-51.1$ $r^2 = 0.61, n = 66$		Stocking & Elwell (1976)
28 – " –	Eastern districts	$EI_{30} = 0.183*Pann-54.2$ $r^2 = 0.83, n = 10$		– " –
29 – " –	Highveld	$EI_{30} = 0.262*Pann-81.1$ $r^2 = 0.5, n = 24$		– "
30 – " –	Lowveld	$EI_{30} = 0.267*Pann-59.6$ $r^2 = 0.44, n = 19$		– " –
31 – " –	Middleveld	$EI_{30} = 0.497*Pann-223$ $r^2 = 0.44, n = 19$		" –

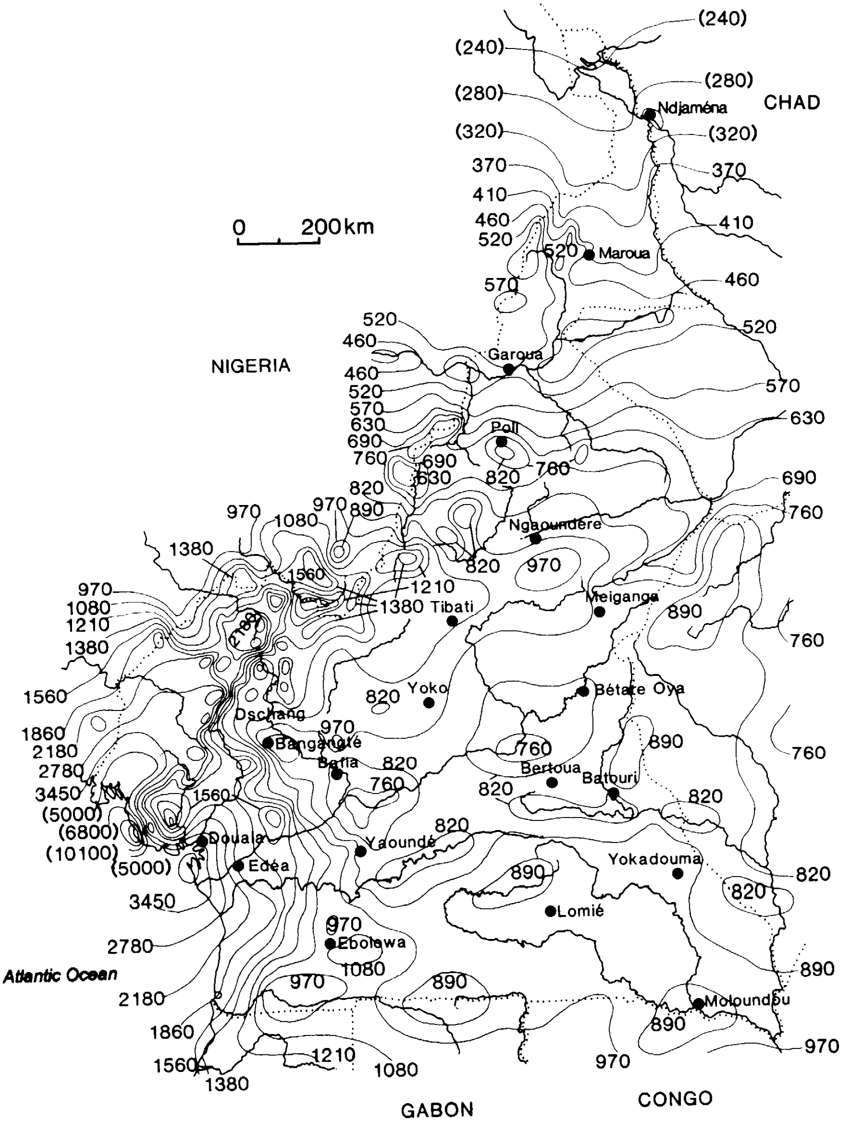
*1 Regressions in Moore (1979; Table 3) for $KE_{15} > 25$ were entered into regression: EI_{30} [ft.tons*in/acre*a] = 0.029*KE>25–26; $r^2 = 0.9$ which was calculated from 11 stations in Kenya (Wenner, 1977) and multiplied by 1.735 in order to transform to SI units

Annex 1.3 National iso-erodent maps

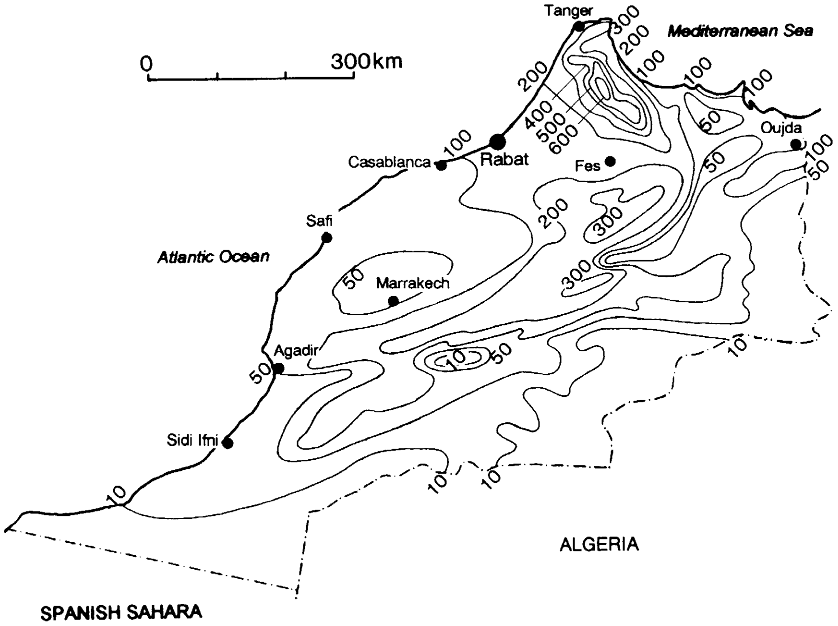
Burundi (Simonart et al., 1993)



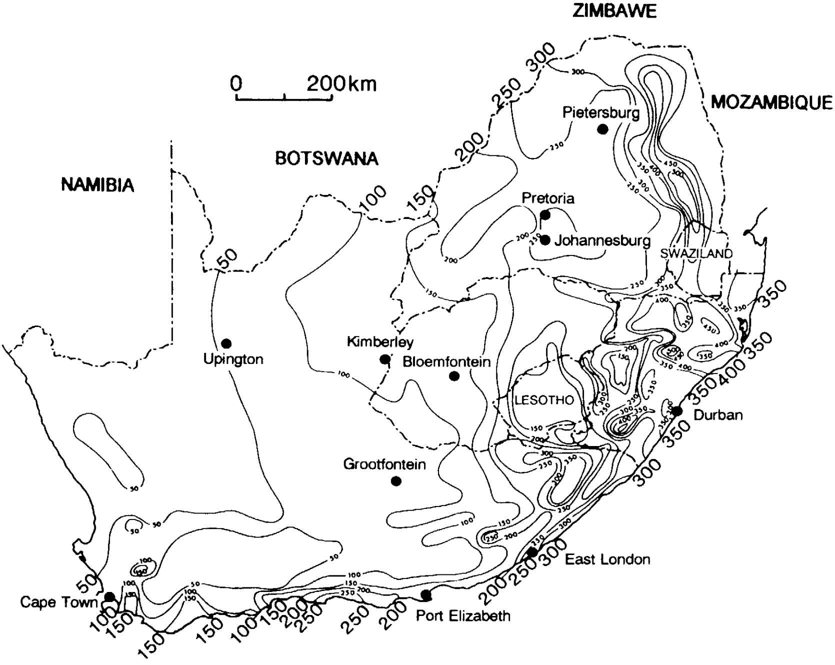
Cameroon (Bresch, 1993)



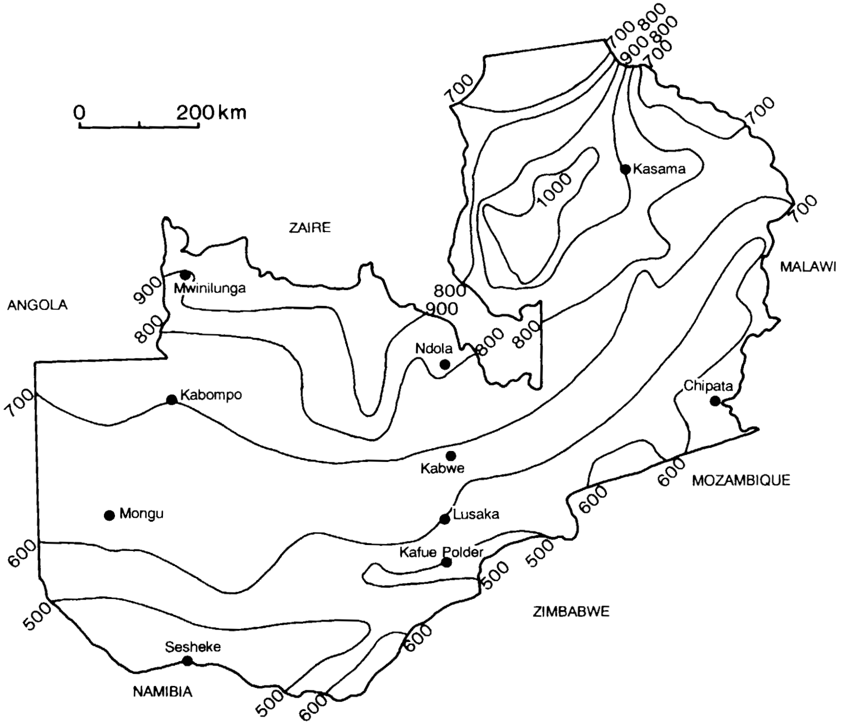
Marocco (Arnoldus, 1977)



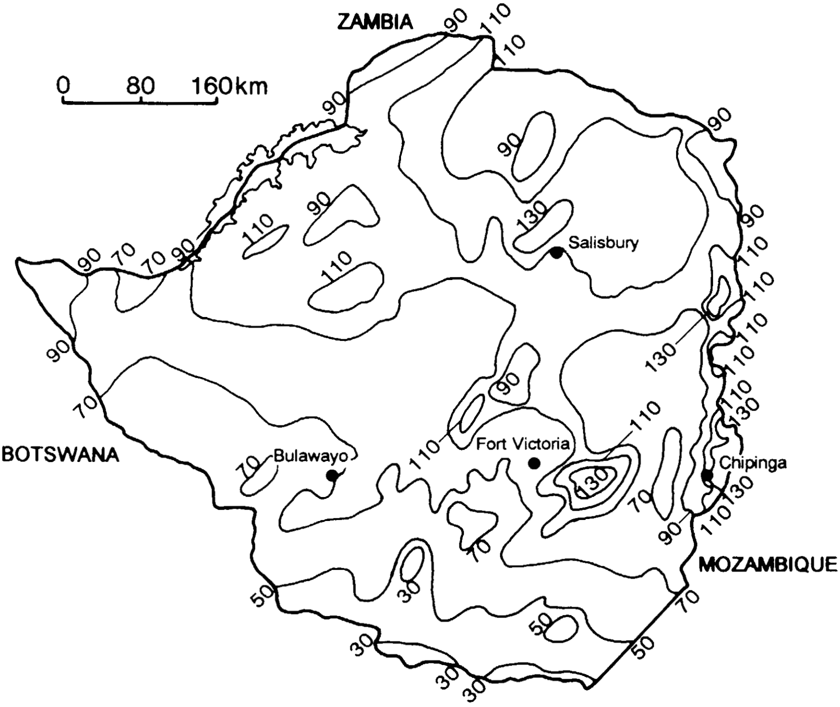
South Africa (Smithen & Schulze, 1982)



Zambia (Lenvain et al., 1988)

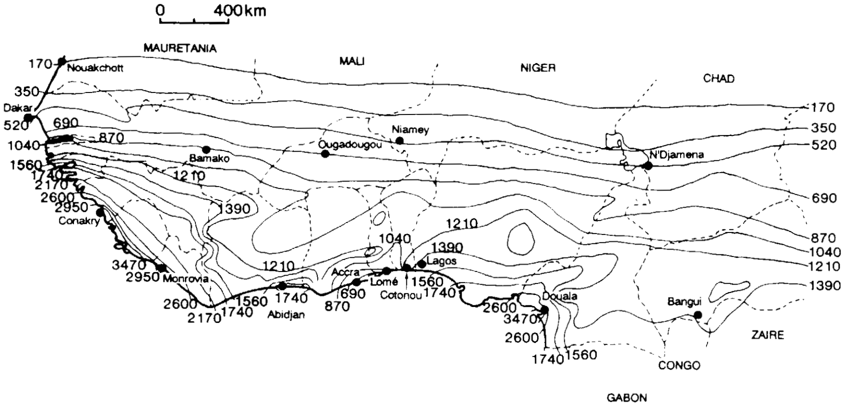


Zimbabwe (Stocking & Elwell, 1976)

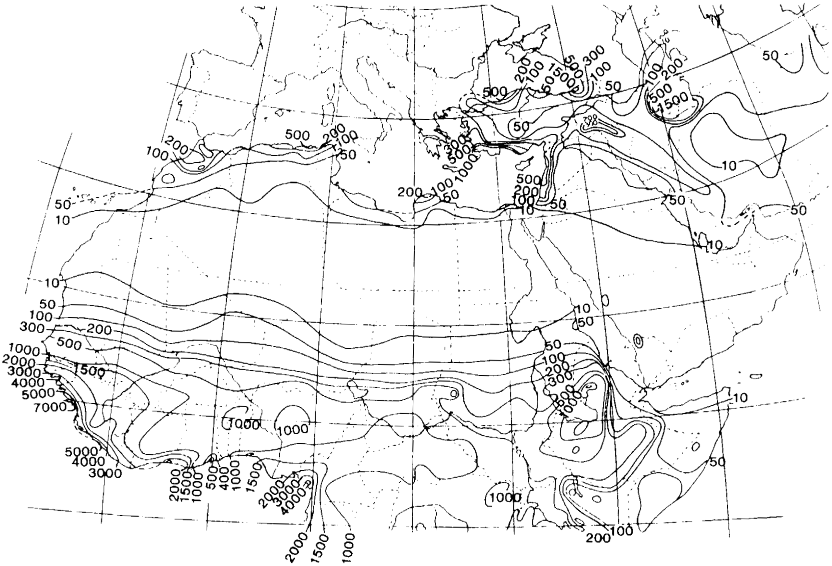


Annex 1.4 Regional iso-erodent maps

West Africa (Roose, 1977)

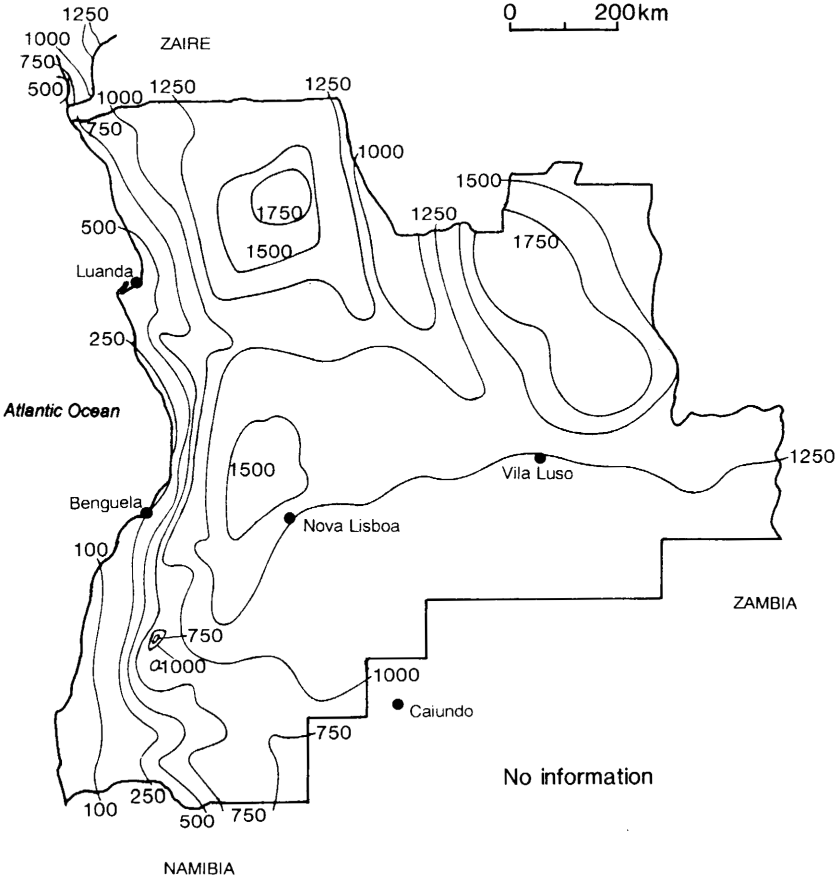


Africa north of the Sahara (Arnoldus, 1978)

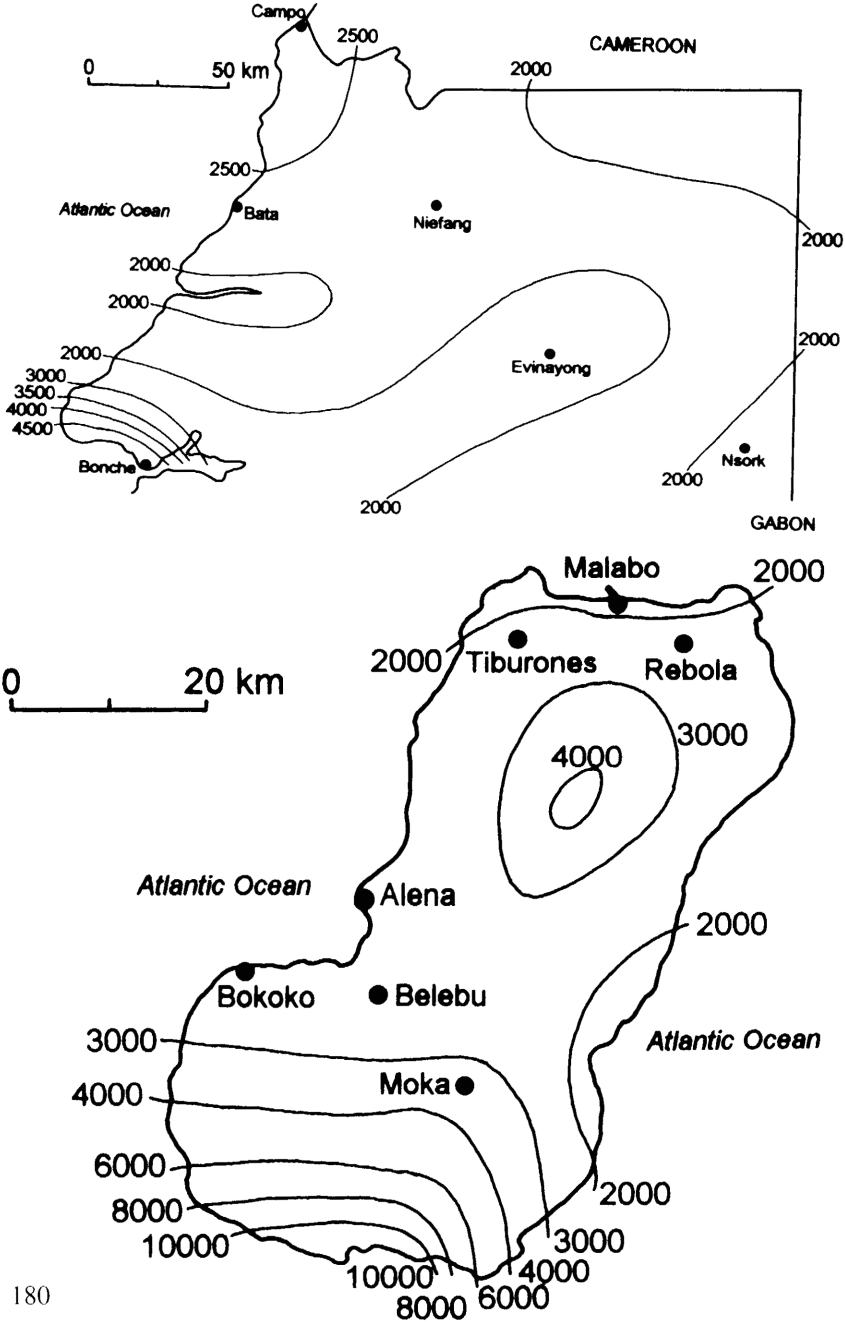


Annex 1.5 National rainfall distribution maps

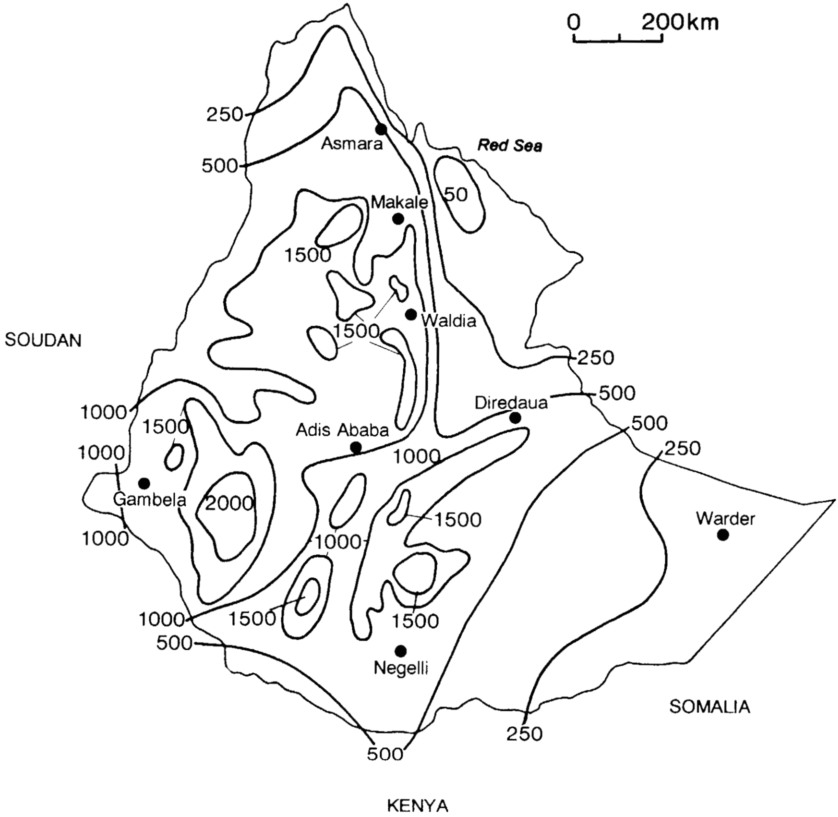
Angola (Griffith, 1972)



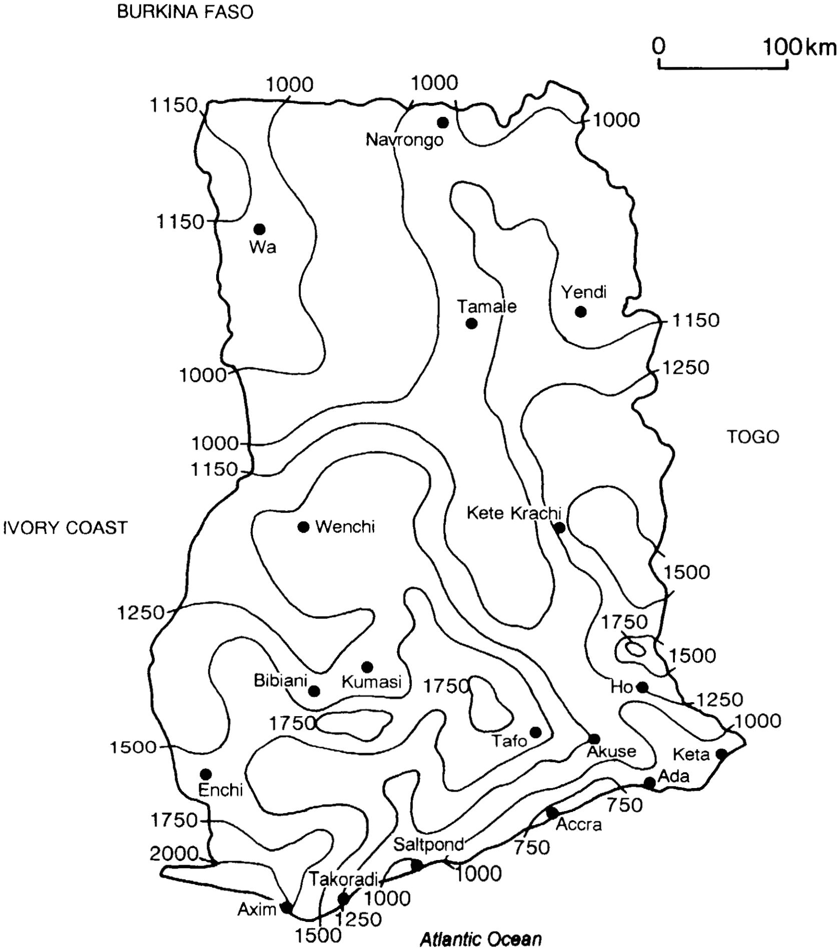
Equatorial Guinea (Griffiths, 1972)



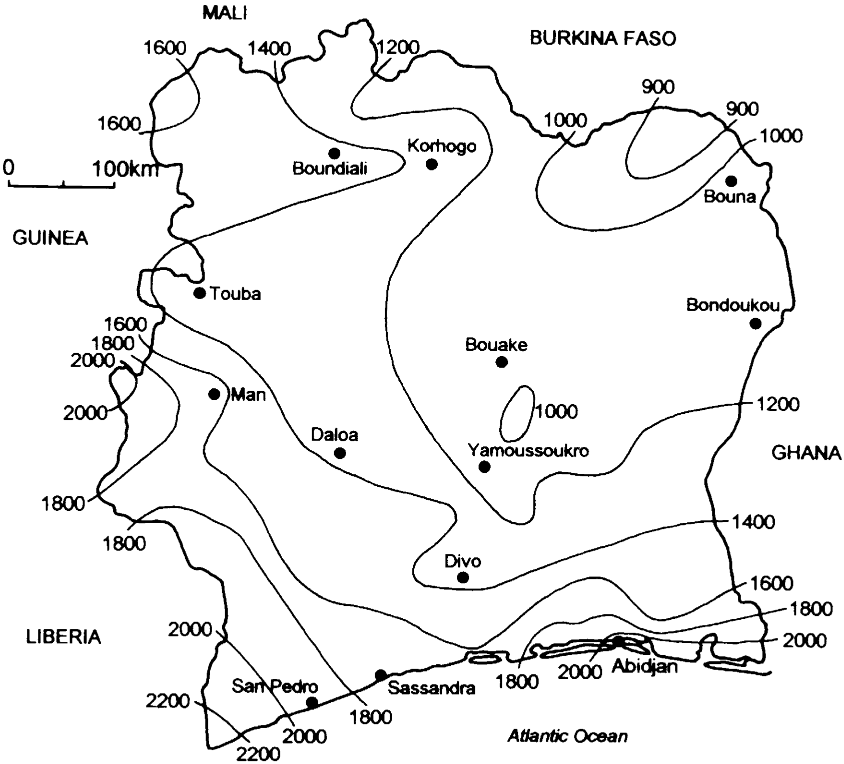
Ethiopia (Griffiths, 1972)



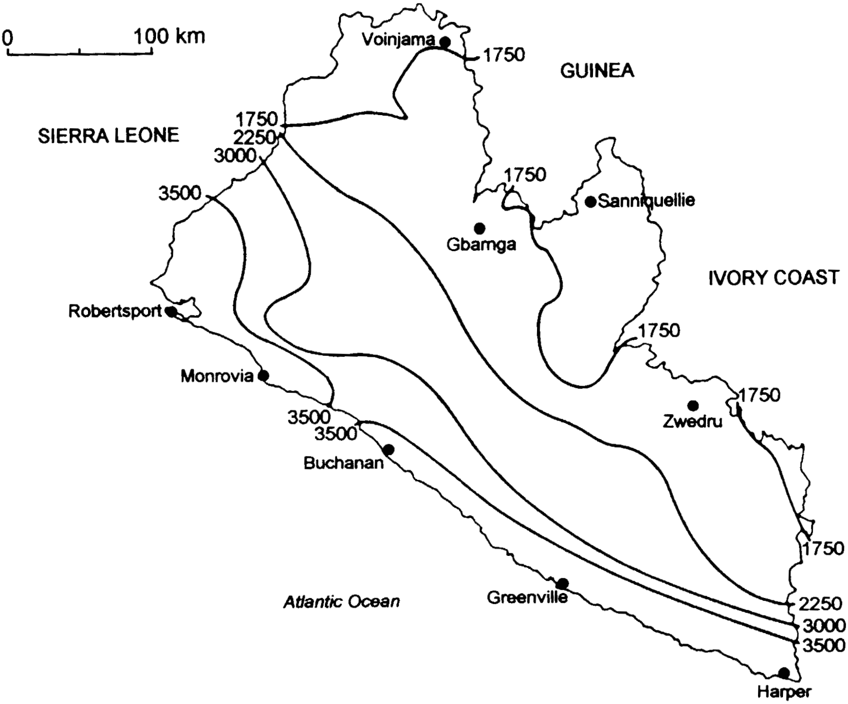
Ghana (von Gnielinski, 1986)



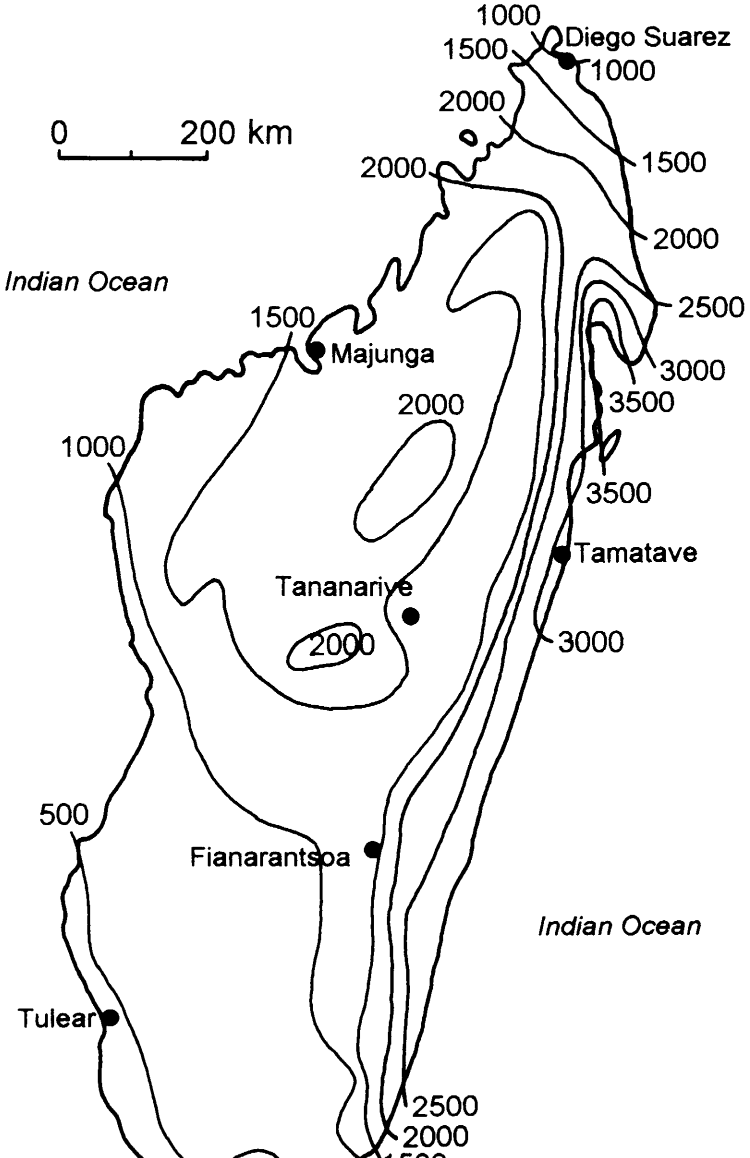
Ivory Coast (Wiese, 1988)



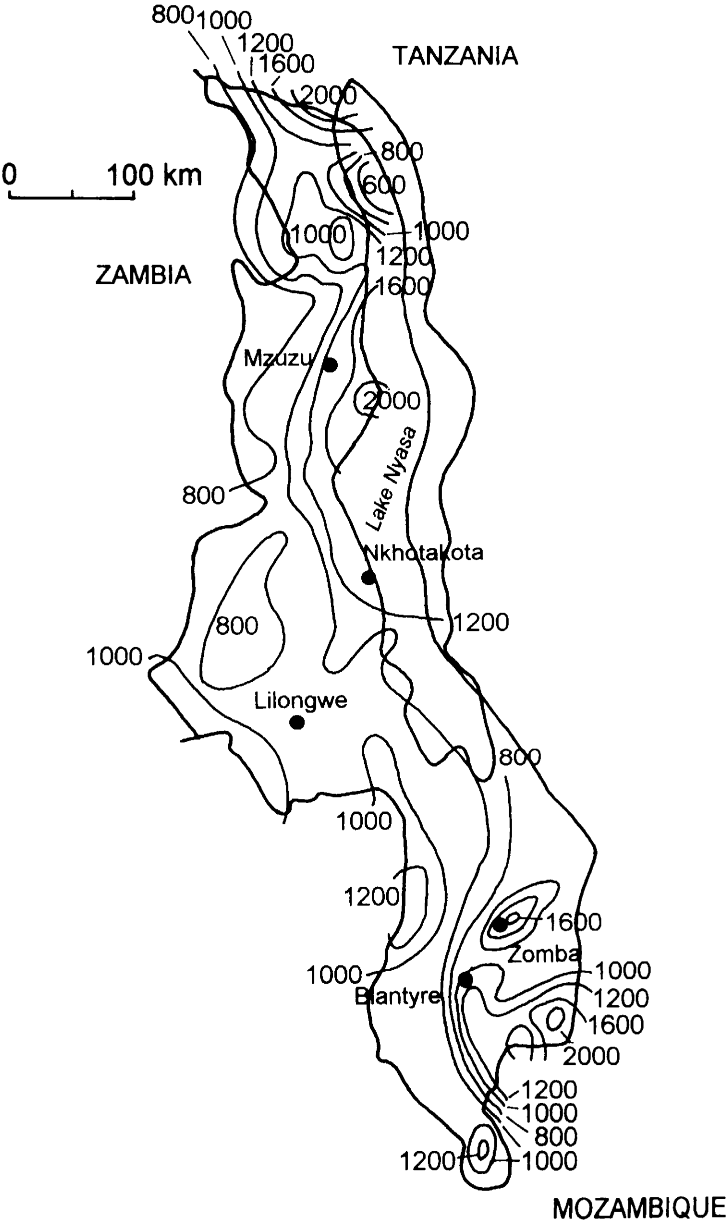
Liberia (Griffiths, 1972)



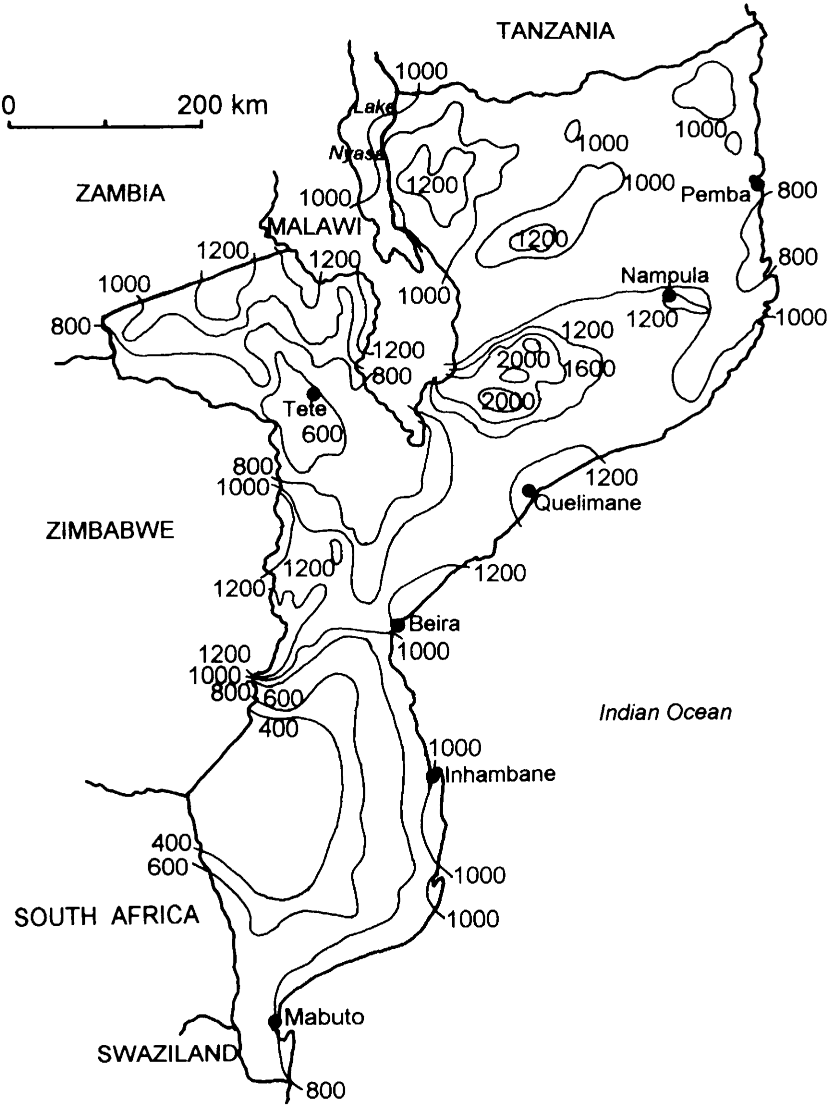
Madagascar (Sick, 1979)



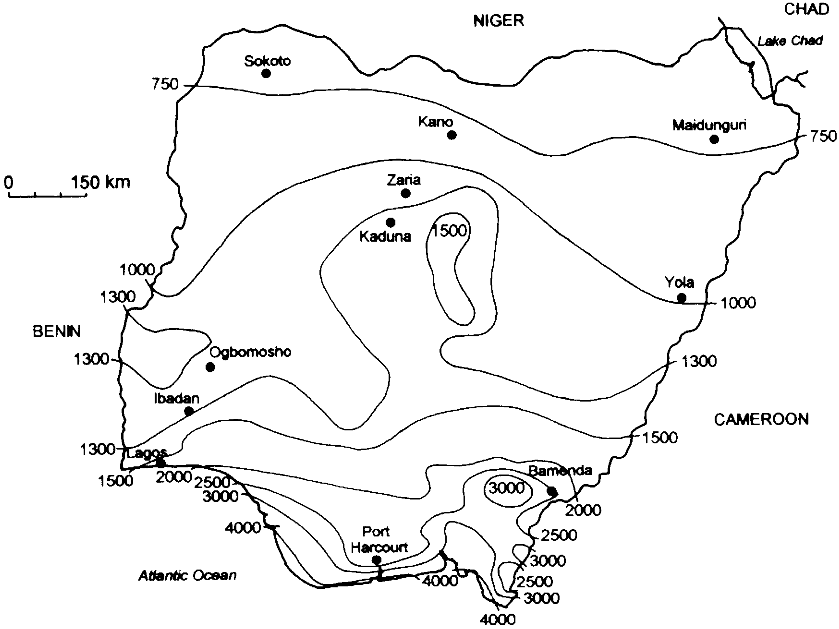
Malawi (Griffiths, 1972)



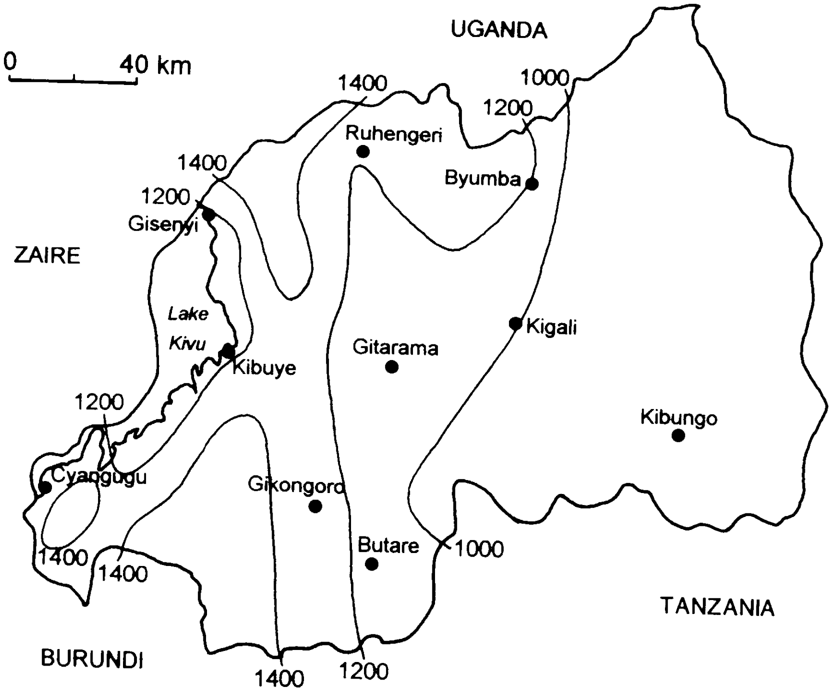
Mozambique (Nelson, 1984)



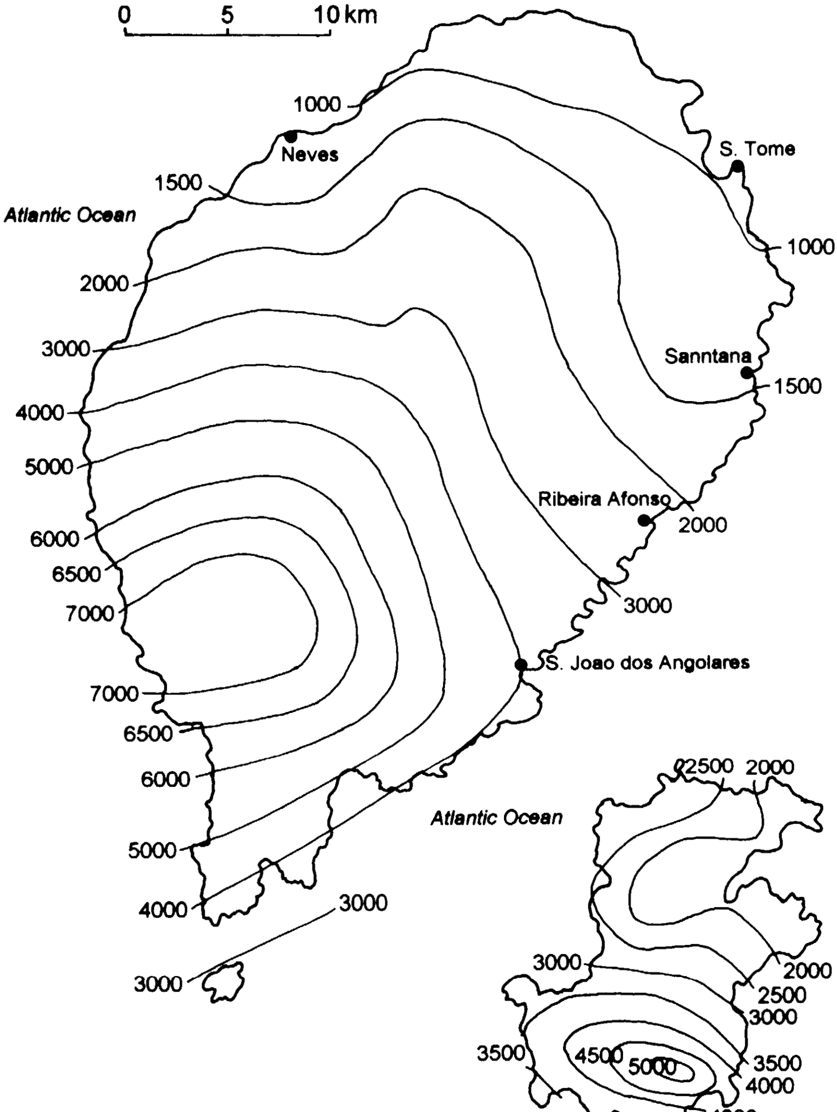
Nigeria (British West African Meteorological Service, 1954)



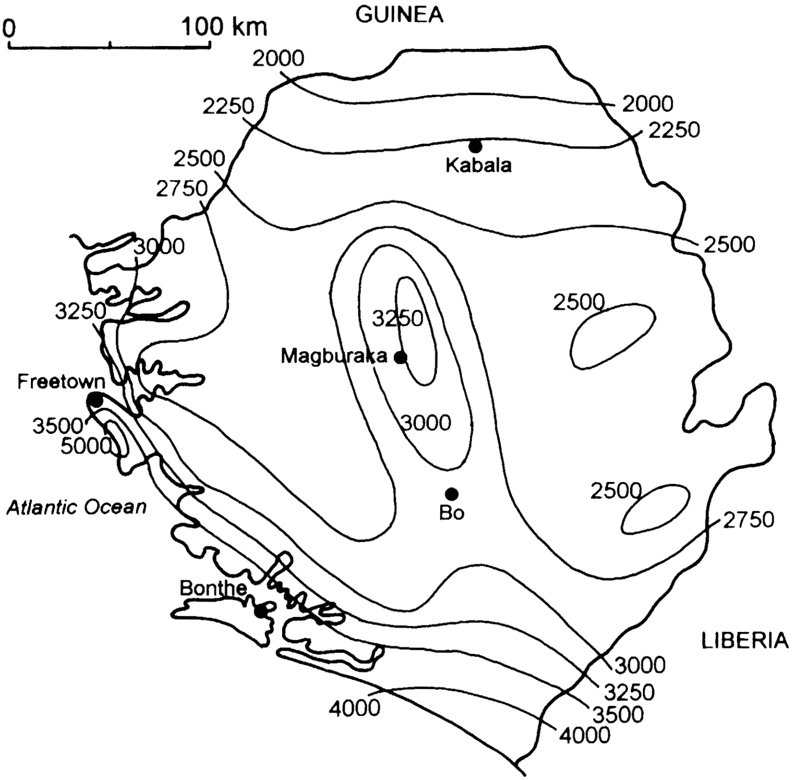
Rwanda (Moeyersons, 1989)



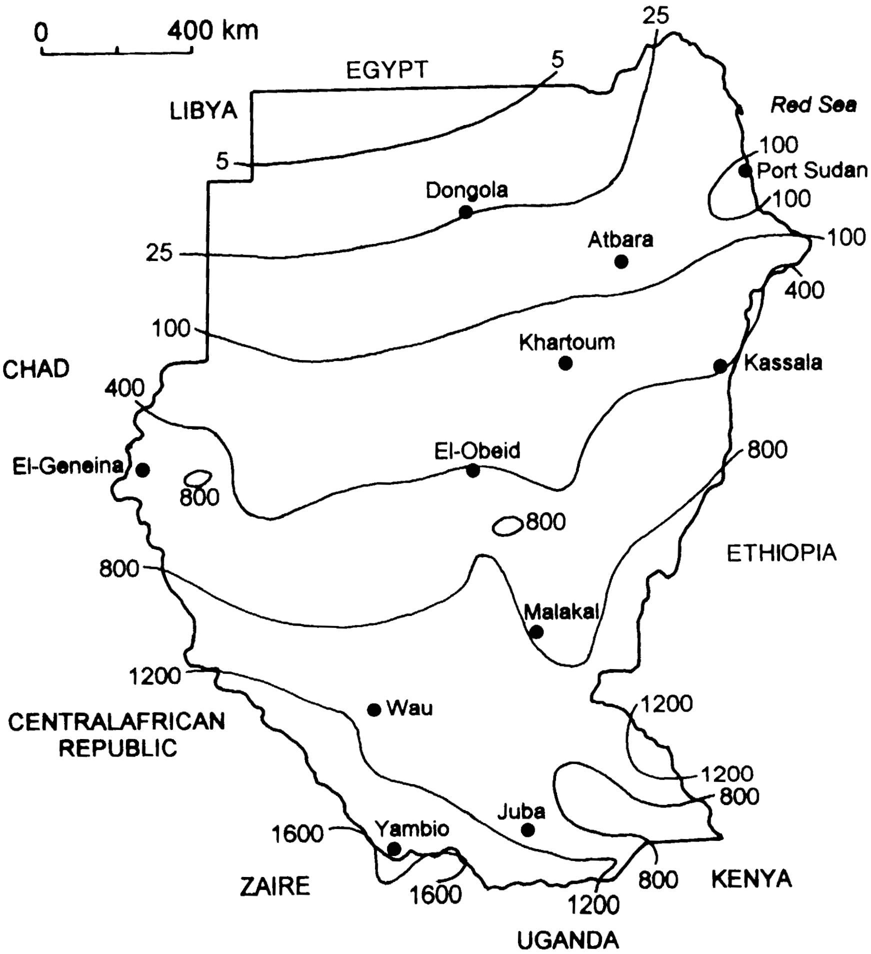
Sao Tomé and Principe (Servico Meteorológico)



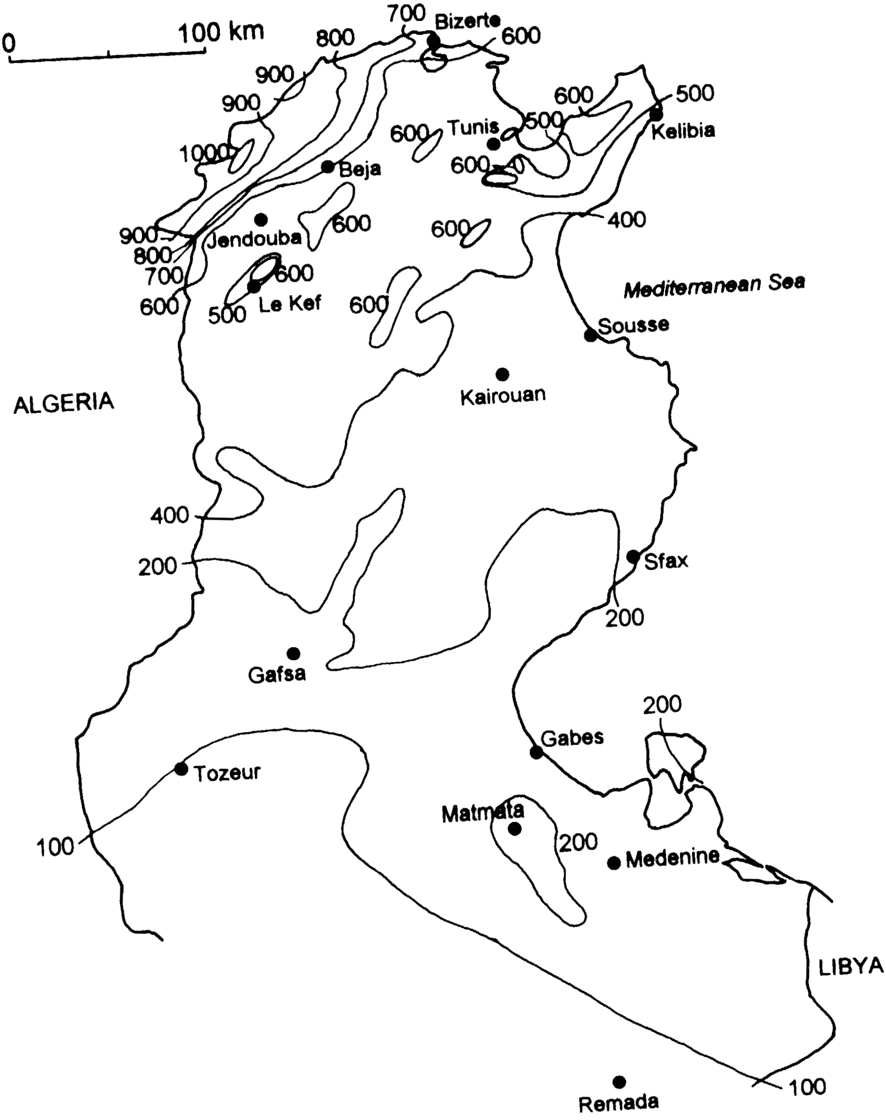
Sierra Leone (Griffiths, 1972)



Soudan (Griffiths, 1972)



Tunisia (Schliephake, 1984)



Annex 1.6 Rain volume and distribution for single sites

Rain volume and distribution are generally easy to be found locally. However, from abroad it is difficult to collect local information. The data which were found in literature are listed in Table 16-1Annex in order to save efforts and for the preparation of a more complete future list.

Table 16-1Annex: Annual rain volume and monthly distribution

		rain volume and distribution [mm]														
country	**site**	**annual**	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**	**record in years**	**literature**
Algeria	Ain Sefra	192	10	10	14	9	15	28	8	7	15	29	29	18	15	Griffiths (1972)
- " -	Algier	762	113	84	74	41	46	15	2	4	40	78	129	136	?	*4
- " -	Oran	428	63	46	41	37	27	9	1	2	14	29	77	82	?	- " -
- " -	Orleansville	400	55	45	39	32	37	9	1	1	20	35	60	66	25	Griffiths (1972)
- " -	Setif	468	60	45	43	36	51	28	11	13	37	39	53	52	25	- " -
- " -	Skikda	829	169	108	72	50	50	10	4	7	34	84	92	149	12	- " -
- " -	Tebessa	335	33	26	38	30	38	29	10	10	33	29	30	29	24	- " -
Angola	Banana	782	28	167	152	140	107	0	0	1	2	20	95	70	?	- " -
- " -	Cabinda	671	59	109	85	117	56	1	0	1	6	34	114	89	?	*4
- " -	Cangamba	1027	225	187	172	46	1	0	0	5	5	41	130	215	7	Griffiths (1972)
- " -	Landana	1045	86	185	192	185	95	0	0	1	3	57	182	59	?	- " -
- " -	Lobito	267	19	38	81	63	5	0	0	0	1	13	20	27	?	- " -
- " -	Luanda	367	26	35	97	124	19	0	0	1	2	6	34	23	30	- " -
- " -	Mocamedes	50	7	10	17	11	0	0	0	0	0	1	2	2	?	*4
- " -	Nova Lisboa	1387	209	179	231	144	16	0	0	1	19	124	231	233	20	Griffiths (1972)
- " -	Sa Da Bandeira	911	140	153	172	94	6	1	0	0	4	70	118	153	30	- " -
- " -	Teixeira De Sousa	1336	228	218	236	112	11	0	1	4	24	89	181	232	20	- " -

		rain volume and distribution [mm]														
country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
Benin	Cotonou	1339	36	51	104	134	201	338	120	22	82	164	68	19	30	- " -
- " -	Kouand	1199	0	0	123	5	103	101	307	285	227	48	0	0	1	GTZ (personal communication)[*1]
- " -	Natitingou	1342	3	8	26	75	126	162	221	254	311	118	33	5	30	Griffiths (1972)
- " -	Pehunco	779	0	0	24	25	151	67	72	235	171	34	0	0	1	GTZ (personal communication)[*2]
- " -	Pobe	1152	13	32	96	142	172	186	125	58	129	147	42	10	29	Griffiths (1972)
- " -	Tchaorou	1212	7	15	58	104	141	161	165	163	214	161	16	7	30	- " -
- " -	Tobr	827	0	0	22	0	113	104	123	231	153	81	0	0	1	GTZ (personal communication)
Botswana	Ghanzi	446	98	94	74	39	8	1	0	0	2	21	43	66	30	Griffiths (1972)
- " -	Mahalapye	511	84	95	77	30	10	6	3	2	7	28	72	97	30	- " -
- " -	Maun	488	110	102	85	26	22	1	0	0	1	15	46	80	30	- " -
- " -	Tsabong	271	37	50	46	31	11	8	2	1	11	13	22	39	20	- " -
Burkina Faso	Bobo-Dioulasso	1113	1	2	17	48	108	130	208	308	206	74	10	1	50	- " -
- " -	Ouagadougou	897	0	2	13	16	83	122	203	280	144	33	1	0	15	- " -
Burundi	Bujumbura	848	94	109	121	125	57	11	5	11	37	64	100	114	30	- " -
- " -	Kisozi	1447	167	160	196	228	120	12	6	16	64	115	174	189	30	- " -
- " -	Rubona	1179	111	156	140	183	164	23	7	27	63	102	110	93	30	- " -
Cameroon	Abong Mbang	1647	26	57	135	169	203	174	76	100	251	306	114	36	40	Suchel (1972)
- " -	Akonolinga	1467	24	33	123	149	186	143	68	87	225	278	119	32	31	- " -
- " -	Ambam	1697	41	79	162	197	212	134	45	48	208	302	183	86	29	- " -
- " -	Bafoussam	1796	11	31	102	181	181	187	232	223	295	280	63	10	32	- " -
- " -	Bafut	2424	18	47	176	184	202	312	404	284	386	265	114	32	7	- " -
- " -	Bamenda	2596	26	54	172	189	206	318	408	375	482	253	83	30	30	- " -
- " -	Bansoa	1742	12	38	119	160	176	228	222	167	303	233	71	13	13	- " -

		rain volume and distribution [mm]														
country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
Cameroon	Batouri	1436	31	45	96	128	161	155	101	125	224	236	96	38	30	- " -
- " -	Berberati	1539	21	53	90	134	163	153	137	192	215	268	90	23	?	Griffiths (1972)
- " -	Buea	2875	33	62	143	186	230	262	458	548	502	339	85	27	34	Suchel (1972)
- " -	Campo	2797	118	148	205	288	347	192	73	131	440	506	252	97	22	- " -
- " -	Debundscha	10299	271	319	545	510	757	1232	1460	1372	1588	1204	658	383	?	Griffiths (1972)
- " -	Douala	3995	63	90	204	224	292	487	741	728	542	397	161	66	49	Suchel (1972)
- " -	Edea	2710	37	42	178	249	311	284	234	304	450	403	168	50	?	Griffiths (1972)
- " -	Ekona-CDC	2316	26	44	123	169	202	233	384	424	365	242	95	9	18	Suchel (1972)
- " -	Foumban	1897	4	21	94	150	191	176	268	311	325	278	70	9	32	- " -
- " -	Garoua	1060	0	0	3	47	128	166	193	227	222	71	1	2	20	- " -
- " -	Godola	882	0	0	1	19	40	105	231	328	138	20	0	0	8	- " -
- " -	Guider	935	0	1	5	30	105	134	187	240	165	65	3	0	34	- " -
- " -	Jakiri	2042	8	45	143	157	176	247	301	337	303	271	48	6	14	- " -
- " -	Kaele	915	0	0	4	30	79	135	206	241	190	29	1	0	22	- " -
- " -	Kounden	2068	8	33	93	153	186	224	366	305	347	272	61	20	15	- " -
- " -	Kribi	3028	102	128	203	264	378	257	117	234	512	540	197	96	30	Griffiths (1972)
- " -	Kumbo	1863	9	33	126	142	175	193	284	274	325	232	59	11	33	Suchel (1972)
- " -	Limbe	4299	50	54	124	171	311	849	1137	817	428	235	97	26	16	- " -
- " -	Lolodorf	2093	39	77	183	271	279	195	60	82	272	377	201	57	27	- " -
- " -	Lomie	1654	40	57	123	175	182	145	91	142	257	268	129	45	37	- " -
- " -	Loum	2993	40	65	159	216	269	360	416	462	480	369	128	29	19	- " -
- " -	Makak	1822	30	57	178	215	238	145	58	95	244	371	157	34	21	- " -
- " -	Mankim	1578	5	24	140	126	144	190	108	103	286	300	136	16	8	- " -
- " -	Maroua	784	0	0	1	10	66	98	169	264	149	27	0	0	21	- " -
- " -	Mbalmayo	1455	27	58	122	167	200	144	65	65	154	287	133	33	19	- " -
- " -	Moliwe	3489	19	60	134	193	208	461	980	743	385	207	84	15	17	- " -

		rain volume and distribution [mm]														
country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
Cameroon	Moloundou	1512	61	91	137	179	147	104	71	93	222	209	135	63	?	Griffiths (1972)
- " -	Mora	753	0	1	1	13	59	91	185	265	121	17	0	0	30	Suchel (1972)
- " -	Nanga Eboko	1590	23	40	110	170	204	150	91	118	263	299	96	26	34	- " -
- " -	Ndikinimeki	1522	17	36	117	170	170	153	84	115	269	293	88	10	32	- " -
- " -	Ngaoundere	1589	0	4	52	146	235	210	246	269	265	147	12	3	14	- " -
- " -	Ngoulemakong	1780	27	68	142	246	234	171	69	76	217	353	167	26	11	- " -
- " -	Nkambe	2465	6	24	86	127	161	288	483	483	439	288	74	6	9	- " -
- " -	Nkongsamba	2762	16	53	151	199	226	261	431	482	476	345	103	19	34	- " -
- " -	Ntui	1398	17	44	129	199	159	159	52	62	170	316	84	7	10	- " -
- " -	Nyombe	2690	29	70	153	185	234	283	389	394	426	387	123	17	12	- " -
- " -	Penja	3084	30	83	213	235	243	335	417	433	510	407	140	38	15	- " -
- " -	Rey Bouba	1177	0	0	8	33	120	160	238	290	235	87	6	0	11	- " -
- " -	Sangmelina	1710	41	65	146	198	212	169	81	84	242	276	151	45	35	- " -
- " -	Santa	2167	10	35	148	204	233	289	269	254	332	310	67	16	10	- " -
- " -	Tchollire	1407	0	1	19	77	137	195	275	307	295	96	5	0	17	- " -
- " -	Tibati	1748	4	13	64	134	183	206	278	270	297	248	45	6	29	- " -
- " -	Tignere	1479	0	5	39	122	194	197	242	274	236	147	22	1	13	- " -
- " -	Tiko	2844	21	49	127	174	195	400	646	560	308	231	119	14	17	- " -
- " -	Wakwa	1737	0	3	37	199	237	254	240	325	275	151	13	3	8	- " -
- " -	Yabassi	2692	42	58	139	199	242	307	383	417	413	341	124	27	36	- " -
- " -	Yagoua	821	0	0	4	21	58	124	182	272	141	18	1	0	33	- " -
Canary Islands	St. Cruz de la Palma	441	81	38	36	20	10	1	1	3	10	38	127	76	?	*4
- " -	Tetia	115	38	13	5	8	3	1	0	1	1	5	15	25	?	*4

country	site	rain volume and distribution [mm]														
		annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
Central Africa	Baboua	1572	11	24	83	116	161	193	170	239	290	228	47	10	13	Suchel (1972)
- " -	Bangui	1560	21	47	124	128	173	135	185	225	185	202	101	34	30	Griffiths (1972)
- " -	Berberati	1530	20	47	89	140	159	159	135	195	221	257	85	23	31	Suchel (1972)
- " -	Birao	860	0	0	2	19	97	112	217	204	171	37	1	0	30	Griffiths (1972)
- " -	Bouar	1575	5	27	75	122	139	174	198	316	282	197	36	4	31	Suchel (1972)
- " -	Ndim	1661	0	6	33	88	159	233	323	327	295	189	8	0	16	- " -
- " -	Nola	1451	26	44	108	133	151	167	138	161	199	176	109	39	25	- " -
- " -	Salo	1698	29	63	146	154	154	155	149	195	214	236	149	54	16	- " -
- " -	Sarki	1375	1	5	33	89	145	190	265	274	225	137	11	0	14	- " -
Chad	Abch	435	0	0	0	2	18	34	112	207	56	6	0	0	31	unknown
- " -	Abdy	407	0	0	0	0	10	96	115	158	28	0	0	0	2	- " -
- " -	Abfcher	505	0	0	0	1	24	26	141	232	67	14	0	0	30	Griffiths, 1972
- " -	Ade	568	0	0	0	0	2	44	122	258	142	0	0	0	2	- " -
- " -	Adre	617	0	0	1	5	19	44	233	229	76	10	0	0	28	unknown
- " -	Am Dam	665	0	0	0	4	19	102	204	224	97	15	0	0	23	- " -
- " -	Am Zoer	322	0	0	0	1	9	19	84	165	43	0	0	0	17	- " -
- " -	Aoue	530	0	0	0	0	1	71	111	262	86	0	0	0	2	- " -
- " -	Biltine	297	0	0	0	1	6	22	85	143	33	8	0	0	19	- " -
- " -	Bol	310	0	0	0	0	7	10	71	172	45	5	0	0	28	Suchel (1972)
- " -	Bongor	882	0	0	5	21	75	133	187	264	176	20	1	0	20	- " -
- " -	Fort-Lamy	633	0	0	0	8	28	66	156	251	103	21	0	0	35	- " -
- " -	Goz-Beid	683	0	0	1	6	26	68	273	185	105	19	0	0	26	- " -
- " -	Guerada	300	0	0	0	1	4	19	105	149	21	2	0	0	17	unknown
- " -	Lr	831	0	0	3	31	64	120	175	215	180	43	0	0	20	Suchel (1972)
- " -	Moundou	1207	0	0	12	48	112	161	242	299	240	89	4	0	34	- " -
- " -	Pala	1065	0	0	7	44	104	165	234	245	198	64	4	0	21	- " -

country	site	rain volume and distribution [mm] annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
Chad	Pandzangue	1261	0	1	12	52	97	160	266	311	256	100	6	0	28	- " -
Congo	Libreville	2592	206	291	264	395	244	40	0	11	106	359	416	260	?	*4
- " -	Ouesso	1636	64	85	142	131	177	137	84	143	223	215	155	80	32	Suchel (1972)
- " -	Sembe	1580	60	103	177	199	163	101	55	72	202	197	186	65	11	- " -
- " -	Souanke	1734	52	83	188	198	220	113	80	96	232	258	166	48	15	- " -
Egypt	Alexandria	192	48	28	14	3	2	0	0	1	0	8	32	56	?	*4
- " -	Port Said	66	11	12	9	2	3	0	-	0	0	2	9	18	?	*4
- " -	Salum	119	16	7	13	1	4	0	0	-	1	17	40	20	?	*4
- " -	Ras Asir	64	8	1	7	3	-	-	0	1	-	2	32	10	?	*4
Equatorial Guinea	Bata	2185	120	119	223	280	283	77	17	19	202	431	306	108	17	Suchel (1972)
- " -	Ebebiyin	1790	36	70	148	208	196	107	46	61	221	387	207	103	12	- " -
- " -	Evinayong	2560	132	324	235	330	279	156	5	31	239	367	299	163	10	Griffiths (1972)
- " -	Malabo	1898	32	64	107	182	238	281	189	167	243	264	89	42	16	- " -
- " -	Micomeseng	1646	39	100	166	200	187	88	49	28	197	310	201	81	8	Suchel (1972)
- " -	Niefang	2112	50	99	228	264	255	126	21	42	269	369	292	97	13	Griffiths (1972)
- " -	Rio-Campo	2630	68	78	170	267	348	162	59	115	416	568	283	96	11	Suchel (1972)
Eritrea	Asmara	468	1	1	10	37	38	32	170	127	33	7	10	2	29	Griffiths (1972)
Ethiopia	Adi Ugri	566	0	1	15	31	34	64	193	161	49	7	10	1	27	- " -
- " -	Adis Ababa	1257	16	44	70	86	95	136	282	294	192	21	15	6	42	- " -
- " -	Assab	28	0	1	0	0	0	0	5	0	0	0	6	16	?	- " -
- " -	Dire Dawa	610	20	29	43	83	30	23	108	165	70	12	17	10	15	- " -
- " -	Ghinda	749	152	89	80	74	58	15	48	52	30	77	52	22	?	- " -
- " -	Harar	890	11	32	60	109	121	101	142	137	98	46	23	10	22	- " -
- " -	Jimma	1529	?	48	82	180	150	220	231	214	192	87	39	37	15	- " -
Ethiopia	Massawa	194	26	36	15	21	3	1	8	1	2	18	21	42	?	- " -
- " -	Neghelli	550	8	4	33	172	102	8	6	7	16	119	52	23	11	- " -

		rain volume and distribution [mm]														
country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
Gabon	Bitam	1746	49	72	182	191	231	101	26	37	277	297	208	75	12	Suchel (1972)
- " -	Libreville	2592	206	291	264	395	244	40	0	11	106	359	416	260	18	Griffiths (1972)
- " -	Makokou	1754	83	124	255	245	182	51	5	18	132	331	210	118	?	- " -
- " -	Medouneu	1967	155	163	235	199	160	59	4	14	168	337	301	172	?	- " -
- " -	Mekambo	1661	77	130	182	174	178	88	28	70	153	268	209	104	?	- " -
- " -	Minvoul	1529	42	79	139	155	194	122	47	55	200	263	175	58	13	Suchel (1972)
- " -	Mitzic	1842	118	110	226	207	222	46	10	14	150	346	247	146	30	Griffiths (1972)
Ghana	Accra	787	16	37	73	82	145	193	49	16	40	80	38	18	?	*4
- " -	Ada	864	7	18	72	94	174	208	57	12	61	99	47	15	?	von Gnielinski (1986)
- " -	Akuse	1118	23	46	105	128	163	180	65	39	96	131	102	40	?	- " -
- " -	Axim	2129	51	62	129	142	420	535	156	54	87	205	192	96	?	- " -
- " -	Enchi	1651	41	65	138	160	210	270	143	75	161	210	125	53	?	- " -
- " -	Ho	1421	36	78	139	145	177	183	111	83	149	191	79	50	?	- " -
- " -	Kete Krachi	1404	19	37	82	127	167	192	158	124	223	185	68	22	?	- " -
- " -	Kintampo	1567	8	40	102	160	186	239	144	117	277	213	68	13	35	Griffiths (1972)
- " -	Kumasi	1481	17	59	137	145	182	234	126	74	176	202	98	31	?	von Gnielinski (1986)
- " -	Navrongo	1073	2	4	19	50	116	126	190	263	231	63	7	2	?	- " -
- " -	Takoradi	1186	33	37	80	95	245	280	89	36	50	120	83	38	?	- " -
- " -	Tamale	1053	2	9	51	88	121	132	128	189	217	98	13	5	?	- " -
- " -	Wa	1111	5	10	42	75	132	145	144	215	234	85	19	5	?	- " -
- " -	Wenchi	1354	8	42	97	150	178	204	93	69	200	219	75	19	?	- " -
- " -	Yendi	1186	2	7	42	95	133	146	153	188	259	132	21	8	?	- " -

country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
		rain volume and distribution [mm]														
Guinea	Beyla	4099	50	147	293	360	631	555	392	490	495	290	274	122	29	Griffiths (1972)
- “ -	Conakry	4296	1	2	5	17	154	564	1321	1057	713	330	122	10	23	- ” -
- “ -	Kouroussa	1504	0	5	20	63	95	205	264	331	339	152	25	5	27	- ” -
- “ -	Mamou	1963	5	8	23	101	180	236	301	439	368	234	58	10	34	- ” -
Ivory Coast	Abidjan	2144	26	42	120	169	366	608	200	34	55	225	188	111	?	*4
- “ -	Bouake	1210	13	46	92	140	154	135	99	108	225	140	35	23	32	Griffiths (1972)
- “ -	Ferkessedougou	1337	5	25	41	81	149	152	185	305	238	118	30	8	28	- ” -
- “ -	Sassandra	1503	25	28	65	102	306	500	122	25	32	78	125	95	?	- ” -
- “ -	Tabou	2353	38	70	100	119	412	579	177	99	198	222	222	117	?	- ” -
Kenya	Equator	1222	33	34	72	168	142	123	163	205	111	53	63	55	25	- “ -
- “ -	Garissa	298	10	6	27	59	16	5	1	6	6	21	77	64	?	- ” -
- “ -	Kisumu	1278	57	70	160	195	177	101	68	96	79	64	106	105	32	- ” -
- “ -	Magadi	398	32	43	66	89	55	8	1	3	5	15	34	47	?	- ” -
- “ -	Mombasa	1191	26	15	61	200	319	112	89	65	68	83	93	60	?	*4
- “ -	Moyale	682	11	17	55	182	118	17	17	17	25	96	86	41	48	Griffiths (1972)
- “ -	Nairobi	1066	88	70	96	155	189	29	17	20	34	64	189	115	9	- ” -
- “ -	Perkerra	638	23	24	54	86	71	54	95	82	35	36	48	30	27	Sutherland & Bryan
- “ -	Port Victoria	2349	386	267	233	183	170	101	84	69	130	155	231	340	?	- ” -
- “ -	Voi	538	32	30	73	92	29	7	3	8	15	27	96	126	59	Griffiths (1972)
Lesotho	Mokhotlong	586	96	85	63	34	26	5	10	15	20	57	83	92	25	- “ -
Liberia	Monrovia	4625	51	71	120	154	442	959	797	354	720	598	237	122	?	*4
Lybia	Bengasi	265	67	41	20	4	2	0	0	0	3	18	46	64	?	- “ -
- “ -	Derna	285	63	46	25	10	8	1	1	0	2	20	43	66	?	- ” -
- “ -	Tripoli	386	81	46	28	10	5	3	1	1	10	41	66	94	?	- ” -

country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
		rain volume and distribution [mm]														
Madagascar	Ambodifototra	3599	383	444	574	454	321	344	281	188	109	85	131	285	?	Griffiths (1972)
- " -	Andapa	2043	363	339	297	181	75	84	106	102	67	60	98	271	?	- " -
- " -	Antalaha	2151	260	246	267	281	150	162	148	132	104	76	114	211	?	- " -
- " -	Antisiranana	914	276	211	187	56	8	8	6	7	5	11	28	111	?	*4
- " -	Antsirabe	1432	293	241	218	77	31	13	17	15	24	77	158	268	?	Griffiths (1972)
- " -	Betroka	847	208	134	95	27	12	11	7	6	15	33	97	202	?	- " -
- " -	Diego-Suarez	916	277	211	187	56	8	8	7	7	5	11	28	111	?	- " -
- " -	Fianarantsoa	1224	291	206	174	44	27	20	19	17	24	34	131	237	?	- " -
- " -	Fort Dauphin	1539	202	184	236	113	117	135	109	94	61	73	91	124	?	- " -
- " -	Maintirano	999	302	220	158	32	9	4	4	4	9	17	63	177	?	- " -
- " -	Majunga	1569	466	370	282	57	8	3	1	2	3	24	110	243	?	- " -
- " -	Mananjary	2795	398	370	498	245	195	230	158	136	103	79	173	210	?	- " -
- " -	Morombe	454	123	134	59	5	7	7	2	1	5	4	22	85	?	- " -
- " -	Morondava	745	228	209	117	13	7	6	1	2	7	9	17	129	?	- " -
- " -	Nossi-Be	2193	464	425	287	141	58	49	33	40	49	96	189	362	?	- " -
- " -	Tamatave	3525	420	441	528	404	303	300	257	208	134	87	184	259	?	- " -
- " -	Tananarive	1360	305	235	221	47	16	9	9	9	14	49	154	292	?	- " -
- " -	Tsihombe	491	78	90	60	19	24	31	14	8	15	15	31	106	?	- " -
- " -	Tulear	342	71	71	42	7	18	11	4	3	10	14	34	57	?	- " -
- " -	Taomasina	3299	363	393	456	386	296	284	285	203	135	95	142	261	?	- " -
- " -	Tolagnaro	1619	176	222	219	157	159	147	103	93	74	71	81	117	?	- " -
- " -	Toleary	356	89	73	39	12	16	12	5	3	10	15	27	55	?	- " -
Madeira	Funchal	513	70	71	59	37	18	4	1	2	24	68	81	78	?	- " -

		rain volume and distribution [mm]														
country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
Malawi	Blantyre	834	200	179	125	43	9	4	3	1	5	20	81	164	20	Griffiths (1972)
- " -	Karonga	1081	183	163	316	187	35	6	1	2	1	4	39	144	30	- " -
- " -	Lilongwe	845	208	207	132	37	5	1	0	2	3	5	70	175	30	- " -
- " -	Mlanje	1796	313	319	308	125	59	64	38	33	28	58	183	268	27	- " -
- " -	Mzimba	869	228	194	173	41	2	1	1	1	2	5	58	163	30	- " -
- " -	Nkhotakota	1442	287	308	371	132	35	11	6	2	3	5	58	224	30	- " -
- " -	Zomba	1367	298	270	246	72	19	13	6	8	8	24	120	283	30	- " -
Mali	Bougouni	1078	0	1	5	17	68	140	231	335	210	61	10	0	34	- " -
- " -	Kayes	746	0	0	1	1	23	96	170	244	160	46	5	0	34	- " -
- " -	Mopti	543	0	0	1	5	23	56	147	198	94	18	1	0	34	- " -
Marocco	Adrar	18	0	1	2	0	1	0	1	1	1	5	5	1	15	- " -
- " -	Agadir	224	48	32	24	16	5	1	-	0	6	22	29	41	?	*4
- " -	Bouarfa	181	11	13	21	19	12	5	1	8	21	24	25	21	13	- " -
- " -	Casablanca	511	80	68	68	37	22	5	-	1	3	25	77	125	?	*4
- " -	Ft. Flatters	29	7	3	2	4	1	1	0	0	1	1	5	4	28	Griffiths (1972)
- " -	Marakesh	235	24	27	39	26	16	9	2	5	11	20	35	21	34	- " -
- " -	Melilla	451	84	56	66	47	29	6	1	1	18	50	47	46	?	*4
- " -	Mogador	286	39	37	33	26	11	4	0	0	5	25	54	52	24	- " -
- " -	Safi	327	44	35	40	24	13	5	0	0	6	40	56	64	24	- " -
- " -	Tanger	887	118	102	112	85	39	15	1	2	25	108	136	144	?	*4
- " -	Tanger	895	114	106	120	90	42	15	1	1	23	99	147	137	?	- " -
- " -	Tidjikja	147	0	7	1	0	7	15	23	53	25	10	5	1	47	Griffiths (1972)
- " -	Tin Zaouaten	67	0	1	1	0	1	1	0	37	26	0	0	0	64	- " -
- " -	Tindouf	33	0	0	6	0	0	0	1	11	7	4	1	3	32	- " -
- " -	V. Cisneros	80	1	1	1	1	3	0	1	5	35	2	5	25	77	- " -
Mauritania	Nouadhibou	29	2	1	1	2	0	1	0	3	6	6	5	2	?	*4

		rain volume and distribution [mm]														
country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
Mauritius	Port Louis	1286	216	198	221	127	97	66	58	64	35	41	46	117	?	*4
Mocambique	Beira	1429	265	225	244	105	58	42	37	30	27	29	133	234	30	- " -
- " -	Fingoe	1062	244	259	168	35	4	8	5	4	1	8	94	232	30	- " -
- " -	Inhambane	918	134	146	107	71	57	63	45	30	31	29	80	125	?	*4
- " -	Loreno Marques	769	130	124	97	64	28	27	13	13	38	46	86	103	30	Griffiths (1972)
- " -	Maputo	769	130	124	97	64	28	27	13	13	38	46	86	103	?	*4
- " -	Mossuril	838	214	205	146	102	24	37	18	15	9	6	28	34	30	Griffiths (1972)
- " -	Nova Freixo	890	246	205	146	25	7	2	1	2	5	15	50	186	30	- " -
- " -	Pafuri	379	90	68	39	19	4	8	1	0	8	14	49	79	15	- " -
- " -	Panda	694	116	136	74	46	34	25	19	12	26	31	67	108	30	- " -
- " -	Tete	604	145	167	81	13	2	4	2	2	2	4	52	130	20	- " -
Namibia	Keetmanshoop	147	22	30	35	13	5	2	1	1	2	5	14	17	30	- " -
- " -	Swakopmund	17	2	3	4	2	1	0	0	1	1	1	1	1	?	*4
- " -	Tsumeb	553	119	139	79	40	6	0	0	0	1	19	53	97	30	Griffiths (1972)
- " -	Windhoek	370	77	73	81	38	6	1	1	0	1	12	33	47	30	- " -
Niger	Niamey	584	0	0	0	7	36	87	138	206	88	21	1	0	37	- " -
- " -	Zinder	529	0	0	0	1	23	48	160	218	69	10	0	0	19	- " -
Nigeria	Agbor	1887	15	41	117	165	213	269	272	183	328	218	53	13	46	- " -
- " -	Ahuji	1246	0	2	30	86	135	168	234	232	226	102	23	8	15	- " -
- " -	Bida	1173	5	5	32	66	147	180	191	201	239	99	8	0	25	- " -
- " -	Brass	3437	76	104	165	251	411	665	211	297	528	432	206	91	26	- " -
- " -	Calabar	3076	38	76	157	218	312	412	455	419	422	328	191	48	57	Suchel (1972)
- " -	Dashen	1172	0	4	31	74	136	201	207	141	232	134	9	3	8	- " -
- " -	Donga	1398	4	5	31	93	197	236	172	164	268	211	16	1	10	- " -
- " -	Gembu	1825	5	38	138	159	220	227	245	186	274	232	95	6	10	- " -
- " -	Kaduna	1328	0	2	15	69	142	216	224	279	292	84	5	0	45	Griffiths (1972)

		rain volume and distribution [mm]														
country	**site**	**annual**	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**	**record in years**	literature
Nigeria	Kafinsoli	829	0	0	0	8	56	97	206	287	145	15	0	15	26	- " -
- " -	Katisina	741	0	0	0	5	56	84	185	274	127	10	0	0	37	- " -
- " -	Lagos	1831	28	45	102	150	269	458	279	63	140	204	68	25	?	- " -
- " -	Lupwe	1730	9	14	66	141	249	279	149	130	305	339	46	3	11	Suchel (1972)
- " -	Maigana	1134	0	2	10	38	130	150	218	335	213	38	0	0	35	Griffiths (1972)
- " -	Mbagbera	1786	15	20	86	117	251	282	147	182	315	305	58	8	15	Suchel (1972)
- " -	Ndian	6202	119	142	290	452	513	864	955	947	823	584	353	160	10	Griffiths (1972)
- " -	Okene	1274	7	18	71	107	163	188	165	170	190	157	18	20	21	- " -
- " -	Oleh	2892	30	64	157	244	338	391	411	302	513	335	89	18	10	- " -
- " -	Ouro-Boki	777	0	0	5	45	72	133	133	168	167	54	0	0	7	Suchel (1972)
- " -	Serti	1815	1	2	50	95	191	298	266	258	309	267	67	11	6	- " -
- " -	War-War	1738	10	25	127	164	171	216	212	198	294	230	71	20	10	- " -
- " -	Yola	991	0	0	8	48	125	157	173	196	198	81	5	0	35	- " -
Sao Tom	Sao Tom	885	81	84	131	122	113	19	0	1	17	110	99	108	?	*4
Senegal	Dakar	540	0	0	0	0	1	17	88	254	132	38	2	8	32	Griffiths (1972)
- " -	Kaolack	875	0	0	0	1	8	61	165	307	268	63	2	0	35	- " -
- " -	St. Louis	388	0	5	0	1	1	12	55	170	111	28	5	0	35	- " -
- " -	Tambacounda	876	0	0	0	1	20	130	172	257	224	71	1	0	35	- " -
- " -	Ziguinchor	1625	0	1	0	0	11	143	407	558	338	159	8	0	30	- " -
Sierra Leone	Daru	2524	10	36	101	152	259	287	297	371	416	336	203	56	22	- " -
- " -	Freetown	4433	8	6	28	68	214	522	1190	1078	800	333	148	38	30	- " -

		rain volume and distribution [mm]														
country	**site**	**annual**	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**	**record in years**	literature
Somalia	Bender Cassim	18	0	0	1	2	3	0	0	0	0	2	7	3	?	- " -
- " -	Berbera	52	8	2	5	12	8	1	1	2	1	2	5	5	?	- " -
- " -	Chisimaio	347	1	1	21	23	92	96	52	17	13	20	7	4	?	*4
- " -	Dijbouti	129	10	13	25	12	5	1	2	8	8	10	22	13	?	Griffiths (1972)
- " -	Erigavo	434	18	13	33	38	81	63	10	41	114	8	13	2	?	- " -
- " -	Galcaio	149	0	3	1	24	60	2	0	2	1	41	14	1	?	- " -
- " -	Hargeisa	416	3	8	25	61	61	58	42	81	58	10	8	1	?	- " -
- " -	Lugh Ferrandi	310	2	4	28	113	40	1	3	0	1	47	56	15	?	- " -
- " -	Mogadischu	399	1	0	9	58	56	82	58	40	23	27	36	9	?	*4
- " -	Obbia	199	9	2	26	21	46	-	0	0	1	24	49	21	?	- " -
- " -	Randa	271	18	4	2	46	6	6	23	32	31	12	30	61	?	Griffiths (1972)
Soudan	Juba	982	5	10	43	107	157	116	136	154	105	101	35	13	30	Griffiths (1972)
- " -	Malakal	785	0	0	3	24	95	115	153	167	144	77	6	1	30	- " -
- " -	Port Sudan	112	4	1	1	1	2	1	9	3	1	12	52	25	?	- " -
- " -	Raga	1146	1	1	15	56	150	165	223	254	192	78	10	1	?	- " -
- " -	Roseires	776	0	0	1	11	58	126	166	221	152	36	5	0	30	- " -
- " -	Torit	995	5	21	46	102	132	122	157	142	113	99	41	15	?	- " -
- " -	Wau	1145	0	4	20	69	132	170	199	234	179	130	8	0	30	- " -
- " -	Yubo	1451	5	23	63	102	187	220	169	212	234	170	51	15	?	- " -
South Africa	Alexander Bay	40	1	1	6	4	5	3	8	3	4	2	2	1	?	*4
- " -	Cape Town	506	12	8	17	47	84	82	85	71	43	29	17	11	30	Griffiths (1972)
- " -	Durban	1003	118	128	113	91	59	36	26	39	63	85	121	124	?	*4
- " -	East London	860	69	78	99	69	48	35	32	42	97	111	93	87	?	- " -
- " -	Estcourt	725	108	115	89	47	23	7	13	15	30	63	98	117	30	Griffiths (1972)
- " -	Kaap Agulhas	498	20	24	33	44	56	57	58	57	51	43	30	25	?	*4
- " -	Messina	340	78	55	40	15	4	4	3	1	7	21	42	70	30	Griffiths (1972)

		rain volume and distribution [mm]														
country	**site**	**annual**	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**	**record in years**	literature
South Africa	Port Elizabeth	632	37	33	48	44	65	58	56	59	68	61	61	42	?	*4
Swaziland	Big Bend	579	94	74	62	37	30	12	10	12	30	52	81	85	20	Swaziland (1990)
- " -	Havelock	1340	208	255	177	96	43	24	26	36	79	152	6	238	20	- " -
- " -	Homestead	676	121	111	81	40	18	12	12	12	30	54	91	94	20	- " -
- " -	Kubuta	838	131	119	85	57	24	15	13	19	45	85	120	125	20	- " -
- " -	Lavumisa	566	90	78	55	41	24	14	10	15	32	54	72	81	20	- " -
- " -	Matsapha	931	145	140	106	65	18	8	12	24	56	108	132	117	20	- " -
- " -	Mbabane	1398	250	214	171	78	34	19	22	30	64	129	177	210	20	- " -
- " -	Nhlangano	801	131	116	95	53	21	15	14	17	40	72	110	117	20	- " -
Tanzania	Daressalaam	1179	71	64	120	280	303	35	33	25	29	49	79	91	70	Griffiths (1972)
- " -	Kigoma	977	134	118	155	151	51	6	2	3	15	61	130	151	29	- " -
- " -	Lindi	897	145	117	170	173	38	10	8	5	13	15	53	150	?	*4
- " -	Mbeya	883	199	165	161	116	17	1	1	1	3	15	52	152	31	Griffiths (1972)
- " -	Morogoro	892	94	104	167	208	96	27	15	10	17	27	54	73	57	- " -
- " -	Mtwara	1159	218	151	165	197	51	11	15	11	65	24	33	218	13	- " -
- " -	Tabora	892	132	129	166	134	27	2	0	1	7	17	103	174	69	- " -
- " -	Wete/ Pemba	1964	63	50	178	413	486	147	73	45	31	104	223	151	?	*4
Tunisia	Djerba	207	28	19	22	11	8	1	0	1	13	34	43	27	50	Griffiths (1972)
- " -	Bone	787	143	105	73	57	37	15	3	7	31	75	108	133	?	*4
- " -	Gabes	175	22	17	21	10	9	1	0	2	14	30	34	15	?	- " -
- " -	Susa	327	43	34	30	22	18	6	1	5	50	43	37	38	?	- " -
- " -	Tunis	415	57	49	44	37	23	12	3	4	27	47	50	62	?	- " -

country	site	annual	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	record in years	literature
		rain volume and distribution [mm]														
Uganda	Entebbe	1585	100	86	141	280	257	98	65	91	87	108	146	126	?	Griffiths (1972)
- " -	Gulu	1470	12	43	89	173	172	148	166	231	127	165	97	47	52	- " -
- " -	Kabale	986	61	91	114	136	92	26	20	55	95	98	107	91	45	- " -
Zaire	Bambesa	1782	34	73	135	199	201	152	184	205	209	220	128	42	30	- " -
- " -	Bongabo	1710	38	63	135	167	189	180	186	250	207	109	130	56	20	- " -
- " -	Eala	1749	107	125	144	155	149	115	80	139	190	203	201	141	30	- " -
- " -	Gandajika	1395	157	131	181	174	51	4	6	35	100	139	200	217	30	- " -
- " -	Kamina	1343	201	193	202	119	18	1	1	5	38	121	191	253	20	- " -
- " -	Kinshasa	1378	128	139	181	209	134	5	1	4	33	137	236	171	30	- " -
- " -	Lubumbashi	1244	256	264	210	53	3	0	0	0	3	27	166	262	30	- " -
- " -	Luki	1136	130	152	171	194	74	1	0	2	11	54	197	150	30	- " -
- " -	Luluabourg	1572	128	123	204	177	89	16	17	50	118	165	238	247	20	- " -
- " -	Nioka	1304	25	63	100	137	124	109	120	175	183	131	85	52	30	- " -
- " -	Santo Antonio	1872	113	105	186	233	229	89	21	36	146	398	174	142	?	*4
- " -	Tshibinda	1833	165	175	195	215	164	56	34	57	145	214	201	212	30	Griffiths (1972)
Zaire	Uele	1787	34	73	135	199	201	152	184	205	209	220	128	47	30	- " -
- " -	Yangambi	1828	85	99	148	150	177	126	146	170	180	241	180	126	30	- " -
Zambia	Chipata	1020	256	236	164	45	5	1	0	1	1	9	94	208	30	- " -
- " -	Kasama	1245	267	251	259	69	8	0	0	1	1	17	135	237	30	- " -
- " -	Kasempa	1139	273	223	161	35	3	0	0	0	3	34	141	266	30	- " -
- " -	Livingstone	779	186	175	101	28	5	0	0	0	2	26	92	164	30	- " -
- " -	Lusaka	837	218	196	106	21	4	0	0	0	0	15	91	186	30	- " -
- " -	Mongu	972	217	211	145	37	1	0	0	0	2	35	102	222	30	- " -
- " -	Mwinilunga	1342	225	221	227	95	8	1	0	1	15	92	196	261	30	- " -
- " -	Ndola	1169	289	252	184	39	5	0	0	1	1	19	130	249	30	- " -
- " -	Beitbridge	338	85	51	40	17	4	5	2	1	7	20	42	64	30	- " -

		rain volume and distribution [mm]														
country	**site**	**annual**	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**	**record in years**	literature
Zimbabwe	Bulawayo	588	134	112	65	21	9	3	0	1	5	25	89	124	30	- “ -
- “ -	Harare	867	213	173	101	39	11	5	1	3	5	30	100	186	30	- ” -
- “ -	Umtali	756	171	134	99	26	10	9	7	11	10	27	91	161	30	- ” -

*1 mean annual rain volume 1982–1991: 1024 mm
*2 mean annual rain volume 1982–1991: 1042 mm
*3 maxima
*4 Bundesamt für Seeschifffahrt und Hydrographie (1991 a and b; 1992)

Annex 1.7 Estimation of the erosivity of the 10 year storm ($EI_{30}/10$)

Data for the $EI_{30}/10$ will be deficient in many cases. For some areas close correlations exist between single storm volume (P_i [mm]) and single storm erosivity (EI_{30i} [N/h]). From these correlations an estimate of the $EI_{30}/10$ can be made if the volume of the 10 year storm is known (c.f. Figure 75-2). However, the regressions in Figure 17-1Annex show that there are rather large differences between climatic zones which recommend a cautious use of such regressions. The regressions in Figure 17-1Annex are mean relationships of several regressions from Cameroon (Bresch, 1993) and Zambia (Pauwelyn et al., 1988):

coast (Cameroon)
Douala: $EI_{30i} = (1.45 + 0.095{*}P_i)2$, $r^2 = 0.75$, $n = 830$

inland (Cameroon)
Yoko: $EI_{30i} = (0.14 + 0.139{*}P_i)^2$, $r^2 = 0.80$, $n = 352$
Batouri: $EI_{30i} = (0.37 + 0.133{*}P_i)^2$, $r^2 = 0.74$, $n = 424$
Yaoundé: $EI_{30i} = (0.07 + 0.153{*}P_i)^2$, $r^2 = 0.81$, $n = 553$

highland (Cameroon)
Bamenda: $EI_{30i} = (-0.08 + 0.152{*}P_i)^2$, $r^2 = 0.82$, $n = 423$
Nkoundja: $EI_{30i} = (0.02 + 0.148{*}P_i)^2$, $r^2 = 0.73$, $n = 469$
north (Cameroon)
Maroua: $EI_{30i} = (0.08 + 0.156{*}P_i)^2$, $r^2 = 0.82$, $n = 252$
Garoua: $EI_{30i} = (0.13 + 0.150{*}P_i)^2$, $r^2 = 0.84$, $n = 132$
Poli: $EI_{30i} = (0.26 + 0.149{*}P_i)^2$, $r^2 = 0.83$, $n = 175$
Ngaoundéré: $EI_{30i} = (0.20 + 0.151{*}P_i)^2$, $r^2 = 0.78$, $n = 573$

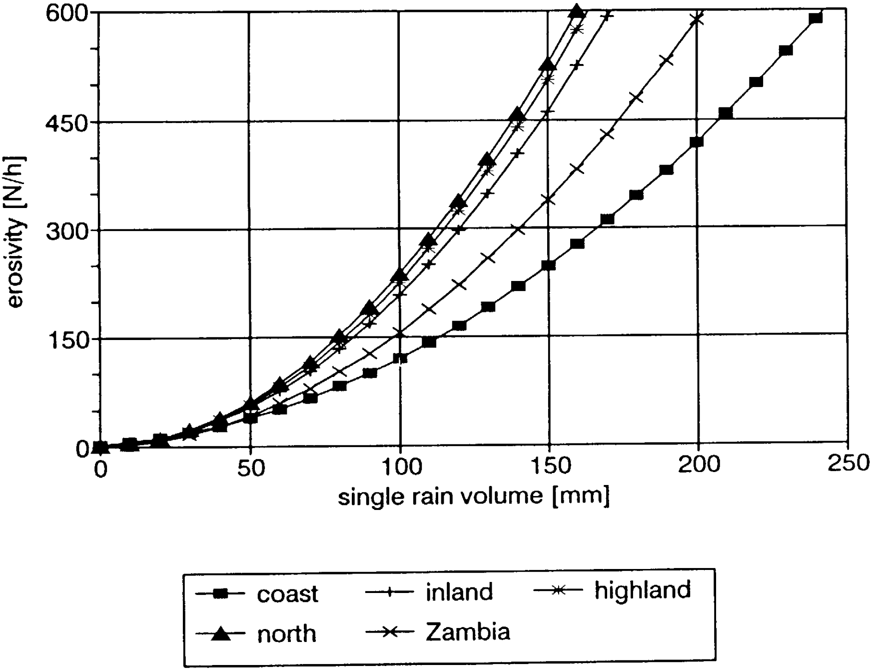
For Zambia a regression was given by Pauwelyn et al. (1988):

$$EI_{30i} = 0.0236 * P_i^{1.91},\ r^2 = 0.71,\ n = 2348$$

The curve for the coast in Cameroon should give reasonable estimates for sites along the West African Coast with pronounced influence of the monsoon. The inland curve should be applicable for the Central

African zone between 1000 and 1500 mm of rainfall. The regression for Northern Cameroon can probably extended to further areas of West Africa in the zone between 600 to 1000 mm.

Figure 17-1 Annex: Single storm erosivity as related to single storm volume for the coast, inland, highland and northern areas of Cameroon and for Zambia



Annex 2 Slope length and gradient

Annex 2.1 Device for measuring slope length and gradient

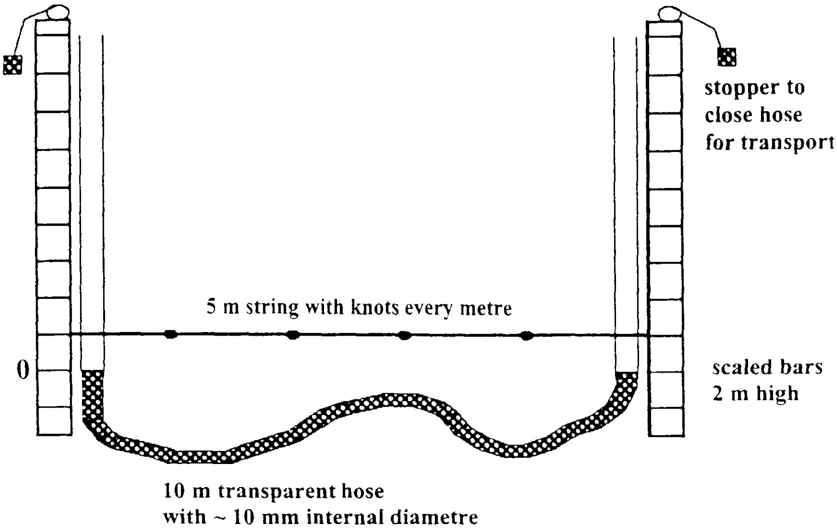


Figure 21-1 Annex: Water level for measurement of slope-length and gradient

The two scaled bars are placed on level ground and the hose is filled with water up to the zero mark on the bars. The stoppers need to be taken off the hose ends before starting the measurement. Make sure that no air bubbles are in the hose! If the hose diameter becomes too small, it is difficult to evacuate air bubbles from the hose. A small quantity of household detergent may help in this case. For the measurement, one person keeps one of the bars upright while a second person moves down-slope until the string between the bars is completely streched out. The distance between the two bars should now be 5 m. The vertical distance between the two bars can be read on the scale. If, for example, the vertical distance is 40 cm, the water in the hose of the lower bar should be beside the 20 cm mark whereas on the higher bar it is 20 cm below the zero mark. The gradient (s) can be calculated by:

$$s = \frac{0.2\ \text{m} * 2}{5\ \text{m}} * 100 = 8\% \qquad (48)$$

For practical purposes it is easier to double the scale on the bars (e.g. 0.2 m = 0.4 m) in order to receive the vertical distance right away.

Annex 2.2 Conversion of slope gradient in degrees to percent

gradient			
degrees	[%]	degrees	[%]
1	2	36	73
2	3	37	75
3	5	38	78
4	7	39	81
5	9	40	84
6	11	41	87
7	12	42	90
8	14	43	93
9	16	44	97
10	18	45	100
11	19	46	104
12	21	47	107
13	23	48	111
14	25	49	115
15	27	50	119
16	29	51	123
17	31	52	128
18	32	53	133
19	34	54	138
20	36	55	143
21	38	56	148
22	40	57	154
23	42	58	160
24	45	59	166
25	47	60	173
26	49	61	180
27	51	62	188
28	53	63	196
29	55	64	205
30	58	65	214
31	60	66	225
32	62	67	236
33	65	68	248
34	67	69	261
35	70	70	275

Annex 3 Cover and management factor

Annex 3.1 Number of day in the year and corresponding date.

date/ no. of day in the year											
01-Jan	1	01-Mar	60	01-May	121	01-Jul	182	01-Sep	244	01-Nov	305
02-Jan	2	02-Mar	61	02-May	122	02-Jul	183	02-Sep	245	02-Nov	306
03-Jan	3	03-Mar	62	03-May	123	03-Jul	184	03-Sep	246	03-Nov	307
04-Jan	4	04-Mar	63	04-May	124	04-Jul	185	04-Sep	247	04-Nov	308
05-Jan	5	05-Mar	64	05-May	125	05-Jul	186	05-Sep	248	05-Nov	309
06-Jan	6	06-Mar	65	06-May	126	06-Jul	187	06-Sep	249	06-Nov	310
07-Jan	7	07-Mar	66	07-May	127	07-Jul	188	07-Sep	250	07-Nov	311
08-Jan	8	08-Mar	67	08-May	128	08-Jul	189	08-Sep	251	08-Nov	312
09-Jan	9	09-Mar	68	09-May	129	09-Jul	190	09-Sep	252	09-Nov	313
10-Jan	10	10-Mar	69	10-May	130	10-Jul	191	10-Sep	253	10-Nov	314
11-Jan	11	11-Mar	70	11-May	131	11-Jul	192	11-Sep	254	11-Nov	315
12-Jan	12	12-Mar	71	12-May	132	12-Jul	193	12-Sep	255	12-Nov	316
13-Jan	13	13-Mar	72	13-May	133	13-Jul	194	13-Sep	256	13-Nov	317
14-Jan	14	14-Mar	73	14-May	134	14-Jul	195	14-Sep	257	14-Nov	318
15-Jan	15	15-Mar	74	15-May	135	15-Jul	196	15-Sep	258	15-Nov	319
16-Jan	16	16-Mar	75	16-May	136	16-Jul	197	16-Sep	259	16-Nov	320
17-Jan	17	17-Mar	76	17-May	137	17-Jul	198	17-Sep	260	17-Nov	321
18-Jan	18	18-Mar	77	18-May	138	18-Jul	199	18-Sep	261	18-Nov	322
19-Jan	19	19-Mar	78	19-May	139	19-Jul	200	19-Sep	262	19-Nov	323
20-Jan	20	20-Mar	79	20-May	140	20-Jul	201	20-Sep	263	20-Nov	324
21-Jan	21	21-Mar	80	21-May	141	21-Jul	202	21-Sep	264	21-Nov	325
22-Jan	22	22-Mar	81	22-May	142	22-Jul	203	22-Sep	265	22-Nov	326
23-Jan	23	23-Mar	82	23-May	143	23-Jul	204	23-Sep	266	23-Nov	327
24-Jan	24	24-Mar	83	24-May	144	24-Jul	205	24-Sep	267	24-Nov	328
25-Jan	25	25-Mar	84	25-May	145	25-Jul	206	25-Sep	268	25-Nov	329
26-Jan	26	26-Mar	85	26-May	146	26-Jul	207	26-Sep	269	26-Nov	330
27-Jan	27	27-Mar	86	27-May	147	27-Jul	208	27-Sep	270	27-Nov	331
28-Jan	28	28-Mar	87	28-May	148	28-Jul	209	28-Sep	271	28-Nov	332
29-Jan	29	29-Mar	88	29-May	149	29-Jul	210	29-Sep	272	29-Nov	333
30-Jan	30	30-Mar	89	30-May	150	30-Jul	211	30-Sep	273	30-Nov	334
31-Jan	31	31-Mar	90	31-May	151	31-Jul	212	01-Oct	274	01-Dec	335
01-Feb	32	01-Apr	91	01-Jun	152	01-Aug	213	02-Oct	275	02-Dec	336
02-Feb	33	02-Apr	92	02-Jun	153	02-Aug	214	03-Oct	276	03-Dec	337
03-Feb	34	03-Apr	93	03-Jun	154	03-Aug	215	04-Oct	277	04-Dec	338
04-Feb	35	04-Apr	94	04-Jun	155	04-Aug	216	05-Oct	278	05-Dec	339
05-Feb	36	05-Apr	95	05-Jun	156	05-Aug	217	06-Oct	279	06-Dec	340
06-Feb	37	06-Apr	96	06-Jun	157	06-Aug	218	07-Oct	280	07-Dec	341
07-Feb	38	07-Apr	97	07-Jun	158	07-Aug	219	08-Oct	281	08-Dec	342
08-Feb	39	08-Apr	98	08-Jun	159	08-Aug	220	09-Oct	282	09-Dec	343
09-Feb	40	09-Apr	99	09-Jun	160	09-Aug	221	10-Oct	283	10-Dec	344
10-Feb	41	10-Apr	100	10-Jun	161	10-Aug	222	11-Oct	284	11-Dec	345
11-Feb	42	11-Apr	101	11-Jun	162	11-Aug	223	12-Oct	285	12-Dec	346
12-Feb	43	12-Apr	102	12-Jun	163	12-Aug	224	13-Oct	286	13-Dec	347
13-Feb	44	13-Apr	103	13-Jun	164	13-Aug	225	14-Oct	287	14-Dec	348
14-Feb	45	14-Apr	104	14-Jun	165	14-Aug	226	15-Oct	288	15-Dec	349
15-Feb	46	15-Apr	105	15-Jun	166	15-Aug	227	16-Oct	289	16-Dec	350
16-Feb	47	16-Apr	106	16-Jun	167	16-Aug	228	17-Oct	290	17-Dec	351
17-Feb	48	17-Apr	107	17-Jun	168	17-Aug	229	18-Oct	291	18-Dec	352
18-Feb	49	18-Apr	108	18-Jun	169	18-Aug	230	19-Oct	292	19-Dec	353
19-Feb	50	19-Apr	109	19-Jun	170	19-Aug	231	20-Oct	293	20-Dec	354
20-Feb	51	20-Apr	110	20-Jun	171	20-Aug	232	21-Oct	294	21-Dec	355
21-Feb	52	21-Apr	111	21-Jun	172	21-Aug	233	22-Oct	295	22-Dec	356
22-Feb	53	22-Apr	112	22-Jun	173	22-Aug	234	23-Oct	296	23-Dec	357
23-Feb	54	23-Apr	113	23-Jun	174	23-Aug	235	24-Oct	297	24-Dec	358
24-Feb	55	24-Apr	114	24-Jun	175	24-Aug	236	25-Oct	298	25-Dec	359
25-Feb	56	25-Apr	115	25-Jun	176	25-Aug	237	26-Oct	299	26-Dec	360
26-Feb	57	26-Apr	116	26-Jun	177	26-Aug	238	27-Oct	300	27-Dec	361
27-Feb	58	27-Apr	117	27-Jun	178	27-Aug	239	28-Oct	301	28-Dec	362
28-Feb	59	28-Apr	118	28-Jun	179	28-Aug	240	29-Oct	302	29-Dec	363
		29-Apr	119	29-Jun	180	29-Aug	241	30-Oct	303	30-Dec	364
		30-Apr	120	30-Jun	181	30-Aug	242	31-Oct	304	31-Dec	365
						31-Aug	243				

Annex 3.2 Field methods for the measurement of mulch cover and canopy cover

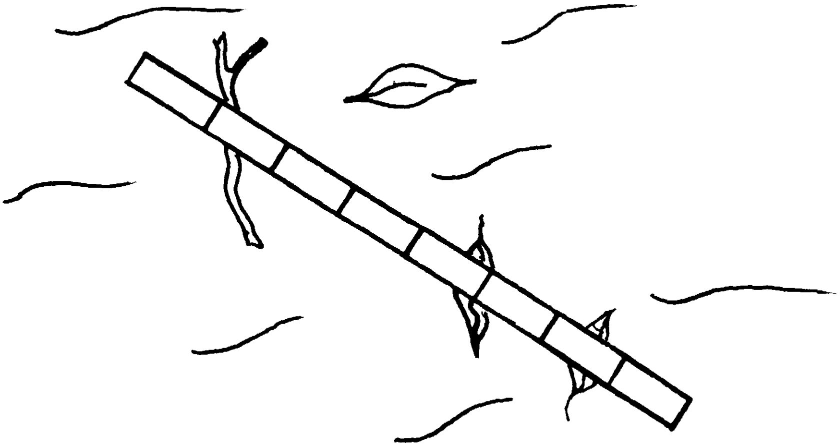
1. Mulch cover measurement by the meterstick method

Put a meterstick on the ground and count on one side all the cm-marks which are in contact with mulch material (Figure 32-1Annex). The mulch cover (MC) is given by:

$$MC\ (\%) = \frac{\text{number of cm marks in contact}}{\text{length of meterstick (cm)}} * 100 \qquad (49)$$

Example: 38 cm-marks are in contact with one side of a 2 m long meterstick. MC is 38/200 = 19 %.

Figure 32-1 Annex: Mesurement of mulch cover by the meterstick method

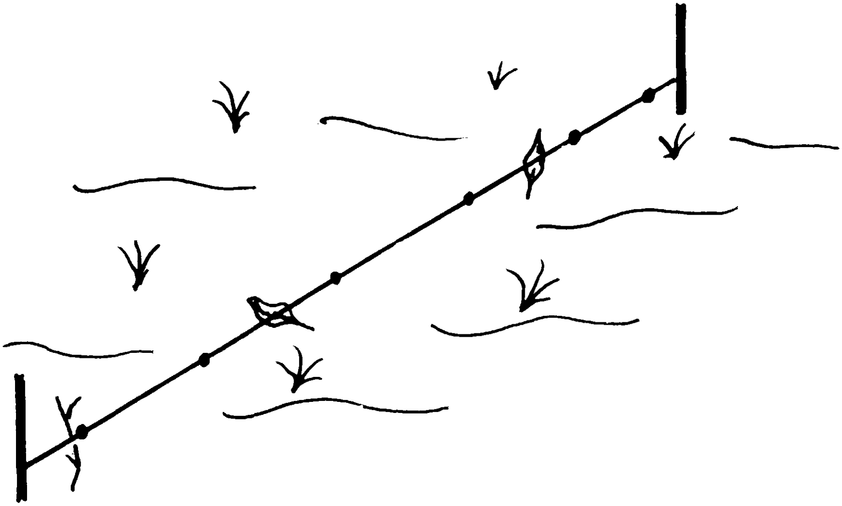


This method is well suited for small plots. The number of measurements depends on the uniformness of the cover. In own measurements 12 replications with a 2 m long meterstick were taken on 500 m^2 plots equivalent to a random 24 m transsect. It is important that the stick is randomly placed in the plot. Random placement can be assured by throwing the meterstick into the plot.

2. Mulch cover measurement by the cord and knot method

This method is similar to the meterstick method. Marks or knots are attached to a 10 to 20 m long cord which is streched out on a field (Figure 32-2Annex). The number of knots in contact with mulch material (*100) divided by the total number of knots on the cord gives the percent mulch cover.

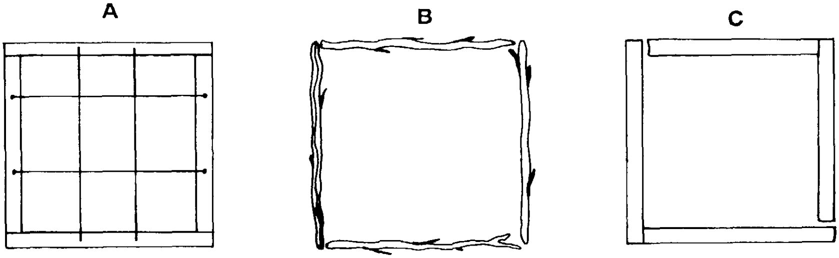
Figure 32-2 Annex: Cord and knot method for cover measurement



3. Mulch and canopy cover measurement by visual estimation

Form a quadrat of 1 x 1 m using 4 wooden sticks of 1 m length or two foldable 2 m-sticks to mark out a 1 m^2 area in the field (Figure 32-3Annex). If the observed area is well delimitated, cover is easier to estimate than on an undefined area. The size of the area can be smaller than 1 m^2 but should not be larger because visual estimation becomes more difficult with increasing size of the area. Cover is estimated visually in the delimitated area. Calibration of the eye can be facilitated by the examples in Figure 32-4Annex. Estimations become also easier if wires are streched at regular distances on the wooden frame. Estimations are reasonably precise after some routine.

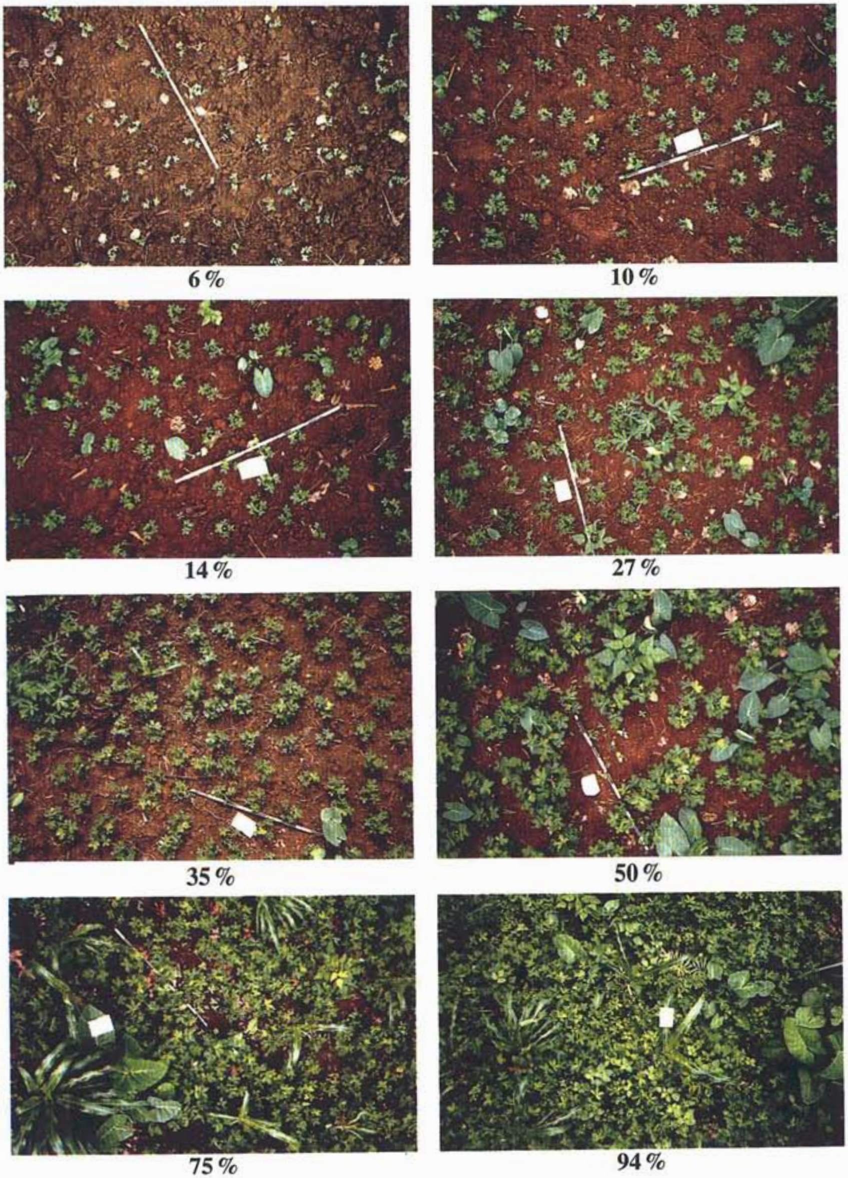
Figure 32-3 Annex: Marking out an area with different devices (a. wooden frame with wire-net, b. twigs, c. two 2 m-sticks)



4. Measurement of canopy and mulch cover by a sighting frame

This method was proposed by Elwell & Wendelaar (1977). Ten hollow pipes are attached to a frame (Figure 32-5Annex). By peering through one of the pipes a small area can be observed. Mulch or canopy cover in this area is either rated as 'yes' or 'no' or rated on a scale between 1 and 10. In the first case, the number of points observed with cover (= yes) divided by the number of all points observed gives the coverage.

Figure 32-4 Annex: Selected coverages for the calibration of the eye (the stick in the pictures is 1 m long)



6 %

10 %

14 %

27 %

35 %

50 %

75 %

94 %

Figure 32-5 Annex: Sighting frame for measurement of canopy and mulch cover

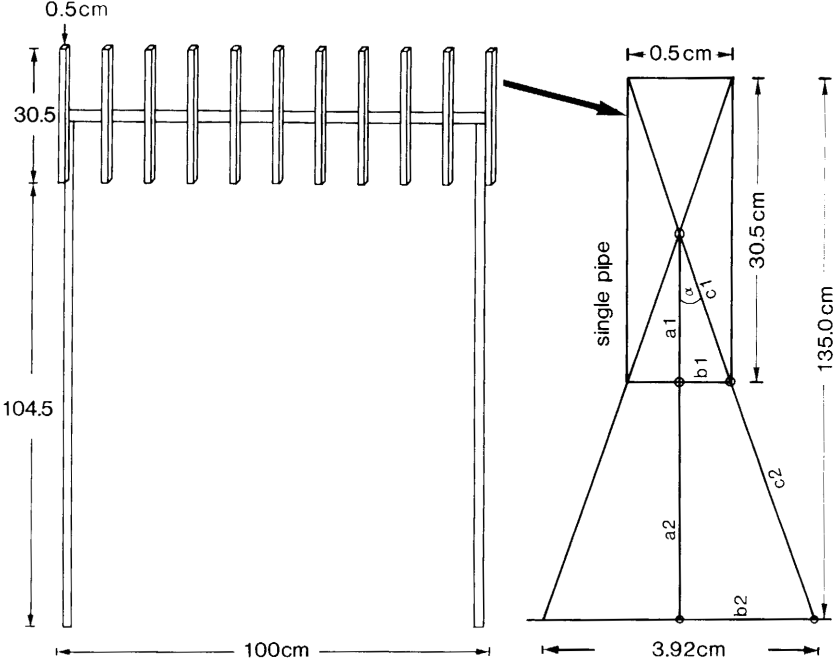


Figure 32-6 Annex: Observation error as influenced by plant height

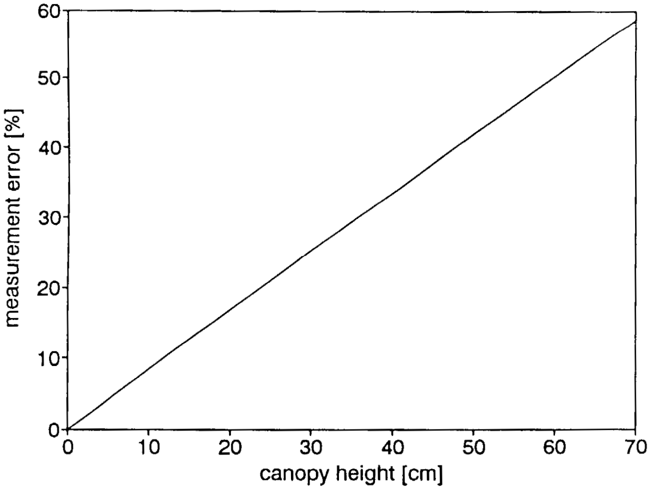
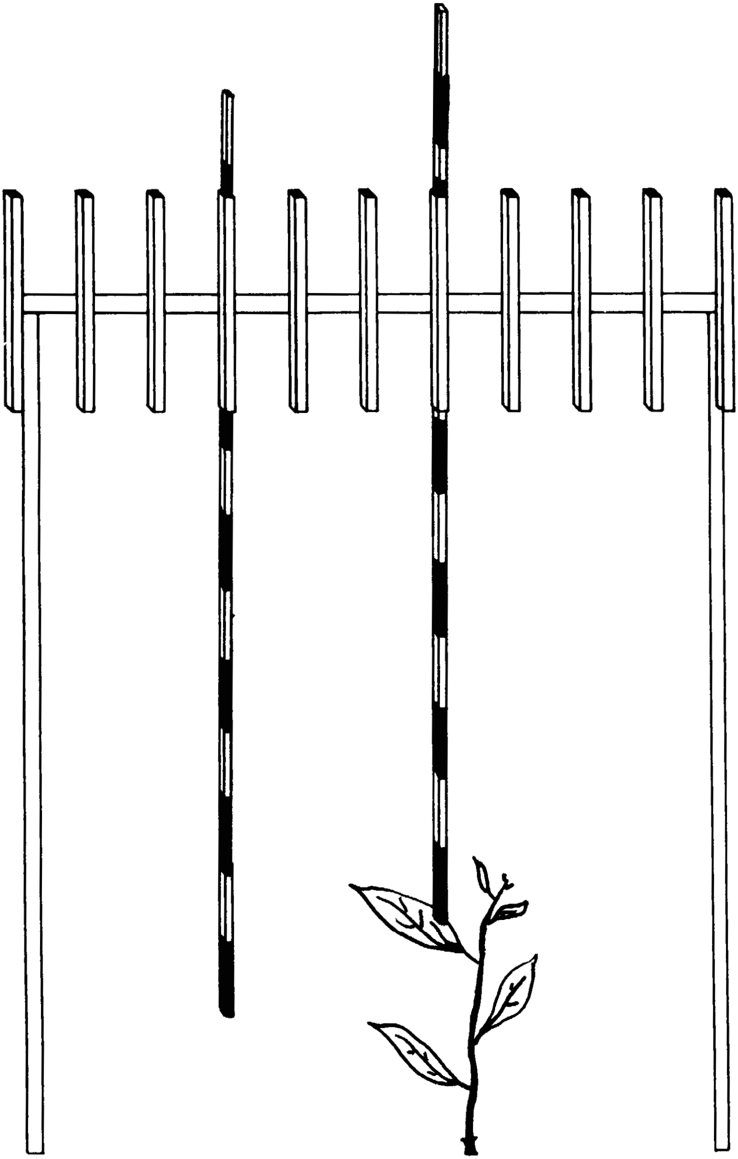


Figure 32-7 Annex: Modified sighting frame for errorless coverage and cover height measurements

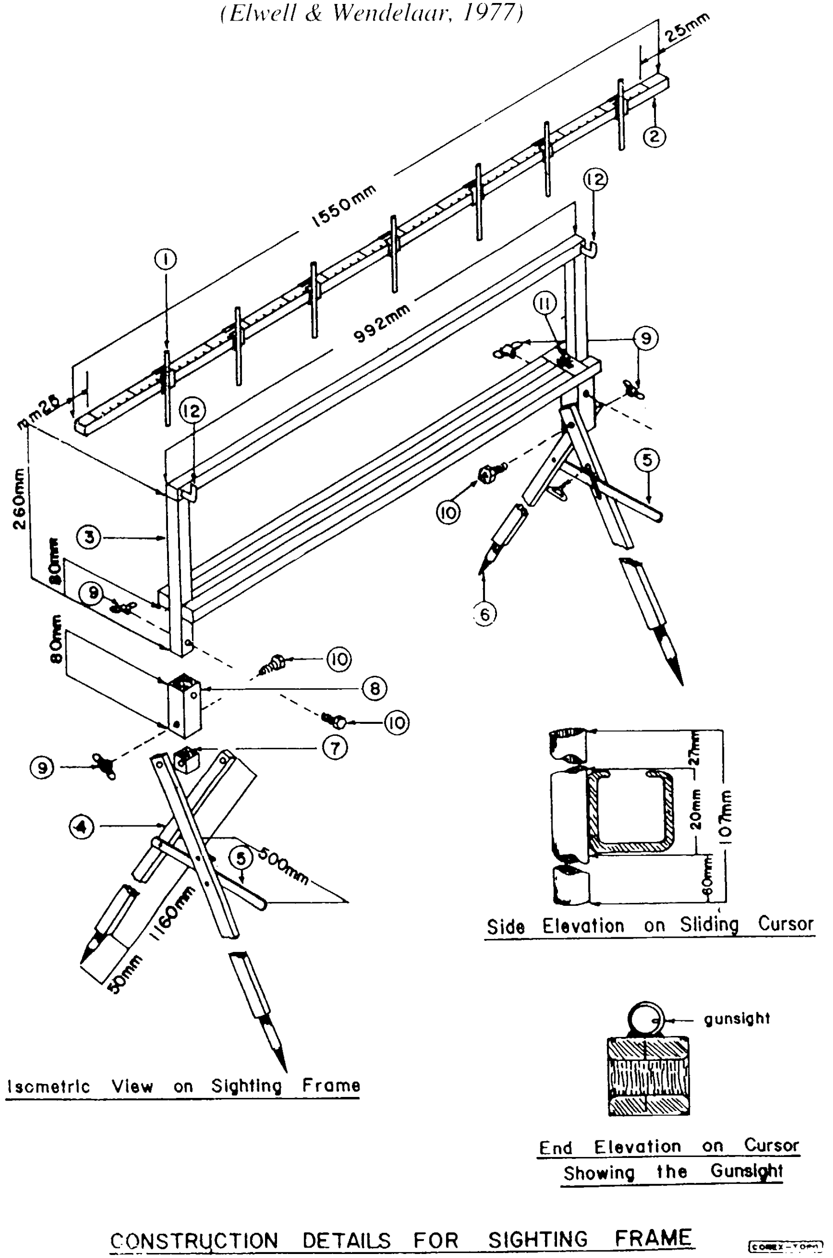


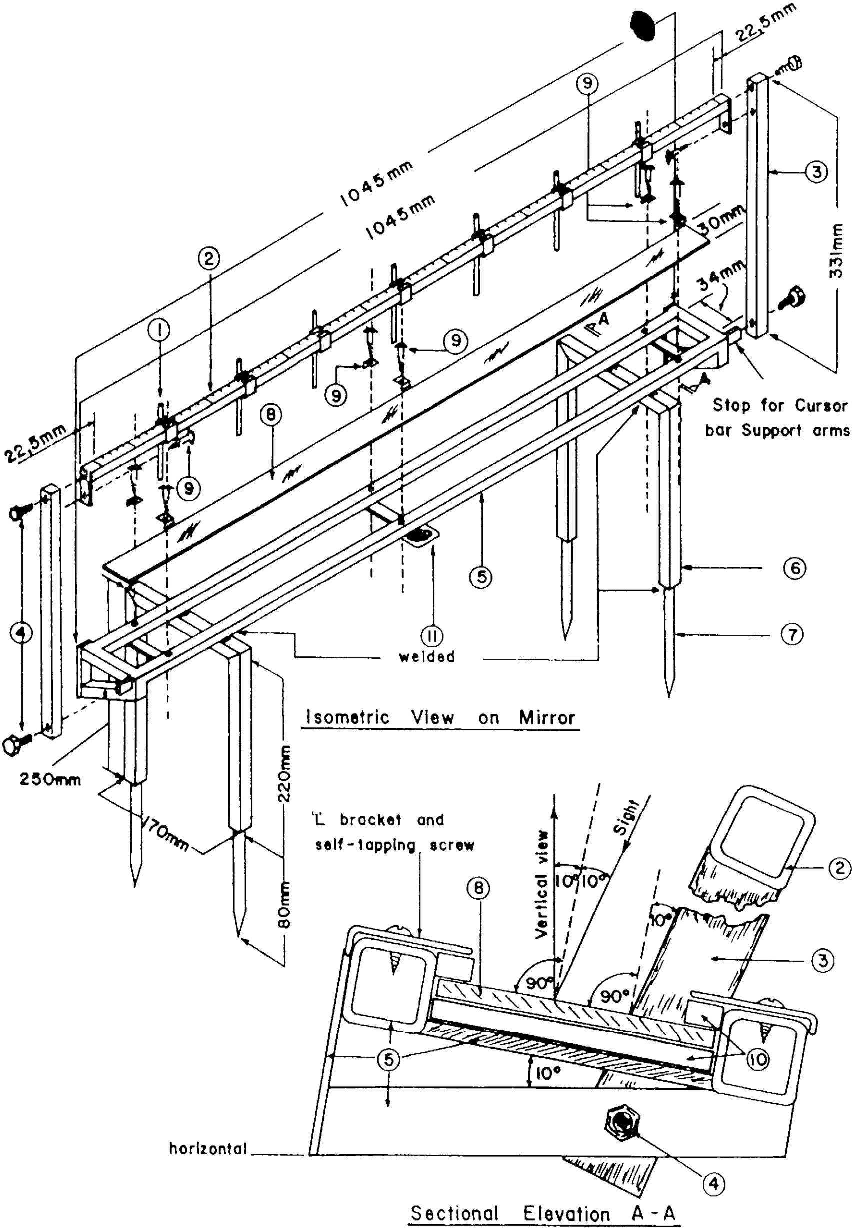
In the second case the sum of ratings for all ten pipes gives the coverage for the 1 m transsect. 100 observations in a regular cropstand were precise within 2% coverage (Cackett, 1964) whereas 300 observations were necessary for a 5% accuracy in an irregular cropstand (Elwell & Gardner, 1975). Quansah et al. (1990) used an average of 5.4 observations/m^2. In own measurements 180 points on a 500 m^2 plot (0.3 observations/m^2) proved adequate (Nill, 1993). This version of sighting frame can be used for mulch and during the first 2–4 weeks of plant growth while the plants are still small because the observation error increases rapidly with increasing plant height (Figure 32-6Annex).

A modified version of the sighting frame avoids this observation error by sliding a graduated stick through the pipes (Figure 32-7Annex). In this case the number of contacts of the stick with leaves or mulch are counted. This version allows at the same time to measure the mean canopy height above ground.

An alternative in tall crops is the use of a mirror on the sighting frame which allows an observation of the canopy cover outlined against the sky (Figure 32-8Annex). The sighting frames are easy and cheap to construct.

Figure 32-8 Annex: Sighting frame with mirror for tall crops (Elwell & Wendelaar, 1977)





CONSTRUCTION DETAILS FOR MIRROR

CONEX-TOPO

Annex 3.3 Growth curves for mono- and mixed crops

Growth curves for the following mono- and mix-crops are given for:

Bambara nut	*Figure 33-1 Annex*
canavalia	*Figure 33-1 Annex*
cassava	*Figure 33-2 Annex*
cotton	*Figure 33-3 Annex*
cowpea	*Figure 33-1 Annex*
groundnut	*Figure 33-4 Annex*
maize	*Figure 33-5 Annex*
maize/cassava mixcrop	*Figure 33-2 Annex*
pigeon pea	*Figure 33-2 Annex*
rice	*Figure 33-5 Annex*
sorghum	*Figure 33-5 Annex*
soya	*Figure 33-4 Annex*
sunflower	*Figure 33-3 Annex*
tea	*Figure 33-6 Annex*
tobacco	*Figure 33-3 Annex*

Figure 33-1 Annex: Canopy cover development of Bambara nut, canavalia and cowpea (Quansah et al., 1990)

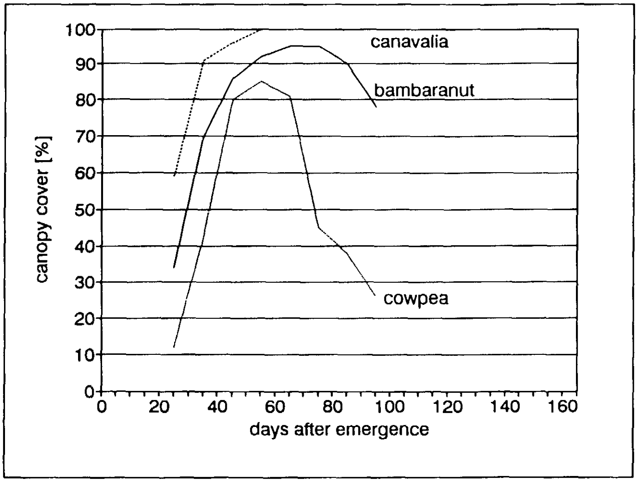
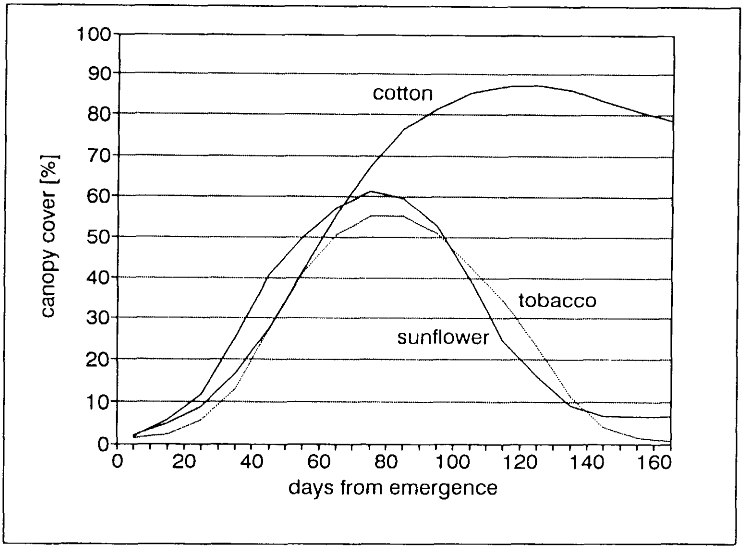


Figure 33-2 Annex: Canopy cover development of cassava, maize/cassava mixcrop and pigeon pea (Aina et al., 1979)

Figure 33-3 Annex: Mean canopy cover development of cotton (n = 45), sunflower (n = 4) and tobacco (n = 44) (Elwell, 1993)



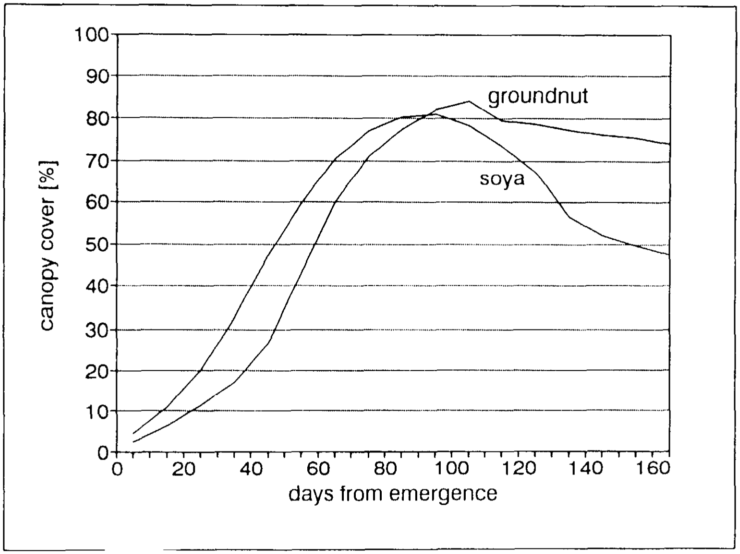
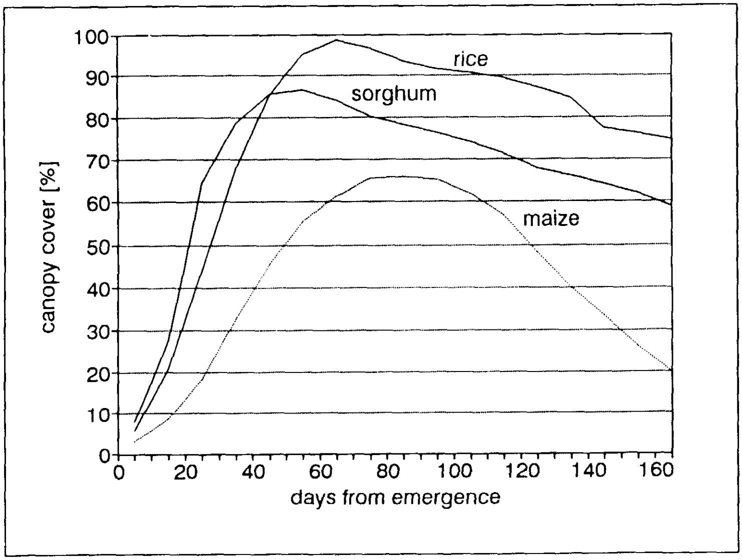


Figure 33-4 Annex: Mean canopy cover development of groundnut (n = 7) and soya (n = 92) (Elwell, 1993)

Figure 33-5 Annex: Mean canopy cover development of maize (n = 76), rice (n = 7) and sorghum (n = 8) (Elwell, 1993)



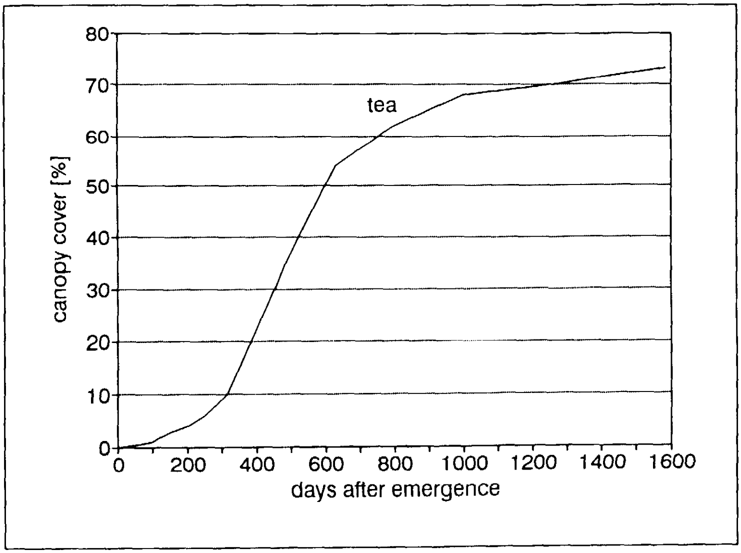


Figure 33-6 Annex: Canopy cover development for tea (Othieno, 1975)

Annex 3.4 Detailed C factors

Table 34-1 Annex: Detailed C factors for forest, bush and grass vegetation

Annex 3.4 Detailed C factors

Table 34–1 Annex: Detailed C factors for forest, bush and grass vegetation

no.	land-use	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
	fallows of							
1	forest	dense, secondary forest; mean of 3 plots	0.0002	1.8E-05 to 0.00035	-	Ivory Coast	Adiopodoum	Roose (1975, p. 30/31)
2	bush	well developed	0.004	-	1	Cameroon	Yaound	Nill (1993, p. 159)
3	grass	poorly developed Imperata grass fallow	0.09	-	1	- " -	Nachtigal	- " -
4	- " -	savanna grass fallow in good condition	0.01	-	-	-	-	Roose (1977, p. 69)
5	- "	savanna grass fallow in poor condition (burned or overgrazed)	0.1	-	-	-	-	- " -

Table 34-1 Annex, continue

no.	land-use	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
6	crop residues*3	fallow with maize residues	0.09	-	-	Malaysia	-	Sulaiman et al. (1983)
7	- “ -	fallow with maize residues and mulch	0.01	-	-	- ” -	-	- “ -
8	- “ -	fallow with mung bean residues	0.25	-	-	- ” -	-	- “ -
9	- “ -	fallow with groundnut residues	0.28	-	-	- ” -	-	- “ -
10	- “ -	fallow with cowpea residues	0.03	-	-	- ” -	-	- “ -
	residual fallow effects*1							
11	bush fallow	well developed; 1st year after clearing	0.8	0.78 to 0.81	1	Cameroon	Yaound	Nill (1993, p. 163)
12	- “ -	2nd years after clearing*2	0.9*2	-	-	- ” -	- “ -	- ” -
13	grass fallow	Imperata grass; 1st year after clearing	0.4	0.33 to 0.49	1	- “ -	Nachtigal	- ” -
14	- “ -	2nd year after clearing*2	0.7	-	1	- ” -	- “ -	- ” -

Table 34-1 Annex, continue

no.	land-use	description	C factor mean	 extremes	measure-ment period [a]	country	location	literature
	cover and fodder crops							
15	diverse	1st year: early planting and good growth (elephant grass, Guatemala grass, Guinea grass, Cynodon dactylon, Setaria)	0.004	0.0007 to	0.014	-	Ivory Coast	Adiopodoum
16	- " -	1st year: late planting or slow growth (Crotalaria, Flemingia, Mimosa invisa, Digitaria umfolozi, Centrosema, Titonia, Stylosanthes)	0.29	0.16 to 0.70	-	- " -	- " -	- " -
17	- " -	2. year: all	0.002	0.00036 to 0.0051	-	- " -	- " -	- " -
18	Cynodon aethiopicu	right after cutting, 60 - 80% canopy cover	0.0024	-	3	- " -	- " -	Roose (1975, p. 33)
19	Stylos-anthes guyanensis	right after cutting, 42% canopy cover	0.026	-	3	- " -	- " -	- " -

Table 34-1 Annex, continue

no.	land-use	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
20	Panicum maximum	right after cutting. 8 - 14% canopy cover	0.058	-	3	- " -	- " -	- " -
21	Digitaria decumbens	slope 12%; planted 3 years old pasture (C = mean of 3 years)	0.007	-	3	Brazil	Alagoinha	Leprun et al. (1986, p. 226)
22	Bracharia decumbens	1st year	0.287	-	-	Indonesia	-	Abdurachman et al. (1984)
23	- " -	fully established	0.002	-	-	- " -	-	- " -
24	- " -	planted pasture (C = mean of six years); 5.5% slope	0.003	-	6	Brazil	Brasilia	Leprun et al. (1986, p. 228)

*1 Surprisingly, savanna fallow had higher residual effect which migjt be due to generally lower organic matter levels and slower turnover

*2 residual effects for 2nd year assumed as 50 % of the 1st year

*3 Only the crop residues are left in the field and the spontaneously growing vegetation after harvest

Table 34-2 Annex: Detailed C factors for banana

Table 34-2 Annex: Detailed C factors for banana

no.	land-use	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
1	monocrop	8% slope, 1st year: leaves placed around trunks; 2nd year: leaves placed on contour; spacing 5 x 3 m. Alternatively for a young plantation (1st year)	0.56	0.14 to 1.08	2	Burundi	Mashitsi	Rishirumuhirwa (1992, p. 90)
2	- " -	as above but spacing 2 x 3 m	0.16	0.04 to 0.3	2	- " -	- " -	- " -
3	- " -	as above but spacing 3 x 3 m	0.3	0.08 to 0.58	2	- " -	- " -	- " -
4	- " -	as above but spacing 4 x 3 m	0.42	0.1 to 0.83	2	- " -	- " -	- " -
5	- " -	with mulch	0.00029	0.00029 to 0.00036	Ivory Coast	Adiopodoum	Roose (1975, p. 30/31)	
6	- " -	as no. 3, spacing 3 x 3 m plus complete mulch cover	0.0009	0 to 0.007	2	Burundi	- " -	- " -
7	- " -	-	0.04	-	-	-	-	Lewis (1986 in: Young, 1989, p. 33)
8	intercropped	with beans	0.1	-	-	-	-	- " -
9	- " -	with sorghum	0.14	-	-	-	-	- " -

Table 34-3 Annex: Detailed C factors for pineapple

Table 34-3 Annex: Detailed C factors for pineapple

no.	**land-use**	**description**	**C factor**		**measure-ment period**	**country**	**location**	**literature**
			mean	**extremes**	**[a]**			
1	monocrop	density 45000 plants/ha; planted on contour; 1st year (9% slope)	0.44	-	4 reps, 1 year	Nigeria	Owerri	Asoegwu & Obiefuna (1990, p. 240)
2	- " -	as above but density 60000 plants/ha	0.31	-	- " -	- " -	- " -	- " -
3	- " -	as above but density 75000 plants/ha	0.24	-	- " -	- " -	- " -	- " -
4*2	- " -	1. year: on level ground	0.087	0.058 to 0.145	-	Ivory Coast	Adiopodoum	Roose (1975, p. 30/31)
5*2	- " -	1. year: on heaps	0.025	?	-	- " -	- " -	- " -
6*2	- " -	2. year: on level ground	0.0015	0.0007 to 0.002	-	- " -	- " -	- " -
7	- " -	residues burned; on contour (as a function of slope)	-	0.2 to 0.5	-	-	-	Roose (1977, p. 69)
8	- " -	as above but residues incorporated	-	0.1 to 0.3	-	-	-	- " -

Table 34-3 Annex, continue

no.	land-use	description	C factor		measurement period	country	location	literature
			mean	extremes	[a]			
9	- " -	as above but residues as surface mulch	0.01	-	-	-	-	- " -
10	intercrop	density 45000 plants/ha + cowpea (20000 plants/ha)	0.34	-	4 reps, 1 year	Nigeria	Owerri	Asoegwu & Obiefuna (1990, p. 240)
11	- " -	density 60000 plants/ha + cowpea (20000 plants/ha)	0.29	-	- " -	- " -	- " -	- " -
12	- " -	density 75000 plants/ha + cowpea (20000 plants/ha)	0.19	-	- " -	- " -	- " -	- " -
13	- " -	density 45000 plants/ha + egusi melon*1 (5000 plants/ha)	0.19	-	- " -	- " -	- " -	- " -
14	- " -	density 60000 plants/ha + egusi melon (5000 plants/ha)	0.16	-	- " -	- " -	- " -	- " -
15	- " -	density 75000 plants/ha + egusi melon (5000 plants/ha)	0.13	-	- " -	- " -	- " -	- " -

Table 34-3 Annex, continue

no.	land-use	description	C factor mean	C factor extremes	measurement period [a]	country	location	literature
	subfactors							
16		increasing density by 15000 plants; calculated from densities above	0.75	0.71 to 0.78	1	- " -	- " -	- " -
17*3	intercropping	intercropping with cowpea (20000 plants/ha)	0.84	0.79 to 0.93	1	- " -	- " -	- " -
18*3	- " -	intercropping with egusi melon*1 (5000 plants/ha)	0.5	0.44 to 0.53	1	- " -	- " -	- " -

*1 egusi melon – *Colocynthus citrullus* L.

*2 10–12 are rather small values; however, it was not specified if the residues were kept within the field

*3 there was a slight trend observable that the subfactor for intercropping increases with increasing pineapple density. The ratios intercrop/monocrop were 0.77, 0.94 and 0.79 for cowpea intercropped with 45.000, 60.000 and 70.000 pineapple plants. With melon the ratios were 0.43, 0.52 and 0.54, respectively.

Table 34-4 Annex: Detailed C factors for cassava

Table 34-4 Annex: Detailed C factors for cassava

no.	cassava	description	C factor		measurement period	country	location	literature
			mean	extremes	[a]			
1	on level ground	monocropping; 1st season C = 0.72; 2nd season C = 0.39	0.56	0.72 to 0.39	1	Nigeria	Ibadan	Aina et al. (1979, p. 506)
2	- " -	spacing 1 x 1 m; planted on level ground	0.53	-	4	Rwanda	Butare	Knig (1992, p. 174)
3	- " -		0.36	-	-	Indonesia	-	Abdurachman et al. (1984)
4	- " -	spacing 1 x 1 m; planted on level ground	0.12	0.09 to 0.14	2 in 2 sites with 2-3 repetitions	Columbia	Santander de Quilichao and Mondomo	Reining (1991, p. 111)
5	- " -	-	0.25	-	-	-	-	Lewis (1986 in: Young, 1989)
6	- " -	1. year		0.2 to 0.8	-	-	-	Roose (1975, p. 40)
7	- " -	75% cover to harvest	0.38	-	-	Cameroon	Nachtigal	Nill (1993)

Table 34-4 Annex, continue

no.	cassava	description	C factor		measurement period	country	location	literature
			mean	extremes	[a]			
8	mounds	1. year	0.23	0.16 to 0.67	-	Ivory Coast	Adiopodoum	Roose (1975, p. 30/31)
9		2. year	0.015	-	-	- " -	- " -	- " -
10	contour	planted on 4 out of 8 different Indonesian soil types	0.64	-	1	Indonesia	-	Keersebilck (1990, p. 560)
11	along slope	1 plant/m , spacing 0.86 x 1.13 (C factor judged to low due to small rain volume in initial growth stages	0.08	-	1	USA/Hawaii	Molokai	El-Swaify et al. (1988, p. 9)
12	ridge	spacing 1 x 1 m; on contour ridges	0.021	0.012 to 0.03	- " -	- " -	- " -	- " -
13	- " -	as above but ridges along slope	0.27	0.13 to 0.4	- " -	- " -	- " -	- " -
14	bufferstrips	1 m large grass strips on contour 8 to 10 m apart; cassava spaced 0.9 x 1 m; 7 to 20% slopes	0.05	0.01 to 0.08	- " -	- " -	- " -	- " -

Table 34-4 Annex, continue

no.	cassava	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
15	notill	spacing 1 x 1 m; only tillage of planting holes; 7 to 20% slopes	0.015	0.015	- " -	- " -	- " -	- " -
16	intercrop	cassava intercropped with maize (75 x 25 cm) and cocoyam; plowed and harrowed; 19, 3, 15 kg/ha NPK; 7.5% slope	0.08	0.109 to 0.023	3	Ghana	Kwadoso	Bonsu & Obeng (1979, p. 515)
17	- " -	as above but 3% slope	0.066	-"[5]	1	- " -	Ejura	- " -
18	- " -	intercropped with maize; 1st season C = 0.43; 2nd season C = 0.05	0.24	0.43 to 0.05	1	Nigeria	Ibadan	Aina et al. (1979)
19	- " -	intercropped with maize; residues incorporated; on 60 cm heaps oriented across 6% slope; distance between heap tops 0.7 x 1.4 m; 2 repetitions	0.007	-	1	- " -	Alore	Sabel-Koschella (1988)

Table 34-4 Annex, continue

no.	cassava	description	C factor		measurement period	country	location	literature
			mean	extremes	[a]			
20	- " -	intercropping maize + rice + cassava	0.588	-	-	Indonesia	-	Abdurachman et al. (1984)
21	- " -	intercropped with soya	0.181	-	-	- " -	-	- " -
22	- " -	with groundnut	0.195	-	-	- " -	-	- " -
23	- " -	as no. 9 but intercropped with stylosanthes and Desmodium triflorum	0.02	-	1	USA/Hawaii	Molokai	El-Swaify et al. (1988, p. 9)
24	- " -	cassava on level ground; spacing 1.7 x 0.6 m across slope; 3 rows of Phaseolus or cowpea between cassava; spacing 0.25 between rows	0.17	0.15 to 0.19	- " -	- " -	- " -	- " -
25	- " -	intercropping of maize + rice + cassava with residue mulch	0.357	-	-	Indonesia	-	Abdurachman et al. (1984)
26	intercrop + mulch	intercropped with rice + maize plus 6 t/ha of rice straw mulch	0.079	-	-	- " -	-	- " -

Table 34-4 Annex, continue

no.	cassava	description	C factor		measurement period [a]	country	location	literature
			mean	extremes				
	subfactor							
27		subfactor for intercropping cassava with maize; maize spacing 100 x 25 cm; cassava spacing 100 x 100 cm (mean of three repetitions on slopes of 5, 10 and 15%)	0.63	0.57 to 0.69	1	Nigeria	Ibadan	Aina et al. (1977, p. 79)

Table 34-5 Annex: Detailed C factors for groundnut

Table 34-5Annex: Detailed C factors for groundnut

no.	**groundnut**	**description**	**C factor**		**measure-ment period**	**country**	**location**	**literature**
			mean	**extremes**	**[a]**			
1	monocrop	spacing: 20 x 40 cm; on level ground; on contour	0.59	0.43 to 0.87	-	Ivory Coast	Adiopodoum	Roose (1975, p. 30/31)
2	- " -	conventional tillage up- and down-slope; residues incorporated; 3 repetitions	0.27	0.22 to 0.31	1	Malaysia	-	Sulaiman et al. (1981, p. 280)
3	- " -	on four of 8 different Indonesian soil types, planted on contour	0.3	-	1	Indonesia	-	Keersebilck (1990, p. 570)
4	- " -	-	0.452	-	-	- " -	-	Abdurachman et al. (1984)
5	- " -	-	0.52	-	-	Malaysia	Serdang	Mokhtaruddin & Maene (1979)
6	- " -	-	0.28	-	-	- " -	-	Sulaiman et al. (1983)
7	- " -	spacing 60 x 30 cm on 3.5% slope; plowed and harrowed; 2 repetitions	0.34	-	0.5	Ghana	Kumasi	Quansah et al. (1990)

Table 34-5 Annex, continue

no.	groundnut	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
8	- " -	spacing 40 x 20 cm on contour; plowed; without residues	0.45	0.22 to 0.64	2	Cameroon	Yaound	Nill (1993)
9	monocrop/notill	as above	0.33	0.19 to 0.47	1	- " -	- " -	- " -
10	intercrop	+ pigeon pea	0.495	-	-	Indonesia	-	Abdurachman et al. (1984)
11	"	+ cowpea	0.571	-	-	- " -	-	- " -
12	mulch	4 t/ha straw mulch	0.049	-	-	- " -	-	- " -

Table 34-6 Annex: Detailed C factors for maize

Table 34-6 Annex: Detailed C factors for maize

no.	treatment	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
1	plow*2	spacing 0.9 x 0.5 m; slope 4.5 %; corrected for contouring (0.5)	0.16	0.02 to 0.12	3*1	Zimbabwe	Domboshawa	Vogel (1992., p. 13)
2	- " -*2	spacing 0.9 x 0.62 m; slope 4.5 %,, corrected for contouring (0.5)	0.18	0.04 to 0.17	3*1	- " -	Makaholi	- " -
3	- " -	-	0.52	0.5	USA/ Hawaii	Molokai	El-Swaify et al. (1988., p. 4)	
4	- " -	-	0.637	-	-	Indonesia	-	Abdurachman et al. (1984)
5	- " -	-	0.38	-	-	Malaysia	Serdang	Mokhtaruddin & Maene (1979)
6	- " -	-	0.39	-	-	- " -	-	Sulaiman et al. (1983)
7	- " -	12 % slope; along slope	0.11	-	3	Brazil	Alagoinha	Leprun et al. (1986., p. 226)
8	- " -	5.5 % slope; hand hoe tillage; 0.56	-	6	- " -	Brasilia	- " -	
9	- " -	spacing: 0.6 m between rows; 20000 to 51000 plants/ha depending on rain volume; 20 - 60 kg/ha N., 20 kg/ha P	0.82	-	3	Kenya	Katumani	Ulsaker & Kilewe (1984., p. 233)

Table 34-6 Annex, continue

no.	treatment	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
10	- " -	disc plow and harrow; planted along slope,, spacing 75 x 25 cm; 120 N., 60 P., 60 K:	0.125	-	1	Nigeria	Ibadan	Lal (1976a., p. 31)
11	- " -	spacing 80 x 20 cm,, 16 % slope corrected for contouring (0.7)	0.37	0.31 to 0.41	2	Cameroon	Yaound	Nill (1993)
12	- " -	according to yield level 0.4 to 0.9	-	-	-	-	-	Roose (1975., p. 40)
13	plow + residues	as no. 10 but with maize residues	0.084	0.057 to 0.099	2	Nigeria	Ibadan	Lal (1976a., p. 31)
14	- " -	with maize residues	0.026	-	-	Malaysia	Serdang	Mokhtaruddin & Maene (1979)
15	- " -	disc plow and harrow; planted along slope,, spacing 75 x 25 cm; 120 N., 60 P., 60 K; cowpea residues	0.176	0.167 to 0.184	2	Nigeria	Ibadan	Lal (1976a., p. 31)
16	- " -	on 6 % slope,, corrected for contouring (0.5),, cowpea residues,. 2 repetitions	0.52	0.44 to 0.58	2	- " -	Alore	Sabel-Koschella (1988)
17	intercrop	with Lotus corniculatus	0.4	-	0.5	USA/Hawaii	Molokai	El-Swaify et al. (1988., p. 4)
18	- " -	with Trifolium hortum	0.29	0.5	-	- " -	- " -	- " -
19	- " -	with beans	0.30	-	-	Rwanda	-	Lewis (1986 in: Young., 1989., p. 33)
20	notill without residues	spacing and fertiliser as above	0.081		1	Nigeria	Ibadan	Lal (1976a., p. 31)

Table 34-6 Annex, continue

no.	treatment	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
21	- " -	spacing 20 x 80 cm., on 16 % slope., corrected for contouring (0.7)	0.017	-	1	Cameroon	Yaound	Nill (1993)
22	- " -	60 cm between rows,, plant density between 51000 and 20000 plants/ha depending on season rainfall; 20 to 60 kg N and 20 kg P	0.24	-	3	Kenya	Katumani	Ulsaker & Kilewe (1984., p. 233)
23	- " -*3	spacing 0.9 x 0.5 m; 4.5 % slope; corrected for contouring (0.5)	0.03	0.01 to 0.04	3	Zimbabwe	Domboshawa	Vogel (1992., p. 13)
24	- " -*3	spacing 0.9 x 0.6 m; 4.5 % slope; corrected for contouring	0.022	0.01 to 0.03	3	- " -	Makaholi	- " -
25	- " -*6	spacing 0.9 x 0.5 m; 4.5 % slope,. corrected for contouring (0.5)	0.028	0.01 to 0.038	3	- " -	Domboshawa	- " -
26	- " -*6	spacing 0.9 x 0.6 m., 4.5 % slope: corrected for contouring (0.5)	0.02	0.014 to 0.026	3	- " -	Makaholi	- " -
27	notill + residues	as no. 22,. but residues of former cowpea crop left	0.001	-	1	Nigeria	Ibadan	Lal (1976a., p. 31)
28	- " -	cowpea residues; 6 % slope; corrected for contouring (0.5); 2 repetitions	0.034		2	- " -	Alore	Sabel-Koschella (1988)

Table 34-6 Annex, continue

no.	treatment	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
29	- " -*4	spacing 0.9 x 0.5; with maize residues; corrected for contour planting	0.012	-	3	Zimbabwe	Domboshawa	Vogel (1992,, p. 13)
30	- " -*4	spacing 0.9 x 0.6 m; with maize residues; corrected for contour planting	0.011	0.016 to 0.017	3	- " -	Makaholi	- " -
31	- " -	7.5 % slope; spacing 75 x 25 cm,, fertilizer 19,, 3 and 15 kg/ha of NPK	0.031	0.0063 to 0.077	3	Ghana	Kwadoso	Bonsu & Obeng (1979,, p. 515)
32	- " -	as above; but 3 % slope	0.035	-*5	1	- " -	Ejura	- " -
33	reduced tillage	spacing: 0.75 x 0.25 m; 7.5 % slope; 19,, 3 and 15 kg/ha of N,, P and K; plowed without harrowing; two handweedings	0.02	0.038 to 0.0057	3	- " -	Kwadoso	- " -
34	- " -	as above; 3 % slope	0.041	-*5	1	- " -	Ejura	- " -
35	mulch	spacing 0.75 x 0.25 m; fertilizer 19,, 3 and 15 kg/ha of N,, P and K; plowed and harrowed; mulch quantity?	0.0029	0.00563 to 0.0013	3	- " -	Kwadoso	- " -
36	- " -	as mulch plot above; 3 % slope; mulch quantity?	0.004	-*5	1	- " -	Ejura	- " -
37	- " -	with imperata mulch	0.02	-	-	Malaysia	-	Sulaiman et al. (1983)
38	intercropped/ mulch	with groundnut plus 4 t/ha straw mulch	0.128		-	Indonesia	-	Abdurachman et al. (1984)

Table 34-6 Annex, continue

no.	treatment	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
39	ridge	spacing: 0.75 x 0.25 m; 3 % slope; 19,, 3 and 15 kg/ha of N,, P and K; plowed and harrowed; ridges across slope	0.026	0.057 to 0.0087	3	Ghana	Kwadoso	Bonsu & Obeng (1979,, p. 515)
40	- " -	ridge on contour; 7.5 % slope	0.054	-*5	1	- " -	Ejura	- " -
41	- " -	spacing: 100 x 20 cm. on ridges along slope	0.67	0.25 to 0.95	Ivory Coast	Adiopodoum	Roose (1975,, p. 30/31)	
42	tied-ridging-/notill*5	spacing 0.9 x 0.5; ridges on contour; 25 cm high contour ridges with 1 % lateral slope; ties at intervals of 1.5 m and app. 15 cm high	0.018	0.006 to 0.026	3	Zimbabwe	Domboshawa	Vogel (1992,, p. 13)
43	- " -*5	spacing 0.9 x 0.6; ridges on contour; 25 cm high contour ridges with 1 % lateral slope; ties at intervals of 1.5 m and app. 15 cm high	0.004	0.003 to 0.006	3	- " -	Makaholi	- " -

*1 Only data of the 2nd to 4th experimental year were considered. Results of 1st year skipped due to residual effects of natural fallow

*2 Plowing with oxen drawn single furrow mould-board plow right after harvest to 20 - 25 cm depth

*3 Ripping between former maize rows with an oxen drawn single ripper tine to 20 - 25 cm depth

*4 As *3 but residues of former maize crop left

*5 Soil was plowed to 20 - 25 cm depth at beginning of experiments. 25 cm high contour ridges (1 % side slope) were formed with oxen drawn mouldboard ridger. In subsequent years,, no plowing was carried out but ridges were reformed after harvest and 6 weeks after planting. 15 cm high cross ties were also formed twice a year at 1 m intervals in the furrows. Planting was on top of the ridges.

*6 Planting holes were opened with hand-hoe (badza holing out in Zimbabwe)

Table 34-7 Annex: Detailed C factors for diverse crops

Table 34–7 Annex: Detailed C factors for diverse crops

no.	crop	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
1	Bambara nut	plowed; 3.5% slope; spacing 30 x 30 cm; 2 repetitions	0.43	-	0.5	Ghana	Kumasi	Quansah et al. (1990)
2	beans	mung bean	0.44	0.40 to 0.47	1	Malaysia	-	Sulaiman et al. (1983, p. 280)
3	- " -	mung bean; tilled up- and down-slope; residues incorporated; 3 repetitions	0.38	-	-	- " -	-	- " -
4	- " -	red bean	0.16	-	-	Indonesia	-	Abdurachman et al. (1984)
5	- " -	-	0.19	-	-	Rwanda	-	Lewis (1986 in: Young 1989, p. 33)
6	- " -	Jack bean (Canavalia); plowed; 3.5% slope; spacing 30 x 30 cm; 2 repetitions	0.17	-	0.5	Ghana	Kumasi	Quansah et al. (1990)
7	cabbage	planted as monocrop on contour on 4 out of 8 different Indonesian soil types	0.6	-	1	Indonesia	-	Keersebilck (1990, p. 570)

Table 34-7 Annex, continue

no.	crop	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
8	chili		0.33	-	-	Malaysia	-	Sulaiman et al. (1983)
9	cotton	12% slope; planted along slope	0.29	-	3	Brazil	Alagoinha	Leprun et al. (1986, p. 226)
10	- " -	as above; planted on contour	0.139	-	3	- " -	- " -	- " -
11	- " -	2nd cycle	0.5	-	-	-	-	Roose (1975, p. 40)
12	cowpea	plowed	0.27	-	-	Malaysia	-	Sulaiman et al. (1983, p. 280)
13	- " -	plowed; semi-erect cultivar; 3.5% slope; spacing 90 x 30 cm; 2 repetitions	0.21	-	0.5	Ghana	Kumasi	Quansah et al. (1990)
14	cowpea + residues	plowed up- and down-slope; residues incorporated; 3 repetitions	0.26	0.23 to 0.29	1	Malaysia	-	Sulaiman et al. (1981, p. 280)
15	cowpea + residues	disc plow + harrow; planted along slope; maize residues	0.043	-	1	Nigeria	Ibadan	Lal (1976a, p. 31)
16	- " -	disc plowed; maize residues; 6% slope; 2 repetitions	0.14	0.05 to 0.28	2	- " -	Alore	Sabel-Koschella (1988)

Table 34-7 Annex, continue

no.	crop	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
17	- " -	plowed; maize residues; 6% slope; spacing 75 x 25 cm; 2 repetitions	0.006	0.002 to 0.014	2	- " -	- " -	Nill (1993)
18	- " -	notill; maize residues; planted along slope	0.01	0.0004 to 0.02	2	- " -	Ibadan	Lal (1976a, p. 31)
19	- " -	notill; maize residues; 6% slope	0.004	0.002 to 0.006	2	- " -	Alore	Sabel-Koschella (1988)
20	- " -	notill; maize residues; 6% slope; spacing 75 * 25 cm across slope	0.0003	0.0002 to 0.0004	2	- " -	- " -	Nill (1993)
21	Irish potatoes	-	0.22	-	-	Rwanda	-	Lewis (1986 in: Young 1989, p. 33)
22	lemon grass		0.434	-	-	Indonesia	-	Abdurachman et al. (1984)
23	papaya	without cover crop	2.1	-	-	-	-	Abdul Rashid (1981 in: Sulaiman et al. 1983)
24	soya		0.399	-	-	Indonesia	-	Abdurachman et al. (1984)

Table 34-7 Annex, continue

no.	crop	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
25	- " -		0.11	0.02 to 0.19	1	Nigeria	Ibadan	Aina et al. (1979)
26	- " -	planted on contour on 4 out of 8 different Indonesian soil types	0.38	-	1	Indonesia	-	Keersebilck (1990, p. 570)
27	- " -	hand tillage; slope 5.5%;	0.154	-	6	Brazil	Brasilia	Leprun et al. (1986, p. 228)
28	- " -	notill (probably without residues left because notill-subfactor = 0.67); slope 5.5%	0.103	-	6	- " -	- " -	- " -
29	sweet potatoes	-	0.23	-	-	Rwanda	-	Lewis (1986 in: Young 1989, p. 33)
30	tobacco	2nd cycle	0.5	-	-	-	-	Roose (1975, p. 40)
31	tobacco	-	0.45	-	-	Rwanda	-	Lewis (1986 in: Young 1989, p. 33)

Table 34-7 Annex, continue

no.	crop	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
32	wheat-soya	rotation on 12% slope, wheat residues burned; soya residues incorporated	0.113	-	6	Brazil	Guaiba	Leprun et al. (1986, p. 230)
33	wheat-soya	as above but all residues surficially incorporated	0.05	-	6	- " -	- " -	- " -
34	- " -	rotation as above but with notill	0.04	-	6	- " -	- " -	- " -
35	wheat-maize	as above, conventionally tilled, residues incorporated	0.1	-	6	- " -	- " -	- " -
36	- " -	as above but notill (residues maintained)	0.014	-	6	- " -	- " -	- " -
37	yam	depending on planting time		0.2 to 0.8	-	-	-	Roose (1975, p. 40)
38	- " -	on mounds	0.23	0.16 to 0.67	-	Ivory Coast	Adiopodoum	Roose (1975, p. 30/31)
39	yam	intercropped with maize; plus residues; 60 cm high mounds spaced 0.7 x 1.4 along slope; 6% slope; 2 repetitions	0.07	0.04 to 0.09	1	Nigeria	Alore	Sabel-Koschella (1988)

Table 34-8 Annex: Detailed C factors for notillage

Table 34-8Annex: Detailed C factors for notillage

no.	notillage	description	C factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
1	without residues	only holes for sowing are opened with a handhoe, rest of field stays undisturbed; traditional tillage system in Zimbabwe (badza holing out)	0.71	0.6 to 1	4	Zimbabwe	Domboshawa	Vogel (1992, p. 13)
2	- " -	as above	0.45	0.32 to 1.14	4	- " -	Makaholi	- " -
3	- " -	calculated from notill and plowed groundnut on 18% slope	0.73	-	1	Cameroon	Yaound	Nill (1993, p. 157)
4	- " -	calculated from notill and plowed maize 1972 (Lal, 1976a)	0.65	-	1	Nigeria	Ibadan	Lal (1976a, p. 31)
5	- " -	subfactor calculated from soya planted plots on 5.5% slope (notill probably without residues)	0.67	-	6	Brazil	Brasilia	Leprun et al. (1986, p. 228)

Table 34-8 Annex, continue

no.	notillage	description	C factor		measurement period	country	location	literature
			mean	extremes	[a]			
6	- " -	seed slit ripped between former maize stubble (across slope of 4.5%)	0.81	0.6 to 1.18	4	Zimbabwe	Domboshawa	Vogel (1992, p. 13)
7	- " -	as above	0.51	0.37 to 1.0	4	- " -	Makaholi	- " -
8	with residues	calculated from cassava; slopes 7 - 13%	0.17	0.11 to 0.37	2 years with 3 reps	Colombia	Santander de Quilichao	Reining (1991, p. 111)
9	- " -	as above but slopes 13 - 20%	0.104	0.06 to 0.27	2 years with 2 reps	- " -	Mondomo	"
10	- " -	maize residues left in field; slope 7 - 13%	0.41	0.3 to 1.18	4	Zimbabwe	Domboshawa	Vogel (1992, p. 13)
11	- " -	as above but slope 13 - 20%	0.29	0.11 to 0.77	4	- " -	Makaholi	- " -
12	- " -	calculated from wheat-maize rotation planted on 12% slope	0.14	-	6	Brazil	Guaiba	Leprun et al. (1986, p. 230)

Annex 4 Protection and management

Annex 4.1 Detailed support and management (P) factors

Table 41-1 Annex: Detailed P factors for contouring

Annex 4.1 Detailed support and management (P) factors

Table 41-1 Annex: Detailed P factors for contouring

no.	derived from	description	P factor		measure-ment period	country	location	literature
			mean	extremes	[a]			
1	USLE	slope: 1 - 2%	0.6	-	-	USA	-	Wischmeier & Smith (1978)
2	- " -	slope: 3 - 5%	0.5	-	-	- " -	-	- " -
3	- " -	" : 6 - 8%	0.5	-	-	- " -	-	- " -
4	- " -	" : 9 - 12%	0.6	-	-	- " -	-	- " -
5	- " -	" : 13 - 16%	0.7	-	-	- " -	-	- " -
6	- " -	" : 17 - 20%	0.8	-	-	- " -	-	- " -
7	- " -	" : 21 - 25%	0.9	-	-	- " -	-	- " -
8		calculated from cotton planted plots on 12% slope	0.41	-	3	Brazil	Alogoinha	Leprun et al. (1986, p. 226)
9		calculated from Pennisetum americanum (pearl millet) on 1 and 1.5% slope under 3 storms	0.73	-	1	India	-	Patil & Bangal (1991)
10		calculated from maize on 7 to 10% slopes, mean of 6 plots	0.66	-	1.5	Kenya	Katumani	Ulsaker & Kilewe (1984, p. 233)

Table 41-2Annex: Detailed P factors for ridges

Table 41-2 Annex: Detailed P factors for ridges

Table 41-2Annex: Detailed P factors for ridges

no.	method	description	P factor[*1]		measurement period	country	location	literature
			mean	extremes	[a]			
1	ridges on contour	ridges 1 m apart on 7 to 13% slopes	0.36	0.3 to 0.59	2 years with 3 reps	Colombia	Santander de Quilichao	Reining (1991, p. 111)
2	- " -	as no. 1 but slopes 13 - 20%	0.08	0.06 to 0.15	2 years with 2 reps	- " -	Mondomo	- " -
3	ridges along slope	ridges along slope 1 m apart with cassava for slopes 7 - 13%	4.4	4 to 6	2 years with 3 reps	- " -	Santander de Quilichao	- " -
4	- " -	as no. 3 slopes 13 - 20%	0.93	0.31 to 3.4	2 years with 2 reps	- " -	Mondomo	- " -
5	tied contour ridges with plow	7% slope, measured with pineapple	0.07	-	4	Ivory Coast	Adiopodoum	Roose (1975, p. 39)[*1]
6	- " -		0.21	0.1 to 0.2	-	-	-	Roose (1977, p. 70)
7	tied contour ridges with notill	ridges (25 cm high) are established in 1st year, afterwards notill, ties (10 - 15 cm high) established every year; 4.5% slope, crop on ridge		0.1 to 0.27	4	Zimbabwe	Domboshawa	Vogel (1992, p. 13)
8	- " -	as no. 7	0.035	0 to 0.14	4	- " -	Makaholi	- " -

[*1] berechnet aus Roose (1975), S. 39, Tab. 23: (1.6/(0.5*(8.6+15.5))*0.5; last 0.5 from Wischmeier & Smith (1978) for contour planting on 7% slopes

Table 41-3 Annex: Detailed P factors for mounds
Table 41-4 Annex: Detailed P factors for bunds.

Table 41-3Annex: Detailed P factors for mounds

no.	description	P factor*1		measurement period	country	location	literature
		mean	extremes	[a]			
1	cassava mounds	1.13	-	1	Ivory Coast	Adiopodoum	Roose (1975, p. 39)
2	pineapple mounds	0.29	-	-	- " -	- " -	

Table 41-4Annex: Detailed P factors for bunds

no.	method	description	P factor*1		measurement period	country	location	literature
			mean	extremes	[a]			
1	stone bunds	3% slope; 30 cm high stone bunds every 80 cm vertical distance, on contour; 1st year	0.27	-	1	Niger	Allokote	Rose & Bertrand (1971, p. 1276)
2	- " -	as above but 2nd and 3rd year	0.05	-	2	- " -	- " -	- " -
3	earthen bunds	like stone bunds no. 1 but with less stones which cover an earthen core vegetated by natural herbes	0.0022	-	1	- " -	- " -	- " -
4	- " -	as above but 2nd year	0.04	-	1	- " -	- " -	- " -

Table 41-5 Annex: Detailed P factors for buffer strips

Table 41-5Annex: Detailed P factors for buffer strips

no.	vegetation of strip	description	P factor^{*1}		measure-ment period	country	location	literature
			mean	extremes	[a]			
1	fallow vegetation	1st year; 2 m large strip on 4% slope and 46 m cropped interspace (groundnut + maize)	0.117	-	1	Ivory Coast	Bouake	Roose & Bertrand (1971, p. 1276
2	- " -	as no.1 but 2nd year: cropped to maize + maize	0.113	-	1	- " -	- " -	- " -
3	- " -	1st year; 4 m large with fallow vegetation (rest like no. 1)	0.04	-	1	- " -	- " -	- " -
4	- " -	2nd year; 4 m large (rest like no. 2)	0.104	-	1	- " -	- " -	- " -
5	- " -	2 m large, interspace 15 m cropped to cassava on heaps	0.3	-	1	- " -	Adioupodoum	- " -
6	- " -	4 m large, interspace 15 m cropped to cassava on heaps	0.1	-	1	- " -	- " -	- " -
7	Andropogon gayanus	3% slope; three rows of A. gayanus every 40 cm vertical distance, contour ridges in between; 1st year	0.64	-	1	Niger	Allokoto	- " -
8	- " -	like no. 7 but 2nd and 3rd year	0.12	-	2	- " -	- " -	- " -

Table 41-5 Annex, continue

no.	vegetation of strip	description	P factor*1		measurement period	country	location	literature
			mean	extremes	[a]			
9	grass	1 m large strip on contour 10 m apart, cassava between strips (7 to 13% slopes)	0.92	1.04 (1st year) to 0.89 (2nd year)	2 years with 3 replications	Columbia	Santander de Quilichao	Reining (1991, p. 111)
10	- " -	like no. 9 but slopes 13 - 20%	0.09	0.08 (2nd year) to 0.15 (1st year)	- " -	- " -	Mondomo	"
11	Pennisetum or Trypsacum or Setaria with or without Sesbania or Grevillea*1	strips (width?) every 10 m on 54% slope	0.14	0.07 to 0.23	0.5 with 6 plots	Rwanda	Gakenke	Nyamulinda (1991, p. 48)
12	- " -	strips every 5 m on 50% slope	0.88	0.47 to 1.7	0.5 with 6 plots	- " -	Mbwe	- " -
13	Pennisetum or Trypsacum or Setaria with or without Grevillea or Calliandra*1	strips every 5 m on 60% slope	0.49	0.39 to 0.57	0.5 with six plots	- " -	Rutoyi	- " -

*1 Pennisetum purpureum; Trypsacum laxum; Setaria splendida; Grevillea robusta; Sesbania sesban; Calliandra calothyrsus

Annex 4.2 Some useful species for soil and water conservation

Table 42-1 Annex: Useful species for erosion control, green manuring, mulch or cover crop

Table 42-1 Annex: Useful species for erosion control, green manuring, mulch or cover crop (abbreviations: p = perennial; a = annual;

botanical name	common name	remarks	longevity	ecology*1							
				biotemperature	rainfall [mm]	pH	drought	waterlogging	salt	shade	literature
Axonopus affinis	carpet grass	mainly for erosion control on risers and waterways	p	?	h	5.1-6.0	-	-	-	-	1
Brachiaria mutica	para grass	mainly for erosion control on waterways	p	> 22	1000-2000	4.5-5.0	-	+	-	-	1
Cajanus cajan	pigeon pea	leguminous bush, severely attacked by termites	p	> 18	< 400-4000	4.5-> 8.1	+	-	-	-	1
Calopogonium mucunoides	Calopo	leguminous cover crop	p	> 22	1000-4000	4.5-6.0	-	-	-	-	1
Canavalia ensiformis	Jack bean	leguminous crop for cover and green manure	a	> 18	600-4000	4.5-7.0	+	-	-	+	1
Centrosema pubescens	Centrosema	leguminous cover crop	p	?	h	?	+	-	-	?	1
Crotalaria juncea	sun hemp	leguminous green manure	a	> 14	400-4000	5.6-7.0	+	-	-	-	1

(abbreviations: p = perennial; a = annual; h = humid; sh = sub-humid; + = tolerant;– = intolerant)

botanical name	common name	remarks	longevity	ecology*1							
				biotemperature	rainfall [mm]	pH	drought	waterlogging	salt	shade	literature
Cynodon dactylon	Bermuda grass	mainly for erosion control on roads	p	> 12	400-4000	5.1-> 8.1	+	-	-	-	1
Desmodium intortum	greenleaf desmodium	leguminous cover and green manuring crop	p	14-24	h	5.6-6.0	-	-	-	+/-	1
Digitaria decumbens	Pangola grass	mainly for erosion control: good fodder	p	> 16	800-4000	5.1-8.0	-	-	-	-	1
Eragrostis curvula	weeping lovegrass	mainly for erosion control on roads	p	10-24	< 400-1600	5.6-> 8.1	+	-	-	-	1
Indigofera spicata	creeping indigo	leguminous cover crop	p	> 22	1600-4000	?	-	-	-	-	1
Lablab purpureus	lablab bean	leguminous cover and green manuring crop	a	8	400-4000	6.6-7.5	+	-	-	-	1
Leucaena leucocephala	leucaena	leguminous bush for hedges and mulch	p	?	h	> 6.5	+	+	-	+	1
Lotononis bainesii	Lotononis	leguminous cover crop	p	?	?	?	+	-	-	?	1
Lupinus luteus	yellow lupine	legminous cover and green manuring crop	a	6-22	400-1800	4.5-7.5	-	-	-	-	1
Melinis minutiflora	molasses grass	cover crop and erosion control	p	> 20	1000-4000	4.4-5-0	-	-	-	-	1

botanical name	common name	remarks	longevity	ecology*1							
				biotemperature	rainfall [mm]	pH	drought	waterlogging	salt	shade	literature
Mucuna capitata	velvet bean	legminous cover and green manuring crop	a	?	h	?	?	?	?	?	1
Panicum maximum	Guinea grass	good on risers; fodder	p	> 20	600-4000	4.5-6.0		-	-		1
Paspalum notatum	Bahia grass	cover crop and erosion control	p	> 12	800-4000	5.1-> 8.1		-	-	-	1
Pennisetum clandestinum	Kikuyu grass	erosion control in highlands	p	8-24	600-4000	5.1-6.0		-		-	1
Pennisetum purpureum	elephant grass	fodder and mulch	p	> 8	600-4000	4.5-5.5			-	-	1
Stylosanthes guianensis	stylo	legminous cover and green manuring crop	p	> 20	1000-4000	4.5-5.0	-	-	-	-	1
Vigna unguiculata	cowpea	legume	a	> 14	600-4000	4.5-> 8.1		-	-	-	1
Euphorbia balsamifera		live hedge, propagated by cuttings or seeds	p	-	-	-	-	-	-	-	1
Jatropha curcas	pourgh re	live hedge seeded; slow establishment; cuttings severely attacked by termites	p	-	-	-	-	-	-	-	2

botanical name	common name	remarks	longevity	ecology[*1]							
				biotemperature	rainfall [mm]	pH	drought	waterlogging	salt	shade	literature
Agave sisalana	sisal	live hedge; sometimes not accepted close to homesteads (hide-away for snakes)	p	> 22	< 400-4000	5.6-> 8.1	+	-	-	-	2
Andropogon gayanus	Gamba grass	erosion control; fodder	p	> 18	1600-4000	4.5-5.0	+	-	-	-	2
Bracharia ruziziensis	Congo grass	erosion control; fodder; quick establishment, regrowth very variable	p	?	?	?	-		-	?	2
Stylosanthes hamata		erosion control; rapid regrowth	p	?	?	?	?	?	?	?	2
Tephrosia vogelii		green manure on clayey soils	p	> 24	1000-4000	4.5-7.5	-	-	-	-	3
Phacelia tanacetifolia	phacelia	fodder, cover and gree manuring crop	a	?	?	?	?	?	?	?	3
Bothriochloa ischaemum	Turkestan bluestem	recultivation of eroded pastures	p	8-10	1000-1400	6.1-7.0	+	-	-	-	3
Pueraria phaseoloides	kudzu	leguminous, creeping cover and green manuring crop, fodder	p	> 22	1000-4000	4.5-7.0	-	+	-	+	3

botanical name	common name	remarks	longevity	ecology[*1]							
				biotemperature	rainfall [mm]	pH	drought	waterlogging	salt	shade	literature
Mucuna utilis	velvet bean	leguminous cover crop and vegetable	a	?	?	?		-	-	?	3
Mucuna mucunoides		leguminous, creeping cover crop	a	?	?	?	?	?	?	?	-

*1 most of the ecological data were from Duke & Terrell (1974)

Literature:
1 Sheng (1989)
2 Hijkoop et al. (1971)
3 Rehm & Espig (1976)

Table 42-2 Annex: Useful trees according to rainfall area (Weber & Stoney, 1986)

annual precipitation [mm]		
200 to 500	**500 to 900**	**900 to 1200**
Acacia albida	Adansonia digitata	Albizia lebbeck
Acacia radiana	Anacardium digitata	Anoegeissus leiocarpus
Acacia senegal	Azadirachta indica	Borassus aethiopum
Annona senegalensis	Bauhinia spp.	Butyrospermum parkii
Balanites aegyptiaca	Cassia siamea	Casuarina equisetifolia
Boscia salicifolia	Combretum spp.	Cordia abyssinica
Commiphora africana	Eucalyptus camaldulensis	Dalbergia melanoxylon
Conocarpus lancifolius	Ficus sycomorus	Erythrina abyssinica
Dobera glabra	Haxoxylon persicum	Markhamia spp.
Euphorbia balsamifera	Parkia biglobosa	Tamarindus indica
Maerva crassifolia	Salvadora persica	
Parkinsonia aculeata	Sclerocarya birrea	
Prosopis juliflora	Tamarix articulata	
Ziziphus spp.	Terminalia spp.	

Further information on suitable species can be found in:

Young (1989)
Hudson (1975)
von Maydell (1983)
Merlier & Montegut (1982)
ICRAF/GTZ Multipurpose Tree & Shrub Database

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