SOIL EROSION BY WATER
-CAUSES AND CURES.
WITH SPECIAL REFERENCE TO MAZIMBU ANC-FARM, MOROGORO TANZANIA

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1988

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PREFACE

This thesis is the result of a request from ANC-Mazimbu for assistance with enhanced erosion at the farm. We received the request via Johs. Bergedalen, who is responsible for soil conservation planning at Mazimbu. He intended the project to be a case study for graduate students at the Agricultural University of Norway (AUN).

The travel and the stay were organized by NORPLAN A/S and NORAGRIC, and financed by the Norwegian Ministry of Foreign Affairs. We are greatful for their contribution, which made this thesis possible.

Many persons have been involved, and we are very pleased for their contribution to fulfill the work. There are some people we want particurlarly to thank.

Johs. Bergedalen at the Department of Hydrotechnics, and Svein Skøien at the Department of Soil Science have been our professional supervisors. We thank them both for their advice and comments during the work.

At the Sokoine University of Agriculture (SUA) in Morogoro, we received professional assistance from Peter Mtakwa. Abel K. Kaaya guided us through soil profile descriptions. Both of them, as all of the Mtakwa family, offered us their friendship. We appreciated it very much; thank you all! Thanks also to Prof. Pőcs at the Department of Forest Biology and to his assistant Eugene Sontiera for preserving and identifying plant species. And thanks to all others who answered questions and offered help at the university.

In Tanzania, we also had valuable help from the NORPLAN staff, and from several public offices to obtain necessary information for the thesis. We are very greatful.

We also wish to thank those who helped us in Norway. Special thanks to Liv and Ola for their patience, care, support and help during these last months. Bernt Johansson, Kate Chapman, Judith Meadow, Mike Moulton and Karl Kerner have struggled with our English. Thank you for corrections and advice!

Last, but not least; thanks to Tom, Mahmoed, Chaephus and the rest of the farm staff at Mazimbu, who helped us with practical work and taught us about the farm. Thanks also to the Mazimbu community represented by Chief Administrator Maseko for hospitality at Mazimbu.

Our period in Mazimbu taught us a lot about soil erosion and soil conservation. But more important: We learned about South-Africa, and we met people fighting for justice. Thank you all for teaching us about the world. We support your struggle!

PREFACE

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SUMMARY

SUMMARY

Litterature concerning general theory about soil erosion by water, and soil conservation is studied. Emphasis is laid on litterature concerning tropical climates and mechanized farming. Data of importance for soil erosion are collected for the Mazimbu ANC - farm in Tanzania. The collected data are used to assess present soil erosion at the farm, and to prepare a soil conservation plan for the farm.

The main forms of soil erosion are splash erosion, interrill erosion, sheet erosion, rill erosion and gully erosion. Soil erosion is affected by the erosive forces of the rain (erosivity), the vulnerability of the soil to be eroded (erodibility) and topographic factors such as slope steepness, slope length and slope shape. Live plants or plant residues on the soil surface are very effective in reducing erosion.

Soil erosion assessment is a study of soil erosion state, erosion rate or erosion risk in an area. The assessment of erosion is important in land use planning and soil conservation work. Soil erosion models are valuable tools in the study of erosion. The Universal Soil Loss Equation (USLE) is an empirical model derived in USA. USLE predicts soil loss caused by rill and interrill erosion, and the equation can be used for the determination of conservation practices. There are several objections to transferring USLE to tropical climates. Another empirical model, Soil Loss Estimation Model for Southern Africa (SLEMSA) has been developed in Zimbabwe. Less input data are needed for SLEMSA than for USLE. SLEMSA estimates soil loss by interrill erosion.

Soil erosion can be controlled with soil and crop management and/or mechanical practices. The main objectives of soil and crop management in erosion control are to provide a soil surface that is resistant to erosion and to provide a protective cover of live plants or plant residues (mulch) on the soil surface. The main crop management factors in erosion control are crop rotations, the use of cover crops, multiple cropping, mulching, and strip cropping. It is also important to provide suitable nutrient conditions and growth conditions for the crops. Soil management

in erosion control is mainly connected to tillage. Conservation tillage is tillage systems which reduce soil loss since crop residues are left on the soil surface and/or the surface is left rough, porous, cloddy or ridged. Several conservation tillage systems are described under the headings stubble mulch tillage, reduced tillage and no tillage.

Mechanical practices in erosion control involves a modification of the land surface. The mechanical constructions control runoff without exessive erosion, or water is stored on the soil surface untill it infiltrates into the soil. Main mechanical practices are contouring, ridging, grass stripping (buffer strips), terraces and waterways.

The Mazimbu ANC - farm was visited in June/July 1987. Information about climate, geology, vegetation, soils and about the farm management were collected. Some soil conservation work were initiated. Values for the USLE (US units) have been estimated. Several equations were used to estimate the R-value, and R=197 was adopted as the most representative value. The adopted R-value is not very high, which reveals that the rain at Mazimbu has moderate erosivity. Soil erodibility (K) varied between 0.04-0.31. The main K-values were within the range of 0.10-0.22. It is therfore assumed that soil erodibility is rather low. The estimated topographic factors (LS) fluctuated between 0.33-2.02, which are rather moderate values. A C-value of 0.82 was obtained from research in Kenya (Onstad et al. 1984). This C-value represents the cultivation practices of growing maize (Zea mays L) in mouldboard ploughed soil. This is similar to the current practices at Mazimbu and it is therefor assumed that the soil and crop management practiced at Mazimbu are main reasons for the erosion. This assumption is supported by referred litterature.

Potential soil loss (Ap) under maize cultivation was estimated by USLE. The potential soil loss varied between 24-110 t/ha/y for the arable crops. These estimated Ap-values are high above the acceptable soil loss, which was set to 5 t/ha/y. Both the high potential soil loss and the observed erosion in the fields indicates that erosion is severe, and that soil conservation work must be initiated.

USLE was used as a basis for soil conservation planning at Mazimbu. To reduce soil loss below the acceptable level, the soil should be protected with mulch (3 t/ha), and grass buffer stripping should be practiced. Mulching resulted in a C-factor of 0.23, and the grass buffer strips gave a P-factor of 0.30. Calculations revealed that mulching and grass buffer strips could reduce soil loss as wanted for those fields with potential soil loss under 60 t/ha/y. On the fields with higher potential soil loss, graded buffer strips or permanent grass was recommended.

The final conservation plan included the following main recommendations:

1) Crop management should be improved by improved rotations.
2) Soil management should be improved by conservation tillage.
3) Inflow from the surroundings and runoff within the fields should be controlled by a stormwater drain, waterways and grass buffer strips.

1 INTRODUCTION

1.1 GENERAL INTRODUCTION

The removal and sedimentation of soil by wind and water; soil erosion, always has occured as a natural, geological process. Soil erosion by water is probably more important and widespread than wind erosion, and it is a function of the erosivity of the rain, running water and the erodibility of the soil. Rainfall erosivity can be defined as the potential ability of the rain to cause erosion. Soil erodibility is defined as the vulnerability of the soil to be eroded (Hudson 1981).

Erosion hazard varies in different geographical locations and climates. In some countries and on some farms erosion causes severe damage, and much effort is required to take care of the soil. Especially areas in the tropics are severely exposed to erosion, mainly because of the high erosivity of the rain. Rainfall in the tropics often has high intensity, and detaches and destroys soil aggregates more than rain of lower intensity in more temperate climates.

Accelerated erosion occurs when man's activities, particurlarly agriculture, causes increased rate of soil loss. Agriculture often leads to clearing of the natural vegetation, which originally protected the soil surface from the raindrops as well as leading to high infiltration capacity of the soil through root activity and plant residues in the surface. Cultivated land is normally covered by plants only a period of the year. Planting in tropical climates often takes place in the beginning of the rainy season. Hence the soil has little protection when the rain starts, and falling rain and runoff can cause severe erosion.

Tillage operations like ploughing and harrowing enhance erosion by destroying soil structure and compaction of soil by heavy machinery. Compaction leads to less infiltration and increased runoff. Not all agricultural systems have the same serious effects on erosion, but generally intensive, highly mechanized agriculture with no conservation measures lead to more erosion than less intensive, manually cultivated land.

Overgrazing is another factor leading to accelerated erosion. Plant cover is removed by grazing animals, the soil can be compacted and soil structure destroyed by trampling animals. In catchments near Dodoma, Tanzania, Rapp et al. (1972b) stresses the importance of overgrazing as a factor causing soil erosion.

The results of soil erosion are many; from the loss of fertile topsoil to landslides and big gullies. The loss of topsoil means that soil with good structure and high content of nutrients and organic matter are washed away, and less productive soil is exposed. This means that plant growth conditions are deteriorated, leaving previous fertile areas unproductive, sometimes as deserts. Further, the soil that is transported by water can be sedimented on cultivated land, on roads, in rivers, reservoirs and irrigation systems. Sedimentation of reservoirs for water storage can reduce their total and economical life-time (Rapp et al. 1972b). In Norway, there is much attention towards erosion as a factor of pollution, since eroded topsoil often is very high in nutrients, especially phosphorus.

Landslides can be a result of erosion when steep slopes are deforested and left unprotected to heavy rainstorms. This is studied in the Mgeta area, Tanzania by Temple and Rapp (1972).

1.2 INTRODUCTION TO STUDY

1.2.1 Study area

Mazimbu is a community for the African National Congress (ANC), located at an abandoned sisal estate near Morogoro, Tanzania (figure 1.1.). The main activity at Mazimbu is education, as the Solomon Mahlango Freedom College (SOMAFCO) is located here. SOMAFCO offers education on different levels, including secondary, primary and nursery schools. The schools were established to give young South-Africans who left and those still leaving South Africa the possibility for an education. In addition to the education centre, Mazimbu has a hospital, small industries and a farm, a part of which is the objective of this study.

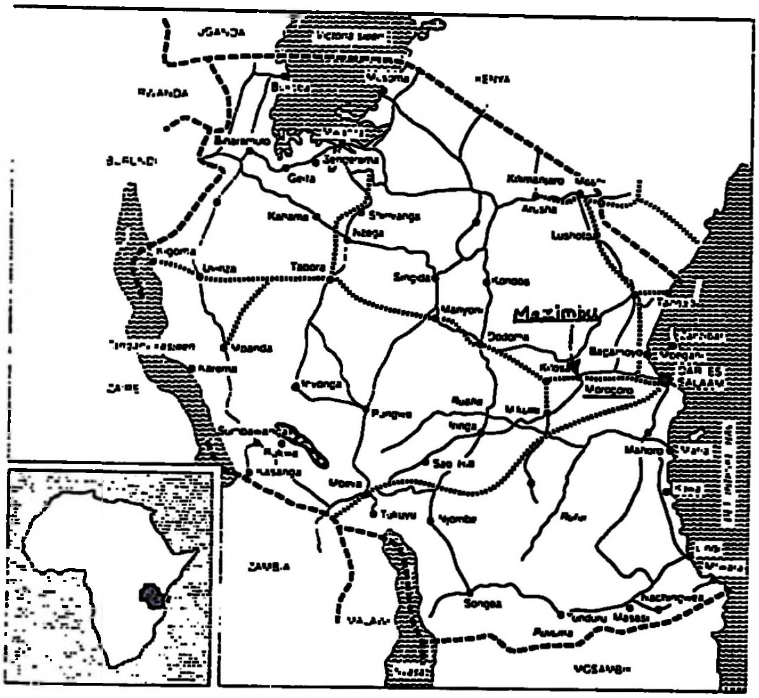


Figure 1.1 The location of Mazimbu.

ANC states that "the farm is intended to make us self-sufficient in food as far as possible and train ANC agricultural workers" (ANC SOMAFCO 1985). Capital intensive methods of farming were chosen to maximize yields and to be able to offer such training. For cultivation, this has lead to the use of highly mechanized tillage systems, which is partly to blame for the soil erosion that occurs at Mazimbu today.

Cultivation started in 1981, and since then more land has been put into production each year. In 1987 approximately 450 hectars were cultivated. Soil erosion at Mazimbu has been a growing problem as the cultivated area expanded. The severity of the erosion was recognized by people at Mazimbu, and they realized that soil conservation had to be practiced at the farm. For, as the ANC authorities stated; the ANC wants to leave the land in a good condition.

1.2.2 Objectives and limitations

The objectives of this study are mainly:

a) To study the general principles of soil erosion; its causes and cures.
b) To evaluate soil erosion at Mazimbu, and to make a soil conservation plan for the farm.

Since the thesis results in a soil conservation plan for a highly mechanized farm in Tanzania, effort is made to relate the theoretical parts to the tropics and to mechanized farming. Traditional farming systems with respect to soil conservation are only briefly reported.

For the conservation plan, it has not been possible to analyse and discuss the economic consequenses of fulfilling or not fulfilling the plan.

1.2.3 Working scheme

A case study was done by Johs. Bergedalen in February 1987. This resulted in a preliminary report on the actual erosion and proposals for soil conservation. It was agreed that two main waterways should be constructed by the ANC as soon as possible, before June/July 1987.

The main field period was in June/July 1987. Climatic data from the Morogoro district and data from the farm were collected. Erosion features in the fields and soil properties were registered, and soil samples taken for further analysis. Planning of physical constructions were continued, and the construction of two main waterways was nearly completed. Contours were made on one field. It was agreed that the waterways should be completed by the ANC with Peter Mtakwa as a consultant. According to

Mtakwa, it has been difficult to fulfill the work for various reasons.

The processing of farm data and climatic data as well as soil analysis were carried out in January - June 1988, parallel to the litterature-study and thesis-writing.

2 THE MECHANICS OF EROSION BY WATER

Erosion processes involve three phenomena, namely, detachment, transport and deposition of soil materials by rainfall and running water.
Detachment is the separation of soil particles from the soil mass.
Transport is the removal of soil particles from one place to another place.
Deposition occurs when no transport agents exist any more.

Ellison (1947) defined that "soil erosion is a process of detachment and transportation of soil materials by erosive agents". The erosive agents are raindrops and runoff (running water). Rainfall is the major source of erosion depending on the quantity, the distribution throughout the year, the intensity and raindrop size (Hudson 1986). Runoff begins when rainfall intensity exceeds the rate of infiltration and the total volume of the rainfall exceeds the surface storage capacity (Hillel 1982).

2.1 DETACHMENT, TRANSPORT AND DEPOSITION

Although the three erosion processes are easily recognized when occurring on a large scale in a farmfield detachment, transport and deposition also occur together on a small scale in any given area.

2.1.1 Splash erosion

Raindrops which fall on bare soil are the initial detachment process of erosion. The raindrops detach soil particles from the soil mass on impact through their kinetic energy. These splashed particles can be dispersed more than 60 cm and move horizontally more than 150 cm on level surfaces. The ability of the raindrops to disperse soil particles is dependent on their final velocity and the drop size when reaching the soil surface (or rainfall intensity, because raindrop distribution often depends on the intensity). Once both soil particles and aggregates are detached from the mass, they are readily available for transport by running water. (Ellison 1947)

At the same time as splashing occurs, rainfall compacts the soil surface, either by the beating action of raindrops (Ekern 1950) or as a result of the spontaneous slaking and breakdown of soil aggregates during wetting (Hillel 1982), and a denser layer is created on the soil surface. This is called surface crust reduce the rate of water infiltration into the soil, which in turn, increases the surface runoff.

2.1.2 Interrill erosion

When either soil moisture storage is saturated or rainfall intensity exceeds the infiltration rate of the soil, there is a transition phase in which both rainsplash erosion and interrill erosion (=sheet erosion) occur simultaneously. Soil transport occurs uniformly over the field due to both splash and interrill erosion which still have some ability to scour soil surfaces. Uniform detachment and transport occur when the field has a relatively uniform slope and has no vegetation. If the soil particles detached by rainsplash, exceed the transport capabilit of interrill flow, some of the soil particles are deposited immediately (Meyer 1986).

As water depth on the field increases, raindrop energy which disperses soil particles does not actually reach the soil surface. Therefore, runoff water of the interrills becomes the dominant agent causing both detachment and transportation.

2.1.3 Rill erosion

Because of more intense rainfall or irregularity of the soil surface, interrill flows concentrate in places which are lower or are vulnerable against running water. This is the onset of rill erosion. The rilling is associated with saturation of the soil by rainfall so that it is not recognized on the upper parts of the slope (Morgan 1986). Meyer (1986) showed simply how the slope length contributes in a similar manner to various types of erosion (Fig.2.1.).

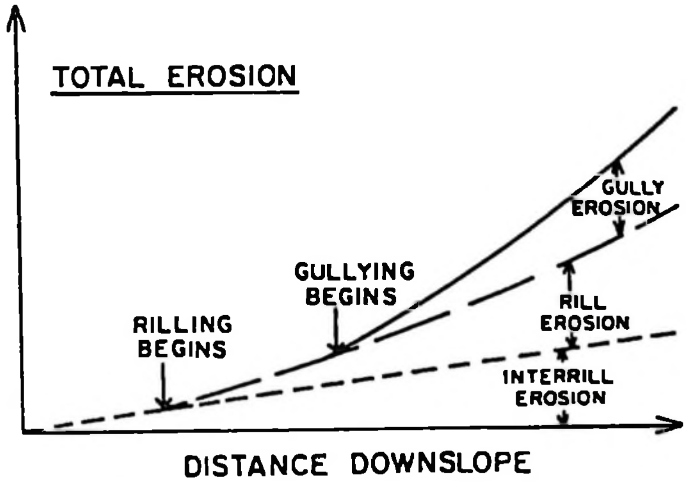


Figure 2.1 Contribution of slope length to various erosions (after Meyer 1986)

The ability of runoff to transport materials is dependent on the velocity and the turbulence. The slowest flow velocity which is capable of initiating the movement of particles, is called the critical erosion velocity. The critical erosion velocity varies with the grain size and the state of the flow, turbulence. The relationship between grain size and the state of flow shows that the presence of particle diameters 0.2-0.5mm indicates the minimum critical erosion velocity, because these grain sizes are the most vulnerable to streamflow due to the reduced cohesiveness of the particles and reduced friction between particle (Sundborg 1956).

The most important factor to start rilling is the length of the slope. An increased slope length may accumulate interrill flows to rill flows which have a greater capacity to transport materials in it. Rill erosion also increases with slope steepness. If running water in rills contains less material than its transport ability (less material supplied by rainsplash and more water supplied by rain), rills start to undercut the bottom and sides so that the rills may keep their balance of detachability and transportability. The process can easily be recognized through revealing small eroding headcuts or knickpoints during rains. The headcuts move upwards for as long as the rainfall lasts (Meyer 1986).

2.1.4 Gully erosion

The distribution of gully erosion in the world appears to be dominated by arid and semi-arid areas which are the most vulnerable to climatic change and the influence of man.

Gullies often have ephemeral streamflow. They are incised into the subsoil layer, and may have a V-shaped cross section, where the subsoil is fine in texture and resistant to rapid cutting, but U-shaped where the subsoil is susceptable to erosion. They are usually bordered by steep sides and heads which often have the apparance of erosional scarps. They are usually so deep that restoration is impossible with normal tools and they can not be crossed by a wheeled vehicle or eliminated by ploughing (Gregory and Walling 1983).

Gully erosion results from higher soil removal by more concentrated runoff water than rill erosion. Gullies are in large scale affected by the landscape (Ellison and Ellison 1947). The gullies are ordinarily formed by surface runoff, however, extreme runoff of subsurface runoff causes the development of gullies (Zachar 1982).

The onsets of gully erosion are affected by two main factors; man-made ones which lead to accelerated erosion, such as improper land use, burning of vegetation, overgrazing, construction site, etc. and natural factors such as changes of climate, topography, etc,. The severity of gully erosion, causes detachment of large amounts of soil and consequent sedimentation which silts up many agricultural facilities such as reservoirs and canals. If no control measures are taken, people eventually have to abandon their farms because of unfertile soils (both eroded areas and soil deposited areas) and because the land will have an unsuitable topography for cultivation.

2.2 FACTORS AFFECTING WATER EROSION

Erosion which is caused by water (raindrops and runoff), was studied by Ellison (1944, 1947). He proved that the most important factors influencing the water erosion would be (1) variables of rainfall (the storm), (2) soil characteristics, (3) slope of the surface, (4) protection of the soil surface against rainfall impact, such as the vegetal canopies, mulches, etc,. Different variables have been proposed by numerous researchers, but this simple grouping has been commonly accepted. The factors are discussed in detail below.

2.2.1 Erosivity

Hudson (1986) defines erosivity as the potential ability of rain to cause erosion. It is a function of physical characteristics of rainfall.

Erosivity = f(amount x intensity x raindrop size x drop size distribution x terminal velocity)

The role of rainfall that causes soil detachment and transport, was dealt with in chapter 2.1. Ellison (1944) established the relationship between soil loss and rainfall characteristics through conducting artificial rainfall tests. He obtained the following relation:

$$E = C \times V^{4.33} \times D^{1.07} \times I^{0.65}$$

where

E = soil loss by splashing during 30-minute period (g)

V = drop velocity (ft/sec)

D = diameter of drops (mm)

I = intensity (in/hr)

C = constant

However, practically speaking, it was very difficult trying to measure V and D under natural rainfall conditions.

Wischmeier et al.(1958) obtained the equation calculating the kinetic energy based on the work of Lars and Parson who found a relation between the medium drop diameters and the intensity.

$$KE = 11.87 + 8.73\log_{10}I$$

where I is the rainfall intensity(mm hr^{-1}) and KE is the kinetic energy (joules m^{-2} mm^{-1})

Hudson (1986) gives a similar equation for kinetic energy based on his measurements in Zimbabwe.

$$KE = 29.82 + \frac{127.51}{I}$$

And several other equations have been published as shown in figure 2.2.

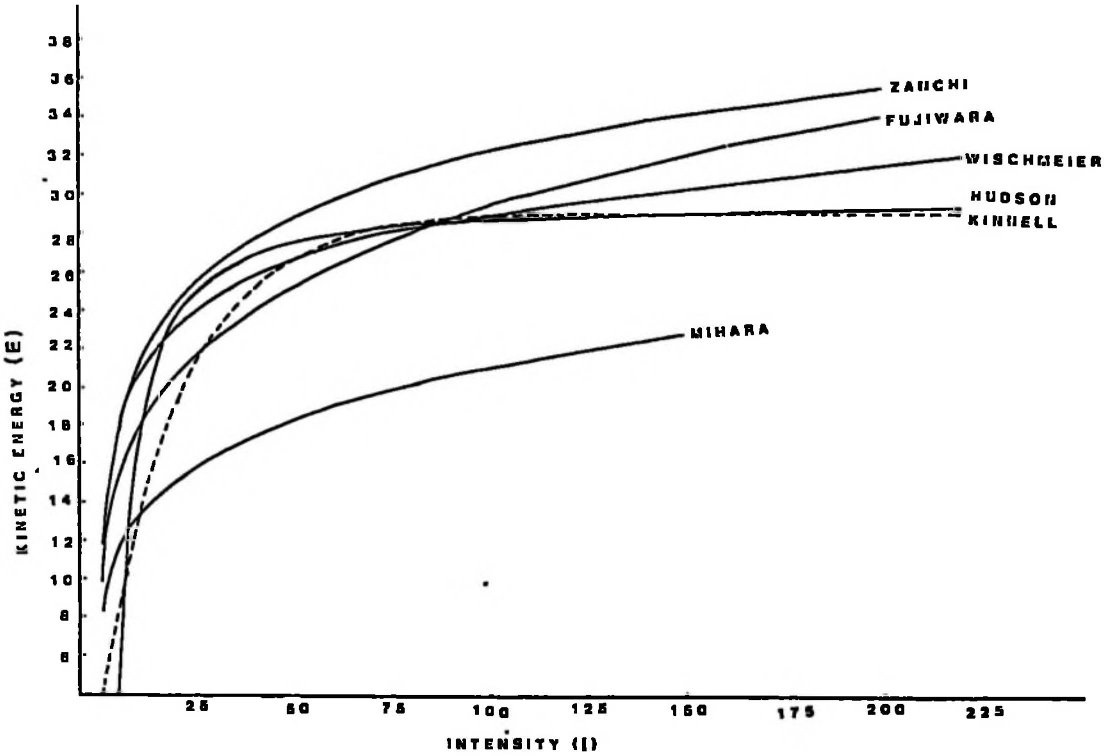


Figure 2.2 The relationship between kinetic energy and intensity
Zanchi: Zanchi and Torri (1980)
Fūjiwara: Fujieara et al. (1984)
Wischmeier: Wischmeier et al. (1958)
Hudson: Hudson (1986)
Kinnell: Kinnell (1984)
Mihara: Fujiwara et al. (1984)

These various equations show that the rainfall characteristics vary from place to place in the world. Therefore, rainfall erosivity indices, which will be discussed below, have already proven their validity in Africa.

Rainfall erosivity index is an expression of the rainfall characteristics based on kinetic energy.

The index according to Wischmeier et al. (1958): EI_{30}
They discovered the relationship between soil loss (by splash, interrill and rill erosion) and rainfall energy of rainstorms. The best parameter of soil loss is the product of the kinetic

energy of the storm and the maximum intensity in a 30-minute period.

The index according to Hudson (1986) in Zimbabwe: KE>25
This means the total kinetic energy of all the rain falling at more than 25 mm/hr, and only rainfall intensities higher than 25 mm/hr promote erosion.

The indices according to Stocking and Elwell (1973) in Zimbabwe: EI_{15} and EI_5
They found that the EI_{30}-index provides a better correlation to soil loss on bare soil. However, they found that EI_{15} and EI_5 are better indices in the case of all covered plots with nearly maximum vegetal cover and for high density late season crops.

Some approximations of rainfall indices are also proposed for Africa
The index by Lal (1976): AI_m
This index is a product of rainfall amount (A) and Maximum intensity over a 7.5-minute interval (I_m). The index is simpler to compute than EI_{30}, KE>25, etc.. One can use the index where data from recording rain gauges are not available.

The index by Arnoldus (1980) is based on Fouriner's index: $\sum_{1}^{12} \frac{p_m^2}{P}$

Where
p_m = monthly rainfall
P = annual rainfall

The index is highly correlated with sediment yields from very large(>10,000 km^2) river basins.

2.2.2 Validity of the erosivity indices in Africa

Stocking and Elwell (1973) studied the relationship between annual soil loss and several erosivity parameters such as KE (total kinetic energy), EI (kinetic energy x maximum sustained intensity), M (total momentum) and R (total rainfall) in Zimbabwe. Amongst them, EI-values generally gave a higher correlation to soil loss. But the most highly correlated parameter varies between plots and time of year. They analyzed whether cover conditions have a greater influence on the correlations than slope or soil type, and they found that EI_{30} is the best predictor on bare-fallow soil. But EI_{15} (kinetic energy x maximum 15 minute intensity) was a better index on plots where vegetal cover was less than maximum, and EI_5 (kinetic energy x max. 5 minute intensity) was a suitable parameter for full vegetal cover. The value of EI_5 is greater than EI_{15} or EI_{30}. This means that more intense or long duration rainfalls would need a threshold of soil erosion, since vegetal cover has the effect of reducing erosion.

Lal (1976) examined several types of erosivity indices for both runoff and soil loss on Alfisol soil in Western Nigeria. The indices covered a wide spread of parameters, such as KE, KE>25, EI_{30}, A (rainfall amount per storm) and I_m (peak rainfall intensity) as well as his own parameter AI_m. The experiment indicated that the correlation between %-runoff and the erosivity indices were very low except on the steepest slope (15 % slope). He found that the index AI_m had the best correlation with soil loss (I_m: 7.5 minute maximum intensity). He described how EI_{30} seems to underestimate the kinetic energy of tropical storms. He recommended the suitability of AI_m so that one can estimate the value where data from recording rain gauges are not available.

Onstad et al (1984) also tested the validity of several indices (AI_m, EI, A, KE, etc.) on Alfisol plots at Katumani in Kenya. All results showed a relatively lower correlation than foregoing experiments by Stocking and Elwell or Lal. AI_m and EI_{15} got a higher correlation coefficient than EI_{30}. KE>25 did not prove so effective there as in Zimbabwe either. They expressed that EI_{30} is a more appropriate index since the information of the Universal Soil Loss Equation (USLE: see chapter 3.2.1) is applicable.

2.2.3 Erodibility

The term erodibility means the ability of the soil to resist both detachment and transport. Soil erosion loss is dependant on rainfall, as discussed earlier, and topography and vegetative cover as will be discussed in the following chapter. Although these factors are constant, soil loss varies with soil properties (erodibility) (Bryan 1968), such as soil texture, soil structure, and chemical and organic composition. Soil particles and aggregates were already mentioned in chapter 2.1.

Soil texture is the key to understanding soil erosion by water. Some roles have already been mentioned in chapter 2 such as different particle size which resists detachment and transportation by raindrops and runoff. The most important indicator of erodibility is the ratio of silt, very fine sand and clay content. Clays generally have low detachability and high transportability due to the cohesive forces and the light mass. Coarse sands have the opposite characteristics, and are transported with difficulty due to the larger particle sizes. Consequently, silts are most vulnerable to raindrops and runoff (Ellison 1944).

Soil structure refers to the arrangement of the soil particles or aggregates, in which the forces holding the particles together are stronger than the forces separating them. The forces that bind the particles together are mainly affected by the content of organic materiales, iron and alumimum oxides and clays. The role of soil structure is important not only for crop productivity but also for soil erosion. The ability of soil to resist erosion is dependant on the type of soil structure and its stability. The stability of a structure means the detachability of particles from aggregates. The stable aggregates have a strong resistance to raindrop impact and running water. The stability of aggregates on the soil surface is particularly important. If unstable aggregates on the surface are broken down immediately by raindrops, the dispersed soil particles can form a thin layer. This thin crust layer hinders infiltration and increases runoff, which may detach more soil particles (Greenland 1977).

Infiltration rate of soils is also important in relation to runoff. Many researchers have shown that the infiltration rate of tropical soils under natural vegetation is relatively high. Root canals and biological activities of earthworm and termites strongly contribute to a high infiltration rate. However, the removal of the natural vegetation hinders these activities. The use of heavy farm machines results in the disturbance of soil structure and soil compaction which can cause a reduction of the infiltration rate (Lal 1979).

The clay type and amount, and the organic matter content of the soil is important for the aggregate stability. The amount of clays and organic materials govern the shear strength of the soil depending on the water content. The shear strength is expressed as a indicator of erodibility. Clay and organic materials may show similar properties as cementing agents of the aggregates. But the most important effect of organic matter is in forming water-stable aggregates which strongly affect soil erodibility by water. (Kandiah 1979)

Erodibility indices. Many reseachers have developed various indices of erodibility so that vulnerability of soils to erosion can be compared with each other. The measurement of the erodibility is based on the properties of the soil texture, i.e. the soil structure and the response of the soil to erosive agents such as water drops or running water. Some important indices will be mentioned below.

Water-stable aggregate(W.S.A) content was devised by Bryan (1968). The index is the ratio of W.S.A. larger than 0.5mm in the soil after rainfall simulation. The greater the amount of W.S.A. the more resistant the soil is to erosion.

Erodibility index (K) is the soil erodibility factor which represents the soil loss per unit of EI_{30} (Wishmeier and Mannering 1969). Soil loss is measured on a unit plot which is a 22m long, 9% slope in bare fallow. The index is accepted world wide in relation to the USLE equation (being presented in chapter 3.2.1). Wishmeier et al.(1971) devised a nomograph to predict K-values according to soil texture, organic content, soil structure and soil permeability (figure 2.3).

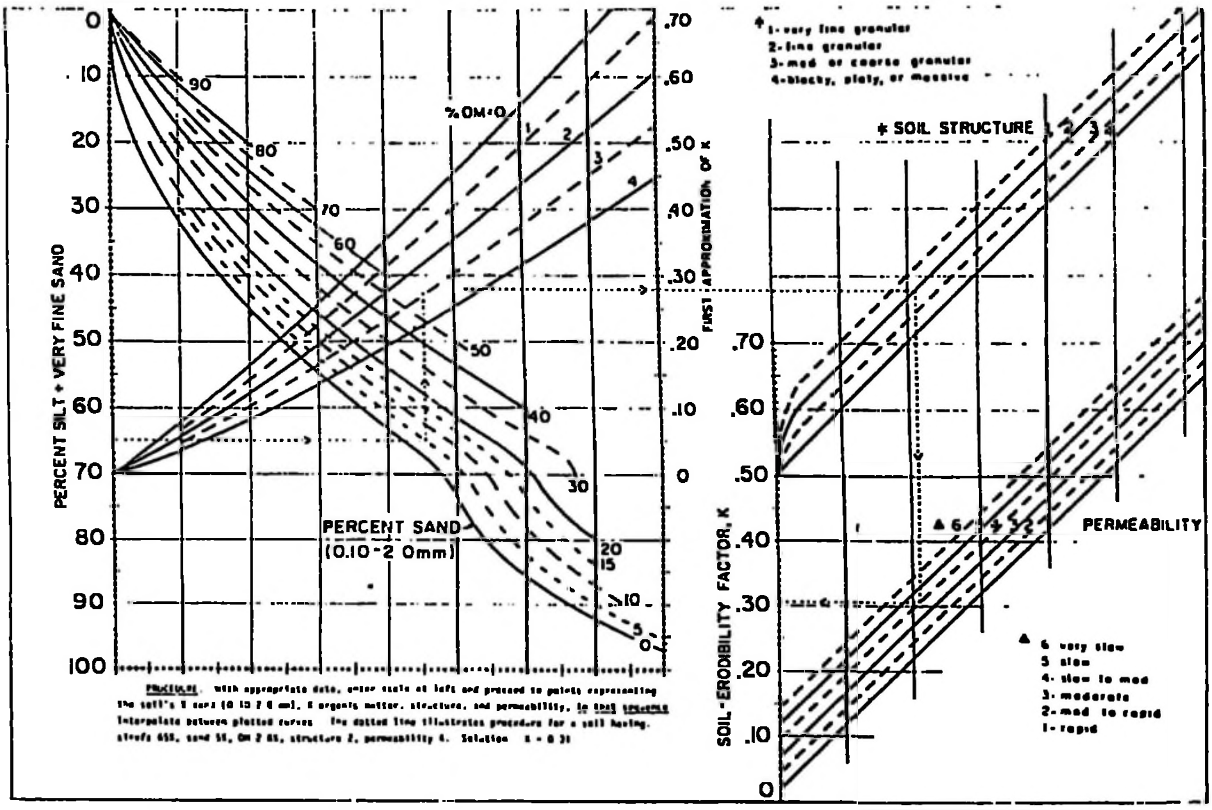


Figure 2.3 The soil-erodibility nomograph (after Wischmeier and Smith 1978)

2.2.4 Effect of topography

The influence of slope on erosion is easily recognised since steep land is more vulnerable than flat land. The effects of the following two components of water erosion are greatest. Firstly, on steeper surfaces raindrops splash soil particles downwards rather than upwards. Secondly, steeper slopes generate more runoff than flat land because on a steep slope in general, less rainfall infiltrates into the soil than on a flat slope. Increasing surface runoff due to slope steepness, causes higher water velocity which can erode more soil.

The relation between erosion and slope was first studied by Zing (1940). He expressed the relationship as follows:

$$A \propto S^m \times L^n$$

where A: soil loss per unit area

S: degree of land slope

L: length of land slope

m,n: constant

Various researchers found that n increases by 1.0 and m ranges between 1.0 and 2.0 (Morgan 1986). In other words, slope steepness has a greater effect on soil erosion than slope length. The reason for this is the higher velocity of runoff from steeper slopes which creates more detachment and transportation of soils.

Another feature of slope is the type of slope, that is, either concave slope or convex slope. On a concave slope, slope steepness decreases from the top of the slope to the toe so that flow velocity decreases as slope length increases. Conversely on a convex slope, it has the opposite effect where flow velocity increases as slope length increases so that it causes more water erosion on the toe of the slope (Castro and Zobeck 1986).

2.2.5 Effect of plant cover

There are major effects of plant cover to reduce water erosion. Firstly, plants intercept raindrops so that the plants reduce the impact energy of the raindrops to detach soils by splashing, and that some of the rain is kept permanent on the plants. Secondly, the roots or stem of the plants reduce velocity of runoff water by their physical resistance.

The effectiveness of plant cover in reducing erosion depends on the height, the continuity of the plant canopy, the density of the ground cover and root density (Morgan 1986). The effectiveness is further dependent on the plant type. The most effective plant cover on arable land is a well-managed sod. Plants have also various subordinate effects in reducing erosion. They improve soil structure, increase organic matter, increase permeability (infiltration) and increase water-stable aggregates (Kandiah 1979).

The effectiveness of agricultural crops varies with their growth stage and how fast crops cover the exposed bare soil. Elwell and Stocking (1976) attempted to find the relationship between percentage of plant cover and soil loss in Zimbabwe. Figure 2.4 shows that both soil loss and runoff decrease considerably when the degree of vegetal cover reaches about 50%, for example on maize growth. The soil loss especially, decreases dramatically.

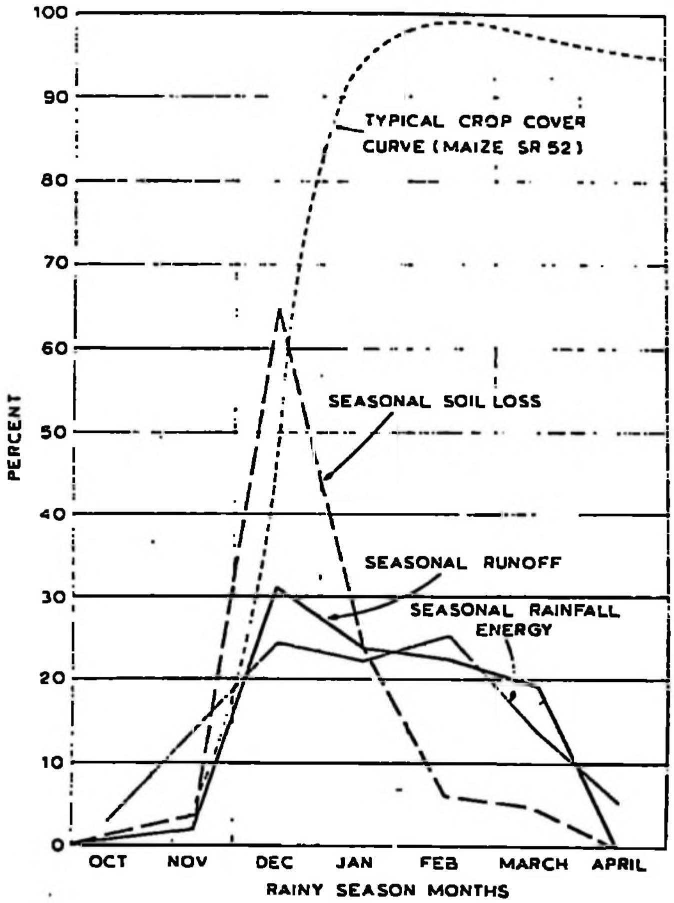


Figure 2.4 Distribution of erosive rains, soil loss and runoff a' Henderson Research Station in Zimbabwe (average of ten years results).

They also showed that both soil loss and runoff decreases exponentially with increasing percentage canopy cover. However, Morgan (1982) found that winter wheat, winter oats and spring barley reduce soil detachment by rainfall compared with bare soil but that detachment increased at lower rainfall intensity. Morgan et al. (1986) studied further plant cover effects in the laboratory. The rate of detachment under Brussels sprouts decreased as the canopy cover increased from 0 to 15-25 % but then increased again with further increases in percentage of canopy cover. With 50% cover, the detachement rate equalled that of bare soil. Although plants can increase soil erosion in some cases due to formation of larger drops on leaves or causing turbulence through stems or roots, plants are still one of the important elements in reducing erosion totally.

2.3 SOIL LOSS TOLERANCE (T)

It is almost impossible to cut off soil loss completely from arable land. Even with natural vegetation, a downward movement of soil is in progress to a degree. However, under natural vegetation the rate of soil loss is often less than the rate of soil formation by weathering. Thus the soil loss under natural vegetation is negligible. But once mankinds changes the balance by removal of the natural vegetation, soil loss will be higher than the rate of soil renewal. The soil loss should be reduced to within a rate which is an acceptable level of soil erosion. Wischmeier and Smith (1978) defined the allowable soil loss, thus: The soil loss tolerance is the maximum level of soil erosion that will permit a high level of crop productivity to be sustainted economically and indefinitely. The soil loss tolerance depends on the rate of the soil formation and soil loss. Since the decision of precise rate of soil loss and soil formation is impossible, further soil loss tolerance is more difficult to be determined. Many reseachers have suggested various values of the soil loss tolerance. Wischmeier et al (1978) noted that soil loss tolerances ranging from 4.9 to 11.2 t/ha/y for the soils of the USA should be chosen. Hudson (1986) reported the soil loss tolerances that the Central African Federation used: 9 t/ha/y for sandy soil and 11.3 t/ha/y for clay soils. At least the maximum soil loss tolerance has to be controlled, so that it is no higher than 11.2 t/ha/y. The aim of soil loss tolerance for Mazimbu will be set to a value of 5.0 t/ha/y. Much lower values of soil loss tolerance may be required to control the water pollution caused by erosion.

3 SOIL EROSION ASSESSMENT AND MODELLING

Soil erosion studies can be based on the conditions in nature as they are (in situ), on simulations of the nature. The "in situ" will be called, in this paper, soil erosion assessment. Modelling of soil erosion is an attempt to simulate nature. An erosion study can, of course, be a combination of modelling and studies of erosion-causing factors and erosion features "in situ".

3.1 ASSESSMENT OF EROSION

Assessment of erosion is a survey of the present erosion rate, the present erosion state or the erosion risk (erosion hazard) in an area.

Erosion assessment results in defining areas with a high actual erosion or a presently high erosion risk under various land uses. The benefits of soil erosion assessment are connected to nature conservation and land use planning. In policy making, it can be valuable to relate soil erosion to financial costs, since it lets decision-makers see the economic effects of actual or potential land use as it influences soil erosion. On a farm, soil erosion assessment is valuable as a basis for farm planning and soil conservation planning.

Erosion rate is the quantification of erosion, as eroded soil in weight or volume per unit of area. It can be recorded by field measurements, measurements of sediment yield from rivers or estimated by modelling.

A survey of the present erosion state is mainly a registration and localization of visible erosion features in the field. Gullies, areas with mass movement (land slides), areas with rill and interrill erosion and sedimented areas etc., are identified. An example of a survey of the erosion state in combination with land use is shown in figure 3.1.

Erosion risk, or erosion hazard assessment includes the collection of data about factors affecting erosion, interpretation and combination of information, and classification of areas according to erosion risk. Important information to collect is climatic data (erosivity), soil data, topographic data such as slope length and steepness, land use, and ground cover. Sometimes fire risk can be recorded as well. For the evaluation of erosion risk it may also be valuable to include erosion rate and erosion features.

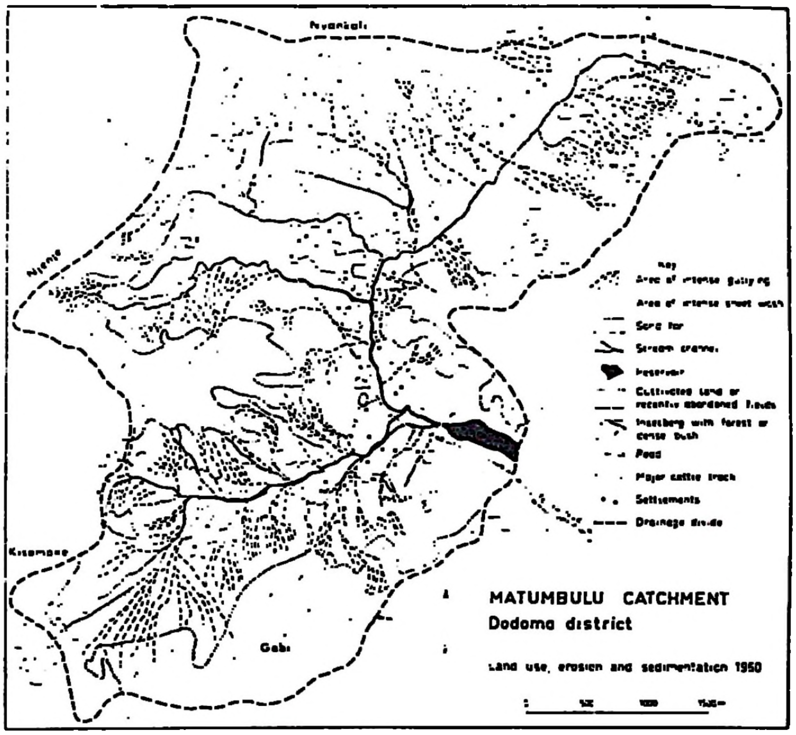


Figure 3.1 Map of land use, erosion and sedimentation; Matumbulu catchment, Tanzania. From Rapp et al. (1972b).

Information for the erosion studies are normally obtained from maps, air photos, and satelitte imagery in combination with field survey.

Erosion assessments can be carried out on several scales; from generalized global maps based on sediment yield and erosivity indices to semidetailed and detailed maps on catchment level and field level. Objectives and availability of data are of importance for the scale and details in the study.

There are several systems of erosion surveys. A detailed description of the systems is beyond the scope of this study. Land capability classification normally includes erosion risk as an important factor for land classification. Various land capability classification systems are described by Hudson (1981) and FAO (1974b). Williams and Morgan (1976) suggest the use of geomorphological mapping in soil erosion evaluation. The last part of this study, chapter 5,6,7 and 8 is an erosion assessment for Mazimbu, partly based on a model (USLE). The assessment results in recommendations for land use and conservation strategies.

3.2 MODELLING SOIL EROSION

A model is an imitation of the real world. It is used to identify relationships between cause and effect. A dada, input, converts into an effect, output, through a model. For example, if an amount of annual rainfall is put into a model, an annual soil loss is derived from the model. There are many kinds of models and the models are often grouped by their process or aim.

Only some models concerning the soil erosion by water will be described in this chapter. The most common models used in erosion studies are empirical type of models. However, in the last ten years a large number of physically-based models have been developed in Europa and the USA. Since the effects of soil erosion have become more complicated and nonpoint source pollution from agriculture has been understood, the situation has necessitated the development of short-term models that are often based on daily observations.

3.2.1 Empirical models

Empirical models are regression models which analyse relationship between input data and output data statistically. Output data is in this case soil loss such as sediment yield (the sediment flow per unit time) or sediment concentration (the ratio of material concentration per unit volume of water), and input data is often climatic, topographical or hydrological variables (Janson 1982).

Empirical drainage basin models

The simplest model can be described in the form of an equation as follows:

$Q_s = a \cdot Q_w^{\,b}$ (Morgan 1986)

where Q_s : sediment discharge

Q_w : water discharge

a,b : constants

Rapp et al. (1972a) used this type of equation for analysing the Morogoro river catchment, Tanzania. He obtained the following equation;

$L = 0.14 \times Q^{1.9}$

where L : suspended sediment discharge (Kg/sec)

Q : water discharge (m^3/sec)

The same type of measurements were made by Dunne (1977) over relatively large areas of south and central Kenya. He obtained four equations according to the different type of land use, such as forest, agriculture and grazing. The same type of model was used for monitoring soil loss by Temple and Sundborg (1972) in the Rufiji river, Tanzania. Dunne (1977) mentioned that this method for monitoring soil loss is relatively cheap, especially, where the monitoring area is large. However, the disadvantage of these models is that the introduction of one model to an other place is not applicable since the model is representative only within the area where the model was constructed (Jansson 1982).

More complicated models were proposed for overcoming this disadvantage by using models with more representative parameters such as p^2/P-index, drainage intensity. Although, the complicated empirical models have got general validity to world-wide application, their introduction should be avoided to areas with extreme conditions. For the achievement of more accurate application of models, physically-based models have been combined with empirical models (Gregory and Walling 1983).

Empirical models based on plot studies

Universal soil loss equation (USLE) is one of the empirical equations which have been adopted world-wide. The equation was developed for predicting average annual soil loss caused by rill and interrill erosion, and it is used for the determination of conservation practices (Wischmeier 1976). The equation takes the form;

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

where

A is the annual soil loss per unit area.

R is the annual average erosion index which is expressed by the equation $R=EI_{30}/100$ (se chapter 2.2.1).

K is the soil erodibility factor which is expressed A/R on a standard unit plot (1.8m wide x 22.1m long, 9% slope, continuously in clean-tilled fallow)

LS is the topography factor which is combined with the slope-length (L) and the slope-steepness (S).

C is the cropping management factor which is the ratio of soil loss from cropped soil to the corresponding soil loss from bare soil.

P is the conservation practice factor which is the ratio of soil loss with a erosion-control practice to that with straight-row farming up and down the slope (Wishmeier and Smith 1978).

The USLE is a "universal" tool for predicting soil loss from cropland, east of the Rocky Mountains in USA. It was derived from runoff and soil loss data which represents more than 10,000 plot-years (Wishmeier and Smith 1978). However, introduction of the equation to tropical countries has some problems.

The correlation between soil loss and EI_{30} in the tropics is not so high as the Americans got in the USA. Therefore, other indices were proposed as alternative indices which were discussed in chapter 2.2.1. The calculation of EI_{30}-values are based on data which are registered by automatic raingauges. Often in tropical countries automatic raingauges are installed in limited numbers only. It should therefore be taken into consideration that EI_{30}-values will be inaccurate when extrapolated from an adjacent station.

The erodibility index (K) is obtained by standard field plot experience. The establishment of experimental plots is less common than the installation of automatic raingauge in tropical countries, because the measurement of K-values under the plots are expensive and time consuming (El-Swaify and Dangler 1982). Morgan (1986) and El-Swaify et al. (1982) described a problem when K-values were predicted from nomograph in the tropics. Vanelslande et al. (1984) tested the applicability of the nomograph in Nigeria and they found that K-values as estimated from the nomograph, in general were shown lower than the values from field experiments. Roose (1977) gave general validity to the nomograph according to his studies in West Africa. However, he also emphasized that application of the nomograph have some limitations for gravelly soils and soils with lattice minerals such as vertisols.

The variation of each factor causing erosion is already discussed in chapter 2.2 which shows that each factor has no fixed value. Roose (1977) for example, mentioned that the LS factor is not independent of soil erodibility, cover or erosivity. It is therefore necessary to obtain the values for tropical regions since the values are needed for the successful designs of mechanical erosion control. Most soil conservationists emphasize the importance of crop management, because erosion control by crop management is cheapest and most efficient since it is known that natural vegetations do not generate soil losses. However, the weakest part of the evaluation of USLE factors in the tropics is the crop management factor, because many crops which are cultivated in the USA, can not be planted in the tropics. Only

Roose (1977) reported a number of crop managements (C-values) in West Africa.

<u>Soil Loss Estimation Model for Southern Africa</u> (SLEMSA) was drawn up by Elwell (1978) for annual soil loss from sheet erosion (interrill erosion). The model framework was based on data from the Zimbabwean Highveld. The advantages of the SLEMSA model is the low cost and that less data is needed as compared with USLE. The SLEMSA frame work is shown in figure 3.2.

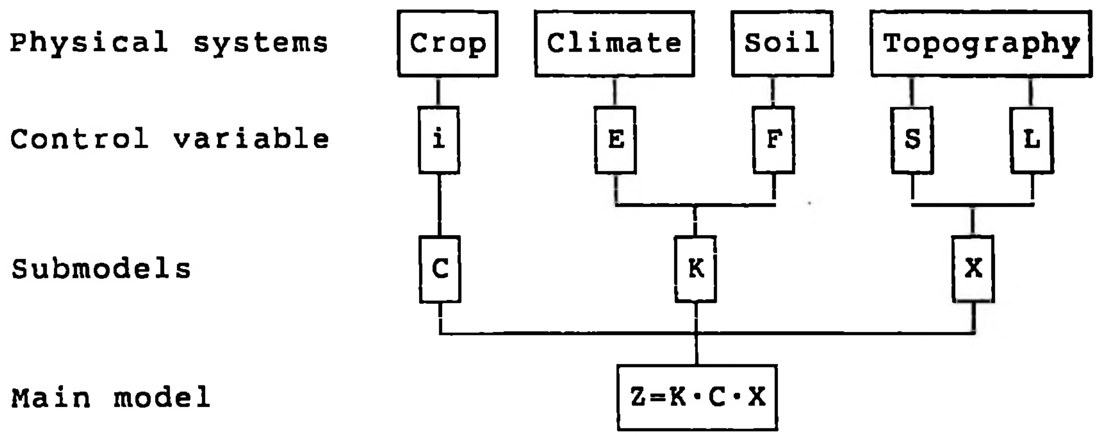


Figure 3.2 Model building SLEMSA (after Elwell 1981)

The derivation of variables in the framework is as follows:

i : This is the amount of seasonal rainfall energy intercepted by the growing crops (%). The energy interception is dependent on the kind of crop and the yield (Elwell 1979a). He got the relationship that poor cover is associated with poor yield and good cover with good yield, for leaf crops.

E : This is the total rainfall energy value. The values were computed from the equation developed by Hudson (Elwell 1979b) (se chapter 2.2.1: KE>25).

F : This is the soil erodibility value which ranges from 1 (most erodible) to 10 (greatest resistance). 'Basic' erodibility (F_b) of soils are determined in situ by use of a rainfall simulator which applies a standard storm of 750 Joules. The influence of management is then added for erodibility (F) . Some approximations for determining the F_b-values were given by Elwell (1978 and Stocking (1987).

S,L : The combination of slope steepness (S) and slope length (L give the topography ratio (X).

$$X = L^{0.5}(0.76+0.53S+0.076S^2)/25.65$$

where L : slope length (m)
S : slope steepness (%)

The equation was based on USLE, but it was modified to a standar plot for SLEMSA (4.5%, 30m long x 10m wide).

K : This is the annual soil loss (ton/ha/yr) from bare fallow soils. The studies by Elwell and Stocking (1973) and Elwell (1978) gave a relationship between soil loss (K) and rainfall energy (E) which is dependent on soil erodibility (F).

$$K = Exp((0.4681+0.7663F)\ln E+2.884-8.1209F)$$

C : This is the crop ratio in submodels. Elwell and Stocking (1976) drew up the relationship percent vegetal cover and soil loss. The soil loss ratio ranges from 0 to 1.0 in proportion to the percent vegetal cover (0 to 100 %). The crop ratio is namely the same as the soil loss ratio which depends on vegetal cover. The relationship between C and i is derived from following equations.

$$C = Exp(-0.06i)$$

For crops and natural grassland when $0\leq i\leq 50\%$
For dense pasture and mulched field $50\leq i\leq 100\%$

$$C = (2.3-0.01i)/30$$

For crops and natural grassland when $50\leq i\leq 100\%$

Z : The soil loss was derived from the three products as shown i figure 3.2.

Erosion control in Zimbabwe has been practiced by relatively intense operations of mechanical conservation techniques. However, interrill (=sheet) erosion caused by thunderstorms represents serious problems on arable lands by erosion and on dams by siltation (Elwell 1984). Thus the SLEMSA model was proposed for predicting the interrill erosion that can be controlled mainly by agronomic management. The modelling approach was based on experimental plots which are not so expensive as the USLE model (Elwell 1978). However, is it really cheap to obtain each value of the SLEMSA factors in a country which has recently started predictions and controls of soil erosion? Or is it cheaper to evaluate each factor for USLE and to adopt appropriate values of USLE for the country gradually? It is considered that the re-examinations of the USLE factors that have been proposed in several contries, are cheaper and more significant for developing countries.

The prediction of soil loss by the SLEMSA model assumes soil erosion caused by interrill erosion since the arable lands are divided into short length of slopes by mechanical erosion control measures. It means that the erosion control is significantly dependent on agronomical managements. Nevertheless, the evaluation of agronomical managements that affect soil erodibility of the model, have been described a little in the article (Elwell 1978). More detailed evaluation of the agronomical managements should be introduced.

The SLEMSA model has been developed in Zimbabwe and applied to erosion control mainly in Zimbabwe. The application of the model to other countries needs more data. Elwell (1981) emphasized that information of the model has only been obtained in Southern Africa. For actual application of the model, planners must prepare data which were obtained from own experimental plots.

3.2.2 Physically-based models

These models are based on several primary processes which were recognized by experimental tests. All processes are further expressed by mathematical equations. A preliminary model which was proposed by Meyer and Wishmeier (1969), gives a very important concept of soil erosion processes for physically-based models. The processes are separeted into four, which are: soil detachment by rainfall or by runoff, and transport capacity of rainfall or of runoff (see figure 3.3). Many computer models have been developed and based on the Meyer and Wishmeier conceptual model (Janson 1982).

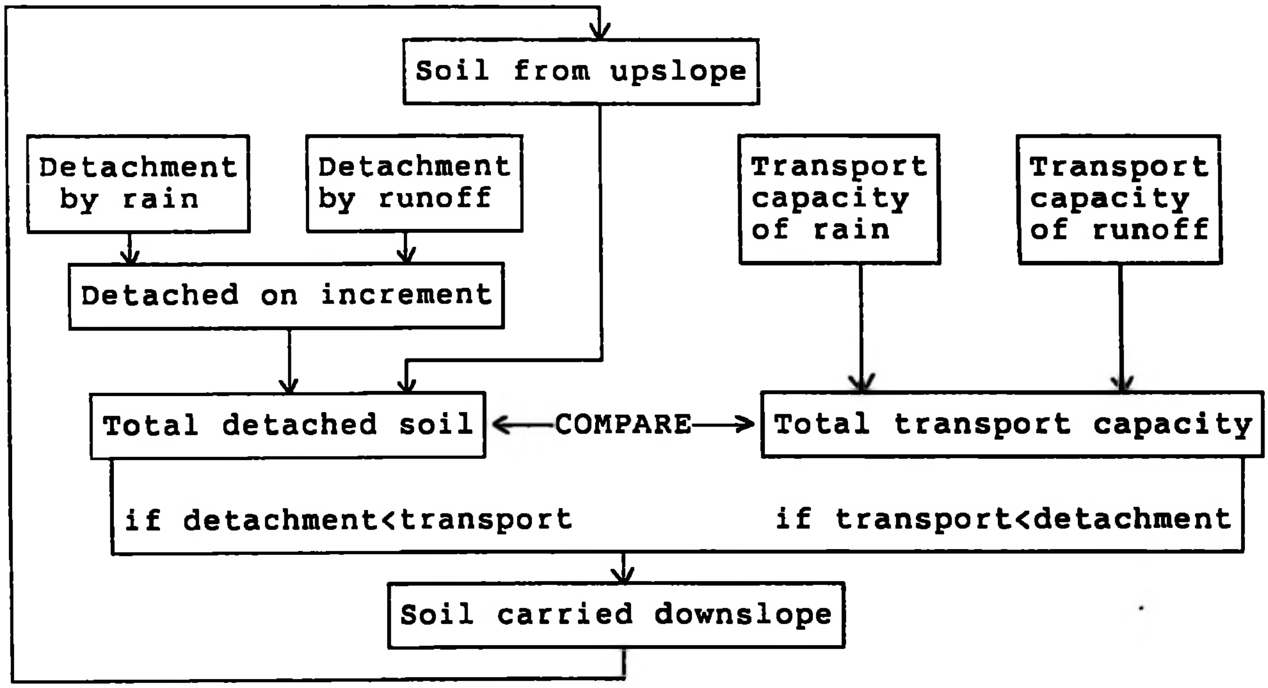


Figure 3.3 Soil erosion process after Meyer and Wischmeier (1969)

Non-point pollution models

Many non-point water pollution models incorporate three components, namely, hydrology, erosion and chemistry. The erosion component includes the concept of Meyer & Wischmeier's model together with elements of USLE (Novtny 1986). There is a tendency that physically-based models have become more popular tools for environment assessment. However, at present a simple empirical model is often more accurate for predicting soil loss and is cheaper than a complicated physically-based model (Morgan 1986). Hudson (1986) also expressed the opinion that empirical models are suitable for practical conservation works. Physically-based models should be used for research studies on the mechanics of erosion.

4 STRATEGIES FOR EROSION CONTROL

Perfect soil conservation planning should have been an integrated part in farm planning. This is to prefere since a conservation plan often interferes with existing roads, drainage systems and production characteristics such as production level, products (crops/animals), field layout etc.. Coordination of farm and conservation planning enhances the chance of adopting suitable productions to the land qualities, and the layout of a conservation plan with minimum interference with production practices.

4.1 CROP MANAGEMENT

Crop management concerns the operations and the decisions that influence crop growth. When soil management is excluded, the following are considered as crop management factors: The selection of crops, crop rotations, time of planting, plant population, fertilization practices, pest control and residue management. Soil management also has a great influence on growing conditions for the crop, but this is discussed separately in chapter 4.2. The covering effect of plants is the most important crop management factor with regard to soil erosion.

4.1.1 Importance of crop cover

Good crop management can be up to ten times more effective than mechanical conservation practices in reducing the amount of erosion (Hudson 1981). The importance of good crop management is also stressed by Lal (1984), who states that good soil surface and crop management practices are crucial in controlling runoff and erosion. Variations in the density of cover will influence erosion more than any other management factor (Hudson 1981).

Good crop management aims at establishing a good crop cover, either as live plants or as plant residuals, mulch, at the surface. Lal (1976 ref. Lal 1977) found that runoff from bare plots was 16 times more than that from mulched plots, while the mean annual soil loss from the mulched plots was 730 times less than that from bare ground (table 4.1). The results are found on an Alfisol near Ibadan, Nigeria.

Table 4.1. Effect of ground cover on runoff and soil loss for 10 % slope (after Lal 1976, ref. Lal 1977).

Mean annual values	Bare ground	Mulched
Soil loss (tonnes/ha/yr)	232.6	0.2
Runoff (mm)	504.1	29.3
Runoff (% rainfall)	42.1	2.4

The main effects of plant cover on erosion are the interception of raindrops by the crop canopy and the reduced velocity of runoff water by the physical resistance by plant residuals, roots and stems.

The plant cover also influence other soil properties. The effect of plant cover is discussed in section 2.2.5.

4.1.2 Crop rotations

Crop rotations as discussed here involve the growing of one or more crops alternately with fallow or with each other when more than one crop is involved. Shifting cultivation, with an area intensively cropped for a short period followed by fallowing and revegetation for a longer period, could also be defined as crop rotation (FAO 1983). Shifting cultivation is connected to traditional farming systems, and it is not discussed here.

Purpose of crop rotations

Crop rotations are beneficial for several reasons. The growing of various crops can reduce the risk of a build up of pests and diseases. Plants with various root systems can utilize nutrient and moisture in the soil better than one continous crop. Also, the crops have differing effects on soil structure. The use of soil building crops can restore soil structure (Hudson 1981). Persistent weeds resulting from monoculture can be controlled with crop rotations. In addition, crop rotations can result in more reliable and improved crop yields. In regions with variable weather, crop rotations with various crops decreases the risk for total failure in infavourable growing seasons. Finally, crop rotations are important for soil and water conservation, as will be discussed below.

Benefits of rotations in erosion control

The main benefit of crop rotation for erosion control is the result of better plant cover and increased organic matter content in the soil. Rotations designed to control erosion normally include crops that produce various levels of plant residuals and have various covering effects. The improved cover leads to improved water utilization, reduced runoff and hence decreased soil dispersion. Plants such as grasses and other close growing crops impede water flow across the surface, and thus reduce runoff and erosion (FAO 1984). Rotations also provide more continuous cover during the year than is possible with the same crop (row crop) grown year after year (Troeh et al. 1980).

The increased organic matter content in the soil enables a more stable aggregate structure to develop (Morgan 1986). This effect is soil conserving because stable aggregates are more resistant to the erosivity of the rain.

Other effects of crop rotations are that alternate tillage practices can be used for the various crops (FAO 1984). This can be of importance because the same tillage operation year after year can result in a plough layer in the soil. The plough layer can restrict water infiltration and root development and thus reduce plant growth. As a result, plant cover will be reduced, as well as the amount of plant residuals. Thus the soil is more exposed to erosion.

Crop rotations allow for the shifting of resources. When various crops with various growth periods are grown, tillage, planting, harvesting and other crop and soil management operations can be performed at the best time for each crop. This provides conditions for the development of a good plant cover and high yield (FAO 1984).

Effects of plant type and rotation periods

Erosion is normally more severe in open row crops like maize and sorghum than in cowpea, and worse in rice than in cassava (Lal 1984a). Continuous cropping of crops producing small amounts of residuals, or where plant residuals are removed or destroyed by insects lead to major soil erosion. This is normally the case fo soybeans, cotton and groundnuts in semi-arid and arid areas (FAO 1984). Crops that tend to preserve the soil and reduce soil erosion are close growing crops such as grasses and some legumes The preserving crops can be grown for harvesting or as green manure, cover crops or mulch to improve soil quality (Troeh et al. 1980).

The benefits from grasses and legumes are different in temperate and tropical climates. In temperate climates, the result of a grass period is normally a build up of a tightly cemented crumb structure and of humus in the soil. The effect persists for several years. In tropical climates, the beneficial effects of grasses and forage crops are a fairly loose soil aggregation and a build up of coarse organic matter in the soil instead of humus. These effects build up and break down quickly (Hudson 1981). Due to the rapid build up and break down of the benefits from grasses, rotations planned to help in controlling erosion should be short. That means quick changes from cash crops to forage crops and back again. According to Hudson (1981) the benefits of grass are build up in 1-2 years and last for a period of the same length. Maximum periods with one crop should then be 2 years.

It is recommended that the least soil preserving crop is grown first in a rotation, followed by a soil building crop. This was illustrated by Lal (1976 ref. Morgan 1986), who found greater soil loss when maize followed cowpeas than when maize was grown first. Maize is concidered a soil depleting crop wich explains this effect. When it was grown second, it was grown in an already partially exhausted soil, thus erosion increased.

Disadvantages

In spite of several benefits with the use of rotations, some disadvantages are found (FAO 1984):

- There might be a hazard of greater erosion when soil depleting crops replace soil conserving crops.
- There will often be lower total production of high value crops.
- There may be need for more equipment and for greater skill in management.
- Saline seeps can develop.

4.1.3 Cover crops and multiple cropping

Cover crops

Cover crops are planted especially for the purpose of soil erosion control, adding organic matter to the soil and improving soil productivity (FAO 1966). Close-growing crops such as grasses, legumes or small grains are considered as cover crops (FAO 1984). Cover crops are grown between the main crop, either in time or in space, when the climate is unfavourable for the main crops or when there is much bare soil between main crops, as for trees (Troeh et al. 1980). In dry and warm climates, use of cover crops is limited since soil water should be preserved for the main crops. In these areas, cover crops can be grown in the main growing season, as a part of the rotation. Frequent use of cover crops in rotations is recommended by Lal (1984b).

Role of cover crops.

Benefits of cover crops in the tropics are (Okigbo and Lal 1977):

- Control of erosion by covering effect and interception of raindrops;
- reduced temperature fluctuations;

-maintenance of organic matter in the soil;
-improved soil structure, aeration and texture while reducing leaching;
-improved infiltration and water holding capacity;
-improved nutrient conditions due to deep rooted cover crops bringing nutrients to the surface;
-increased nitrogen content in the soil in the case of leguminous cover crops;
-weed control, because the cover crops compete with weeds;
-control of plant diseases and pests (sometimes);
-they provide a source of mulch.

In no-tillage systems, cover crops in the rotation are important to maintain soil structure, for weed control, to achieve crop residue and for other purposes (Okigbo and Lal 1977). Some species used for cover crops can provide forage, but this reduces the other benefits of the cover (Triplett 1986).

Management of cover crops

The cover crops can be seeded directly into the main crop before harvesting. Plant cover may then establish before the main crop is harvested. Alternatively, the cover crops are seeded after harvesting of the main crop, with or without tillage. If tillage is practiced, the risk of erosion is increased. Before planting the main crop, the cover crop is ploughed under and conventional tillage practiced, or it can be killed with herbicides. The use of herbicides is needed for no-tillage and reduced tillage. When plants are killed in this way and left on the surface, they provide better effect than if residues are incorporated to the soil (USDA 1978). Some legumes are grown as live mulch, through which crops are drilled without cultivation or killing of the cover (FAO 1977).

Disadvantages of cover crops are (Okigbo and Lal 1977):
-They compete with the main crops for water and nutrients.
-They sometimes harbour pests and diseases.
-Climbing species can damage the main crops.

Other disadvantages are that they normally give no direct income and that special tillage systems and equipment are required when seeding through the plant cover. Also, the use of herbicides can be considered as a disadvantage because the herbicides may have undesireable effects on plants and the environment. Herbicedes also mean an extra expense, and they may be unavailable in some places and during certain periods.

Multiple cropping

Multiple cropping is either sequential cropping of two or more crops a year on the same field, or intercropping; growing two or more crops at the same place and at the same time (Morgan 1986).

The objective of multiple cropping is mainly to increase the total production from the land (Troeh et al. 1980). This means that none of the crops need to be grown for their soil conserving effect. Sequential cropping, and especially intercropping, is still effective in preventing soil erosion due to the dense plant cover provided from these systems.

Sequential cropping is adaptable for all cultivation systems (FAO 1984). Soil conservation effect is obtained by having a crop on the land most of the year. The use of cover crops can be sequential cropping.

Intercropping often includes the growing of a cereal (maize or sorghum) together with a legume, but several crop combinations exist. Intercropping is mainly practiced in traditional farming systems i.e. subsistence farming, labour-intensive farming, shifting cultivation. Intercropping in highly mechanized farming systems may be impractical or impossible due to the dense plant cover and special requirements of individual crops. Intercropping can be practiced in some cases of mechanized farming, for example as in the case of row crops.

Multiple cropping as a method of reducing soil erosion is not further discussed in this paper. It is assumed that the main factors in sequential cropping are included in the sections crop rotations and cover crops. Intercropping is not further discussed since soil erosion related to mechanized agriculture is the main objective of this study.

4.1.4 Mulching

Mulching is the use of plant residues to cover and protect the soil from raindrop impact, runoff and wind (Morgan 1986). Crops can be grown exclusively for mulch, or cover crops and crop residues from rotations can provide mulch. Artificial materials, for example polythene, paper, gravel, coal etc. can also be used as mulch (FAO 1984, Ngatunga et al. 1984). The maintainance of a constant cover on the soil surface should normally be combined with reduced tillage or no tillage.

Effects of mulching

In general, mulching has similar effects to those described for cover crops. In an experiment with sandy clay loam on Zanzibar, Tanzania, Khatibu et al.(1984) found that mulching with polythene and no tillage resulted in greater moisture reserve, lower soil temperature at 5 cm and higher infiltration rates than ploughing and ridging. Runoff, soil loss and nutrient loss was less for mulching than for the other treatments. Mulching resulted in the highest grain yields of maize, cowpeas and soybeans. In another experiement in Tanzania (Ngatunga et al. 1984) on slopes of 10-22 % at Mlingano, mulching resulted in great reductions in runoff and soil loss compared to bare fallow and ploughed soil. In this case, grass cover provided slightly better protection than mulch. These results correspond well with other references (Lal 1975, Morgan 1986).

Other effects of mulching are increased organic matter content, minimized crusting, maintained soil structure and porosity and suppressed weed growth. Some of these effects could be due to the influence mulching has on the activity of microflora and fauna (Lal 1975). Much of the effect mulching has on plant yields is due to influence on soil properties such as moisture content and temperature. Hence the advantages of mulching are especially found in regions or seasons where soil temperature is over the optimum for plant growth and soil moisture is a limiting factor for growth. In cool climates, reduced temperature may shorten the growing season, while in wet climates, increased moisture content can lead to anaerobic conditions and soil that is too cold (Morgan 1986).

To give adequate protection, mulch should cover 70-75 % of the surface. This corresponds to 0.5 kg/m2 or 5 t/ha with straw (Morgan 1986). According to Ngatunga et al. (1984), mulch rates of 6 ton/ha can provide effective erosion control on slopes up to 22 %.

Except for the negative effects of mulching in cool and wet climates, there are some other problems with mulching. The mulch competes with the main crop for nitrogen as the microfauna use N when breaking down mulch, also weed growth may be encouraged (Morgan 1986). The mulch can harbour pests. Special tillage techniques and equipment is required for planting when the soil is covered with mulch. Tillage operations for mulching are treated in section 4.2.

4.1.5 Strip cropping

Strip cropping is the practice of cultivating protection effective crops alternately with row crops in strips normally along the contour. Every other strip is cultivated with protective plants. Erosion occurs mainly under the row crop, and the strips with close growing protection crops (grasses and/or legumes) provide erosion control by slowing down runoff water and trapping transported soil. The infiltration rate is increased under the protection strips and hence total runoff is reduced (FAO 1965, Morgan 1986). When crop rotation is applied to the strips, the benefits of rotations are achieved as well.

There are three main methods of strip cropping (FAO 1966), namely contour strip cropping, field strip cropping and buffer strip cropping.

Contour strip cropping

This involves the arrangement of strips along the contour and at right angles to the slope of the land. If the contours are strictly followed, and the slope is non-uniform, strip width vary as the slope changes. Contour strips are best suited on regular slopes.

Field strip cropping

Field strip cropping consists of strips of uniform width that are placed across the general slope of the terrain. The strips do not strictly follow the contour. This method is recommended for fields with irregular slopes where contour strip cropping is impractical.

Buffer strip cropping

This corresponds to filter strips and narrow grass strips (Thomas and Barber 1983). Narrow strips of a grass or a legume or a mixture of the two are laid out between strips of crops grown in regular rotations. Buffer strip cropping is further described under mechanical practices for erosion, (chapter 4.3.1).

Strip width (exept for buffer strips) depends on soil properties and slope. Generally, the width varies between 15-45 meters (Morgan 1986). Protection strips and the strips with row crops are normally of uniform width. Recommended strip width for some slopes are given in table 4.2.

A disadvantage of strip cropping is that large areas are often used for less valuable protection crops. The need for these crops might be lower than the production value of the main crop. In addition, if the protection crops are to be grazed, fencing is needed to save the neighbouring strips from grazing (FAO 1965). Other disadvantages are the need to farm small areas, which limits the kind of machinery to be used. Weed and insect control can also be problematic when strip cropping is practiced (Morgan 1986).

Table 4.2. Recommended strip widths on soils with fairly high water intake (after FAO 1965).

Slope (%)	Strip width (m)
2-5	30-33
6-9	24
10-14	21
15-20	15

4.2 SOIL MANAGEMENT

Soil management can include tillage operations, cropping practices, fertilization, liming and other operations conducted on the soil or applied to the soil for plant production (Resource conservation glossary, SCSA 1976). The aims of soil management are to maintain good growth conditions for the plants in the form of high fertility and good soil structure. All management operations are of importance for soil conservation, but emphasis is placed on tillage operations in this section. Cropping practices were discussed previously.

Tillage operations are needed to prepare a seedbed for the plants and to control weeds. Traditionally a smooth, residue free, well pulverized soil has been considered the best seedbed (FAO 1965). These conditions are normally prepared with conventional tillage, including primary tillage with a plough and one or more following operations with implements such as disc harrows, chisels or cultivators.

Conventional tillage corresponds to clean tillage systems described by FAO (1984). This system might be well suited to locations or soils with low erosion risk. However, the repeated tillage operations often enhance erosion risk. The vegetation free soil surface leaves the soil unprotected from raindrop impact, and the mixing of plant residues into the soil often results in a general decline in organic matter content due to more rapid decomposition. The pulverized soil, especially soil of low aggregate stability, tends to crust and thus reduce infiltration. Subsoil compaction as a result of frequent tillage with heavy machinery also reduces infiltration and results in increased runoff.

To overcome the negative effects of conventional tillage, conservation tillage practices have developed. Conservation tillage can be defined as any tillage system which reduces loss of soil or water compared to unridged or clean tillage (SCSA 1976). Reduced soil erosion is achieved because conservation tillage leaves appreciable crop residue on the soil surface and/or the surface is left rough, porous, cloddy or ridged (Mannering and Fenster 1983). The effects of crop residues on the soil surface are already discussed. A rough, cloddy soil surface can store water in pits and depressions, thus increase infiltration and decrease runoff (FAO 1965). The clods on the surface reduce runoff velocity.

Several methods of conservation tillage exist. The systems are often referred to as limited tillage, reduced tillage, no tillage and zero tillage. These terms include various tillage operations, often without ploughing or with reduced amount of secondary tillage operations. Eventually, the areas that are being tilled can be concentrated to the crop rows, leaving the inter-row zone untilled as with strip tillage or zonal tillage.

It is impossible to describe all the various conservation tillage systems that are practiced. A selection of some generally used systems has been compiled by Unger and Mc.Calla (1980) and FAO (1984).

It is not appropriate here to describe the array of mechanical equipment required for tillage operations. This is well described by Throckmorton (1986).

4.2.1 Stubble mulch tillage

Stubble mulch tillage or mulch tillage refers to tillage practices that leave the stubble of crops, plant residues or other materials on the soil surface (SCSA 1976, FAO 1984). Tillage operations that undercut residues to loosen soil and control weeds are included in stubble mulch tillage (FAO 1984). Because this tillage system involves the mentioned tillage operations, it is a tillage-intensive system (Unger and Mc Calla 1980) in contrast to other conservation tillage systems. The main purpose of stubble mulch tillage is to maintain a good cover of plant residues on the soil surface to control erosion.

Operations for stubble mulching normally include (FAO 1965, Unger and Mc Calla 1980, FAO 1984):

- -Uniform spreading of crop residues on the soil surface;
- -in the case of large amounts of residues, a kind of disk implement can be used to incorporate some residues into the soil before the first tillage operation;
- -tillage with special equipment that loosens subsoil and maintains surface residues, for example sweeps, chisel ploughs and rodweeders.

The first tillage operation is normally deeper than the following. At least two tillage operations are performed. The number of tillage operations depends on weed growth, as tillage controls weeds.

Stubble mulch tillage was originally developed for wheat and other small grains, but it is also suitable for crops such as sorghum and maize.

The positive and negative effects of stubble mulching are mainly connected to the effects of the mulch cover (chapter 4.1.4).

4.2.2 Reduced tillage and no-tillage

The descriptions in this section are mainly based on FAO (1984) and Unger and McCalla (1980).

Fall plough, field cultivate

Ploughing is done with a mouldboard plough. Secondary tillage is reduced to one shallow cultivation with sweeps, a rotary tiller or a disk at planting.

Spring plough, wheel track plant

The field is ploughed, and planting is done within 12-24 hours. The planted rows may be in the tractor or planter wheel tracks, as the wheels break clods and make a firm seedbed. It is important that planting is done soon after ploughing because then the soil water content is suitable for seedbed preparation. A zone with rough soil is left within plant rows. Ploughing in the spring provides better protection against erosion than fall ploughing, because crop residues are kept on the surface until planting.

Fall chisel, field cultivate

Ploughing is replaced with chiseling, 20-25 cm deep. Secondary tillage is as for the fall plough, field cultivate system. Chiselling leaves more residues on the surface than moldboard ploughing, and this system is therefor more effective in control ling erosion.

Disk and plant

Tillage is performed with standard tandem disks or heavy disks operated to 8-10 cm or 15-20 cm respectively. The method often includes one primary tillage (in the fall) and one or two more tillage operations prior to planting. Crop residues are conserve best if shallow disking is performed.

Till-plant

This method means that tillage and planting are accomplished in one operation. Till-plant is practiced for row crops planted on ridges that are prepared in previous seasons. The tillage operation involves preparation of a seedbed on the ridge top by removing crop residues and clumps/clods to the interrow zone. Wide sweeps, operating soil 5-8 cm deep may be used for this.

Tillage operations to reshape ridges are accomplished when necessary.

Strip tillage (zonal tillage)
Seedbed preparation is limited to a narrow band, ca. 20 cm wide. Typical tillage depth is 5-10 cm. Rotary tillers where some of the knives are removed are suggested as suitable for this system. Planting equipment can be attached to the tiller, resulting in a one-pass operation. Plant residues are maintained between the tilled strips.

No-tillage
No-tillage is a method of planting crops with no seedbed preparation except for opening the soil for the purpose of placing the seed at the intended depth (SCCA 1976). No-tillage is also refered to as sod planting (Lal 1975), no-till, zero-tillage, slot planting, ecofallow, chemical fallow and direct drilling. Opening of the soil may be accomplished with nonpowered colters running ahead of planters with disk openers, narrow chisels or angled disks. The preparated zone is narrow and shallow, for example 5-7 cm wide and 5 cm deep (Lal 1975). Herbicides are used to control weeds. The effectiveness of no-tillage depends heavily on an adequate use of mulch (Lal 1984b). This means that in areas with restricted growing seasons, f.ex. semi-arid/arid climates with long dry seasons, other conservation practices have to be considered.

Some problems connected to reduced tillage and no-tillage in addition to those mentioned for mulch are:
- The reduced tillage operations cause reduced mixing of added fertilizer, lime and manure.
- The system relies heavily on herbicides to control weeds.

4.2.3 Soil and site suitability for conservation tillage

Tillage systems must be adapted to the local conditions such as soils, crops, pests, climate, equipment and personnel. Soil characteristics of importance for no-tillage systems are erodibility, rooting depth, available water holding capacity, cation exchange capacity, pH, clay mineralogy and others. Generally, coarse-textured, friable and structurally active soils with good conditions for mulch production respond better to conservation tillage than easily compactable soils or soils with massive structure (Lal 1986). According to Hayward et al.(1980), no-tillage in the tropics requires fertile soil with good structure and adequate levels of organic matter and clay. Mulch should be kept on the surface.

Research in Tanzania (Macartney et al.1971, Northwood and Macartney 1971) on various soils at Tengeru, Kongwa, Sambwa and West Kilimanjaro showed that compacted soils of high bulk density were unsuitable for direct drilling (no-tillage). The result was attributed to delayed and reduced germination due to restricted root-development in the compacted soil. No-tillage was successful on the highly fertile and good structured soils at West Kilimanjaro. For the compacted soils zonal tillage (strip tillage) was recommended.

4.3 MECHANICAL PRACTICES OF EROSION CONTROL

These conservation practices are mainly achieved by change of the land surface. The constructed structures can store, convey, regulate or dispose of runoff water without excessive erosion. It should be considered that the names of mechanical erosion control methods are not clearly defined.

4.3.1 General description of main mechanical practices

Contouring

Field operations such as ploughing, planting, cultivating and harvesting are carried out on the contour. The efficiency of contour farming depends on the slope steepness. It is most efficient on slopes from 2 to 7 % (Hudson 1986). The effect of contour farming is that tillage marks on the contour can make small dams which hold water and reduce runoff (FAO 1965). This method is often combined with other methods such as ridging or grass stripping.

Ridging

Ridges can be made either by hands, drought animal or tractor. The type of the ridge can be divided into four, namely, narrow, wide, tied and graded. The choice mainly depends on the climate and the soil characteristic. The ridge method is useful for retaining water during light rains on gentle slope. However, during storm rains excess water can cause overflowing and the collapse of the ridges in lower parts (FAO 1984). Hudson (1986) recommends that to minimize the risk, the graded ridges should b made or ridges on the contours should be combined with conventional graded channel terraces (see paragraph terraces).

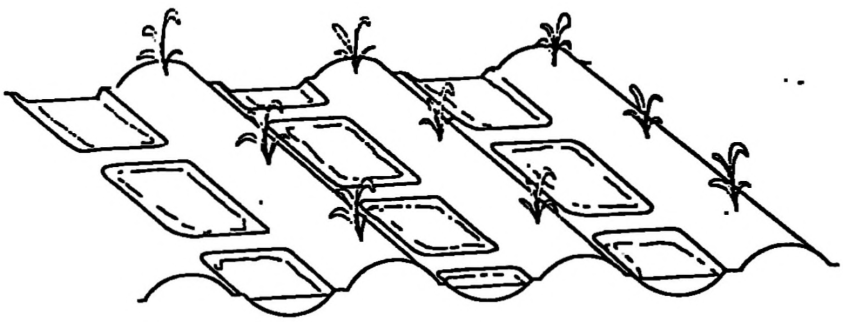


Figure 4.1 Tied ridges (after FAO 1987)

Grass stripping (Buffer strips)

Grass strips are left unploughed between bands of cropped land s that the grass filters out soil which is transported by runoff water (FAO 1984). The grass strips should be laid out on the contour in the dry areas, or on a graded slope in the wet areas (Thomas and Barber 1983). The strip width is ranging from 15-40 in USA depending on the slope gradient, however 2-4 m width have been used in West Africa (Roose et al. 1971), and 2 m or less widths are common in East Africa (Thomas and Barber 1983). The effect of the stripping is rather an agronomical erosion control than mechanical control. The grass strips provide active biological activities which contribute to more water infiltration into the soil. The grass buffer strips (narrow stripping) do not provide a very efficient erosion control unless surplus water is diverted along the grass strips (Thomas and Barber 1983). Thus the grass strips should be combined with some kind of terraces or graded channels. The most troublesome problems associated with grass stripping is weed control and insect control.

Spacing of buffer strips

Grass width, which is often dependent on the vertical interval, has been recommended by several writers in Africa. Thomas and Barber (1983) gave the general dimensions of grass strips in East Africa as 2 m or less, with the spacing between strips the same as the spacing of terraces.

In Uganda it is recommended a horisontal interval of about 30 m on gentle slopes (Stephens 1971; described by Ahn 1981).

In Kenya an empirical formula to determine terrace spacing has been presented by Gichungwa (1970; described by Ahn 1981).

$$\text{Vertical interval (VI)} = 0.3\ \frac{(\%\text{slope} + 2)}{4}$$

It seems that the terrace spacings given by the formula is too narrow.

In Ethiopia Hurni (1986) recommeds that the width of the grass strips should be greater than 1 m (1 meter is the absolute minimum), and the vertical interval should be fixed at 1 m.

In Zimbabwe Hudson (1986) notes the following empirical formula;

$$\text{VI (m)} = 0.3\ \frac{(\%\text{slope} + f)}{2}$$

(where f varies from 3 to 6 according to the erodibility of the soil)

From Swaziland Hudson reported that grass strips have a 2 m width at a 2 m vertical interval (FAO 1987). He emphasized that the grass strips halted the worst erosion problems though many of the strips were planted incorrect by due to the lack of sufficient field advisors.

Contour bunds

By definition, a contour bund is an erosion control structure which is a small embankment thrown up by hand on the contour (Hudson 1986). The method is suitable for unmechanised cultivation. In Ethiopia, the embankments can be made of stones in the area where slopes range from 3 to 50 %. Under construction of the embankments, depressions are constructed on the uphill side of the embankments so that the depressions provide soil deposition. Overflowing should never occur, and runoff can be diverted to appropriate channels by graded depressions (Hurni 1986).

Terraces

Morgan (1986) classified the type of terraces into three, diversion, retention and bench. The diversion terraces (=channel terraces) intercept runoff water on the slope and convey the intercepted water within unerodible velicities along the terraces (across the slope). Some examples of terraces are shown in figure 4.3. The embankments in general have gentle slopes so that farm machinery can cross the embankments. This method is very suitable for mechnized farming on moderate surface slopes up to 7° (Morgan 1986).

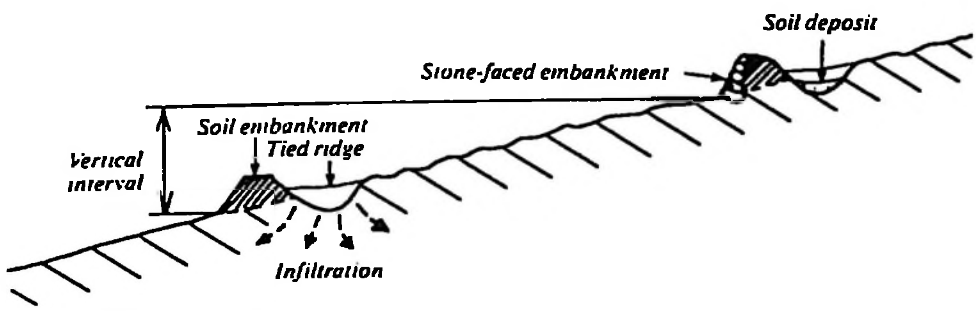


Figure 4.2 Contour bunds (after Hurni 1986).

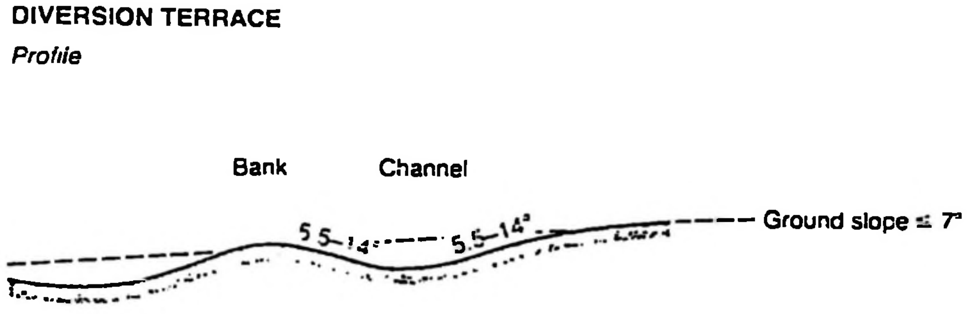


Figure 4.3 Diversion type terraces (after Morgan 1986).

Retention terraces

This structure looks like a diversion terrace. However, the aim is the storage of runoff water by gentle slope embankment. The construction of the terrace is recommended for land which has a slope steepness less than 4.5°. The channels go on the contours, so that they can store water efficiently (Morgan 1986).

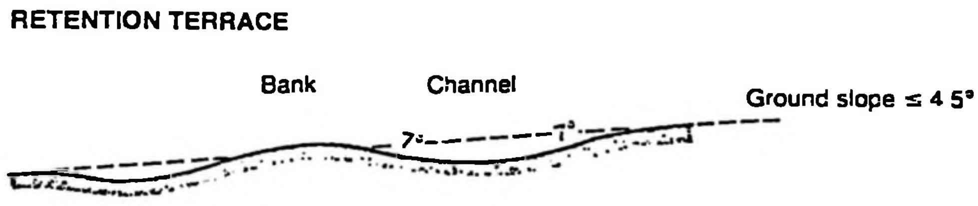
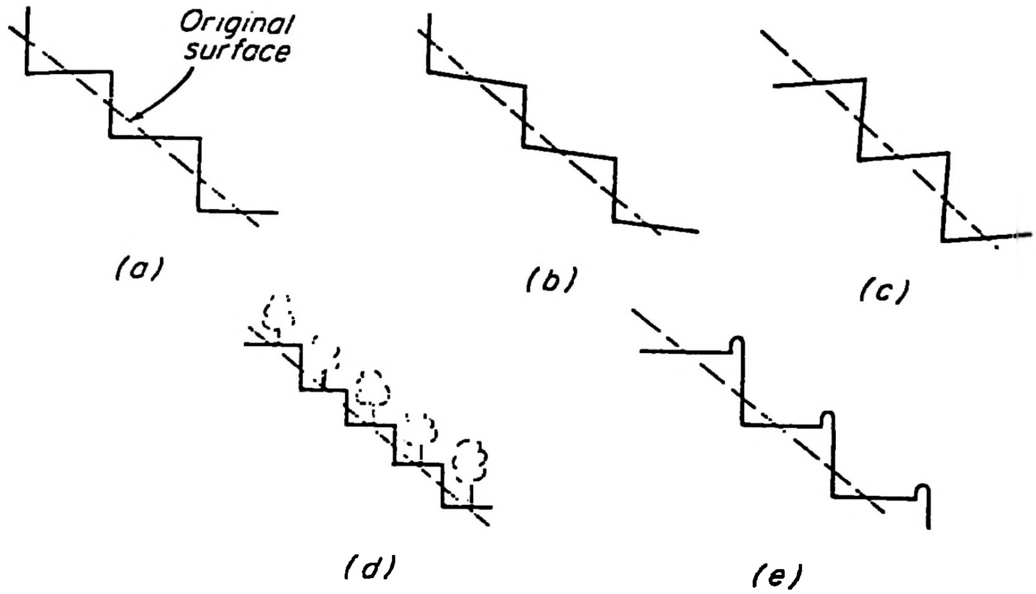


Figure 4.4 Retention terraces (after Morgan 1986).

Bench terraces

Most of the traditional terraces are included in this group. Hudson (1986) shows the general features of the terraces (figure 4.5). This method is suitable for steep slopes. The cultivated surface is nearly horizontal, and the walls are kept vertical by well-established vegetation or stones. Other special terracing which does not necessitate changing cultivated surface is shown in figure 4.6.

Bench terraces



Types of bench terraces
(a) Level bench (b) outward-sloping bench (c) inward-sloping (or reverse-slope) bench (d) step terraces (e) irrigation terraces

Figure 4.5 Types of bench terraces (after Hudson 1986).

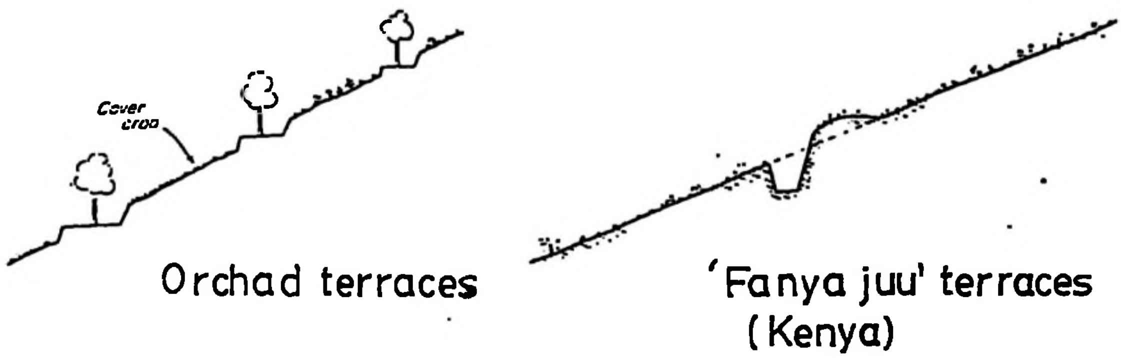
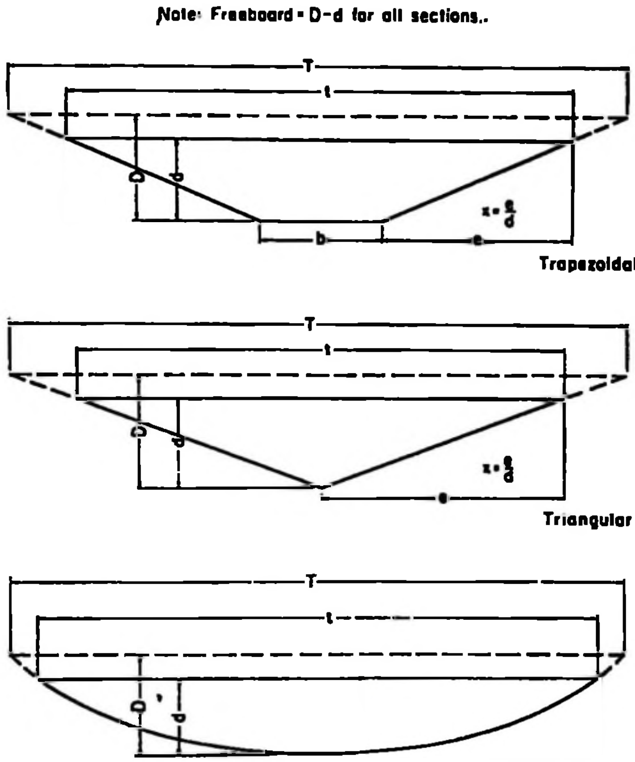


Figure 4.6 Some special terraces (after Hudson 1986).

Waterways

Two types of waterways can be considered apart from channelled terraces, namely, storm water drains and conveyance waterways. Storm water drains are placed on the upslope of an area. They provide protection of arable land by intercepting runoff which comes from outside the land. Open channels are constructed eithe by digging or the building of embankments.

Conveyance channels are constructed on the slope so that water both from the storm water drains and from cultivated areas is transported with appropriate velocity. The channels are in general covered by vegetation, and are therefore called grassed waterways. On steep slopes, the channels can be constructed from concrete or grass waterways can be combined with drop structures which are made from stones or concrete. The shape of a grass waterways is often of a parabolic cross section because it is same as a cross section of natural waterway.



Cross-Sectional Area (A)	Wetted Perimeter	Hydraulic Radius (R)	Top Width (t)
$bd + zd^2$	$b + 2d\sqrt{z^2+1}$	$\frac{bd + zd^2}{b + 2d\sqrt{z^2+1}}$	$b + 2dz$
zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2dz$
$\frac{2}{3}td$	$t + \frac{8d^2}{3t}$	$\frac{t^2d}{1.5t^2+4d^2}$	$\frac{A}{0.67d}$

FIGURE 67. Channel cross sections, notations, and formulas.

Figure 4.7 Channel cross sections and characteristics (after FAO 1965).

5 STUDY AREA

5.1 GEOGRAPHY AND GEOLOGY

The elevation of the farm ranges from 560 m above sea level to 480 m a.s.l. near the Ngerengere River. The area is on the N W edge of the Ruvu drainage basin. Ngerengere river, which runs along the boundary of the farm, joins Ruvu river on its way to the Indian Ocean. Many tributaries of the Ngerengere river, which springs from the Uluguru mountains, have discharge all the year round. Other tributaries for example from the Lugala mts. and the Mindu mts., provide the Ngerengere with water in the rainy season only. The valley which lies between the Ulugurus and the Lugala, forms a shallow concave-shaped valley.

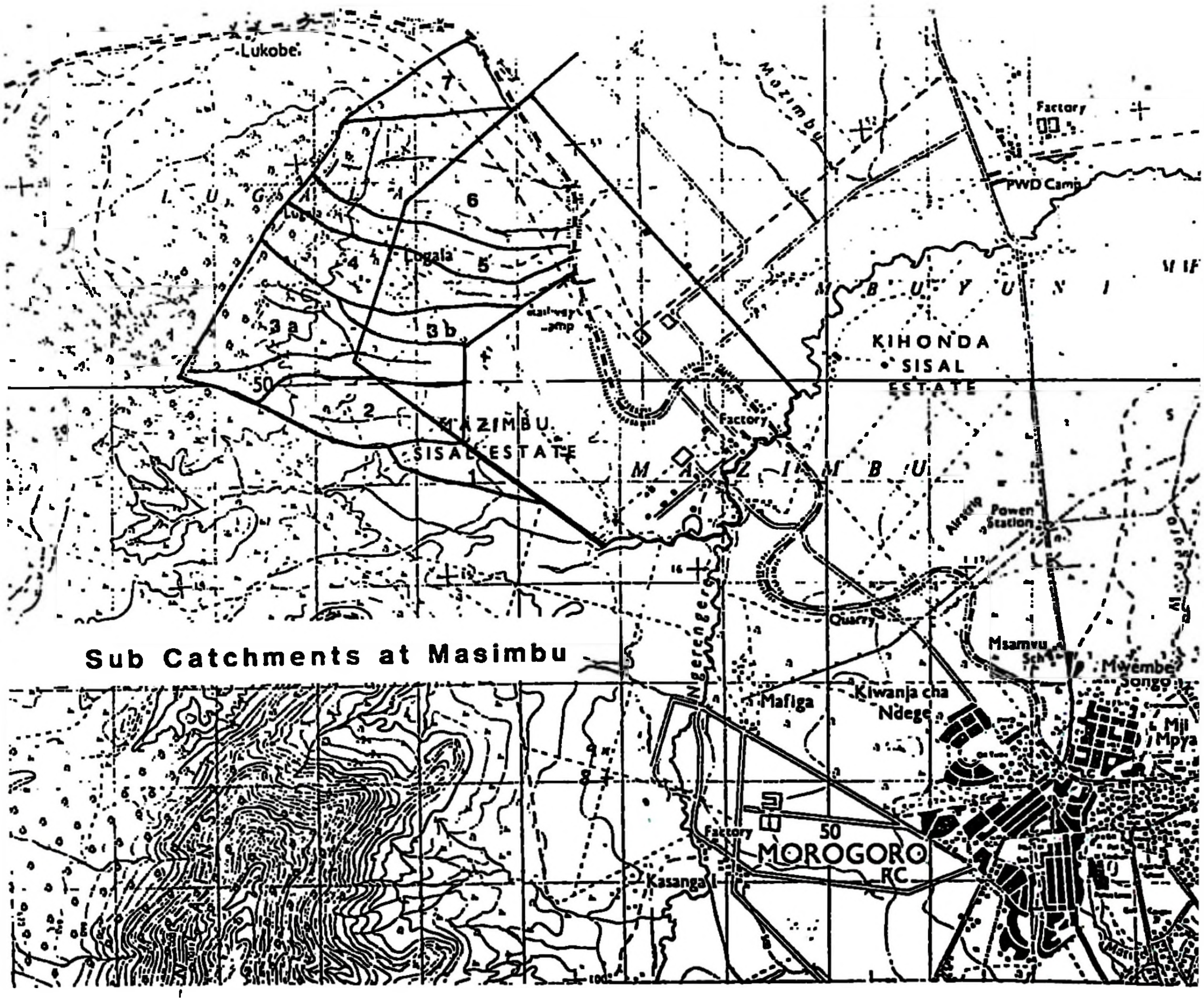


Figure 5.1 Location of Mazimbu farm.

Tanzania is one of the contries which has been affected by the African Rift Valleys. However, although the country has been affected by active geological process due to the rifting, it has also experienced a long stable geological period. The bulk of Tanzania is, therefore, underlaid by Precambrian.

Though much of the country has not been directly affected by the faulting, the formation of the Uluguru mountains and drainage systems nearby has been affected by rift tectonics. As a result, the bedrocks exposed are different from each other, even though the distance between the Uluguru Mts., the Lugala Mts. and the Mindu Mts. is only some ten kilometers. The bedrocks are originally the same group as the Mozambique Belt. The Uluguru mts. have been uprifted as a horst block against pediments which has given the gently sloping land along the Ngerengere river. The exposed bedrocks at the Uluguru mts. show hornblende and pyroxene granulites, and the Mindu mts. and the Lugalla mts. consist of micaceous gneisses (Rapp et al. 1972).

5.2 VEGETATION

This description of vegetation concerns the grazing area northwest of the fields (see figure 5.5). Common plant species found in the grazing area are listed in table 5.1.

The existing vegetation on the lower slopes is secondary, after sisal. The vegetation type is probably Combretaceous wooded grassland. On the steeper slopes of the Lugala Mountains tree cover is more dense, probably Combretaceous woodland (Kjelland-Lund, pers.comm., Lind et al. 1984).

Some species; the grass Heteropogon contortus and the shrub Dichrostachys cinerea are typical for overgrazing. Acacia species can also be a sign of overgrazing since overgrazing enhances their competitive advantage.

The ground cover becomes sparce during the dry season, due to grazing, trampling and limited moisture (fig. 5.2).

Table 5.1 Common plant species in the grazing area of Mazimbu.

Grasses and herbs
Andropogon gayanus Kunth Chloris gayana Kunth (Rhodes grass) Eragrostis aspera (Jacq.) Nees Eragrostis setulifera Pilg. Heteropogon contortus (L.) Roem. et Schult Hibiscus micranthus L.f. Hyparrhenia umbrosa (Hoch st.) W.D. Clayton Panicum maximum Nees (Guinea grass) * Urochloa mosambicensis (Hack.) Dandy
Trees and shrubs
Acacia species Combretum fragrans F. Hoffm. Combretum zeyheri Sond. Dichrostachys cinerea (L.) Wight. et Arn. Diospyros ursambarensis Diplorhynchus condyaocarpon (Muell.Arg.) Pichon Markharnia obtusiflora (Baker) Sprague

*doubt about classification since spikelets were gone from sample.

Figure 5.2. Vegetation in the grazing area, June/July 1987.

5.3 CLIMATE

The climate is mainly governed by two major airstreams since the country is located between 1 and 11 degrees southern latitude ; a southeasterly airstream during the northern hemisphere summer, and a northeasterly airstream during high summer period in the country (Jackson 1971). The air masses which come from both direction, are relatively dry so that the formation of rainfall necessitates the movement of the air masses upwards.
Monthly rainfall amounts are dependent on the movement of the Inter-Tropical Convergence Zone (ITCZ; a low pressure trough) not only over the country but also in the area of Morogoro (Nieuwolt). Existence of the Uluguru mts. is also important since the Ulugurus affect the air mass movement.

The seasons of the year can be devided into four types due to the influence of the ITCZ;

*Long-rain season (March to May); ITCZ dominates over the country, very unstable atmosphere

*Dry season (June to October); ITCZ disapears from Africa, very stable atmosphere

*Short-rain season (November to December); ITCZ comes back to East Africa

*North-east monsoon (January to Febrary); ITCZ passes through to Southern Africa (after Nieuwolt)

The variation of the annual rainfall at 3 stations in Morogoro is shown in figure 5.3. The figure shows the influence of the different altitude of the stations and that the distance of the stations from the mountains strongly affects the amount of rainfall. Jackson (1970) analysed rainfall variations over time and place in the Ruvu Basin. It shows that the amount of rainfall decreases dramatically as the altitude decreases on north-western slopes of the mountains, while rainfall on south-eastern slopes decrease moderately. Consequently, the rainfall amounts at Mazimbu can not be expected to be same as Morogoro Water Department (Maji) recieves, but may be somewhat less. Jackson also obtained annual rainfall probability at Morogoro Meteorological

Station that the station has an 80 % probability of reciving 722 mm/yr and a 90 % probability of 633 mm/yr. The probability value are very important to avoid failure of harvest.

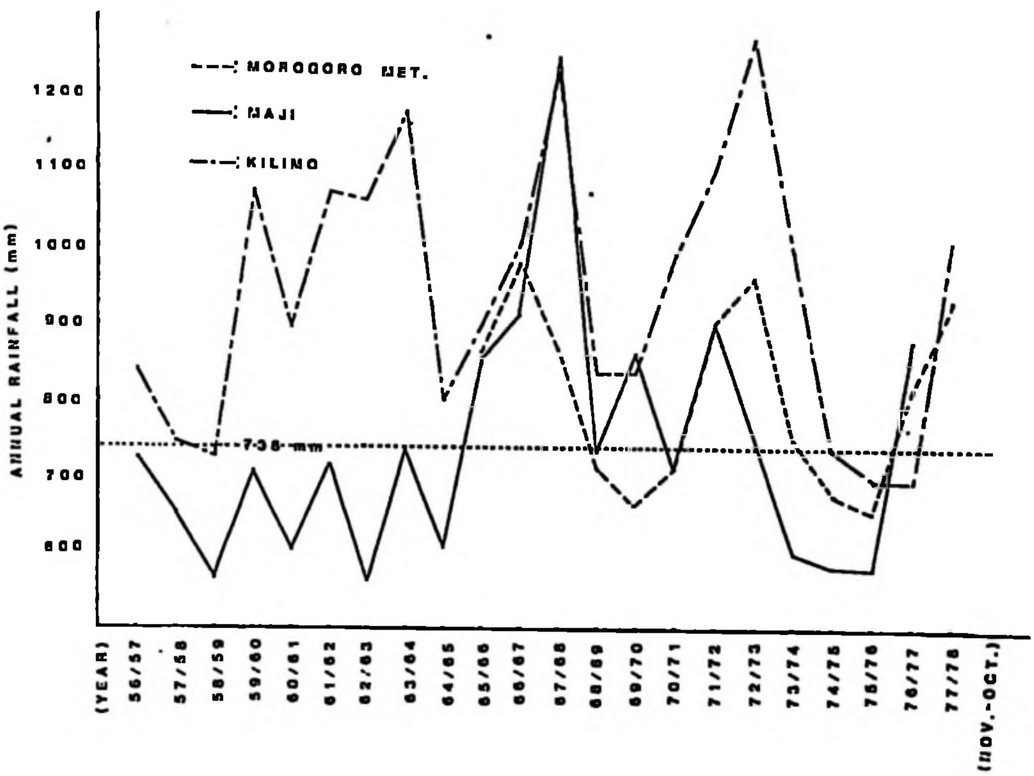


Figure 5.3 Annual rainfall of 3 stations in Morogoro
MAJI: Morogoro Water Department
KILIMO: Morogoro Agricultural Office
738mm: Mean annual rainfall at MAJI

Table 5.1 Climatic data in Morogoro (after DHV consulting engineers 1980).

Rainfall mean (mm): Morogoro Water Department (Maji).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
100.6	90.1	111.9	185.0	56.6	15.7	11.6	6.5	12.5	29.8	49.7	81.5

*Total Rainfall 738.8 mm(Interval Nov.-Oct.)(1956-1977)
Tab.5.1(continued)
Monthly climatic records at Morogoro Meteorological Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
#1	26.2	26.2	26.1	25.0	23.5	21.6	21.1	22.1	23.2	24.6	25.6	26.5
#2	173	159	167	126	111	106	112	126	146	179	176	179
#3	301	261	500	386	402	143	119	79	110	168	320	258
#4	63	100	93	64	40	23	38	34	62	72	88	77

#1:Mean temperature (°C) (1946-60)
#2:Potential evaporation (E_0: mm/month)
#3:Rainfall highest (mm) (1906-1970)
#4:Rainfall Max. 24 hours (mm) (1906-1970)

5.3.1 Rainfall intensity

Rainfall intensity is an important factor with respect to soil loss and runoff. High rainfall intensity causes much soil loss and runoff from arable land. Many reseachers have shown that rainfall in tropical countries is much more aggressive than that of temperate countries. Lal (1979) recorded a maximum intensity of 213 mm/h (7.5-minute duration) in Western Nigeria. Kowal and Kassam (1981) noted that individual storms with rainfall exce-eding 50 mm and peak intensities of 120 to 160 mm/h are not uncommon in the country. Hudson (1986) reported an intensity 340 mm/h (a few minute duration) from Zimbabwe. He reported that rainfall intensities greater than 70 mm/h (a few minute duration) are quite common in the tropics.

Some rainfall intensities which were recorded by the automatic raingauge in Morogoro Met. Sts., were analysed in the peroid Nov./'70 to Oct./'86. A few typical records of rainfall are shown in figure 5.4.

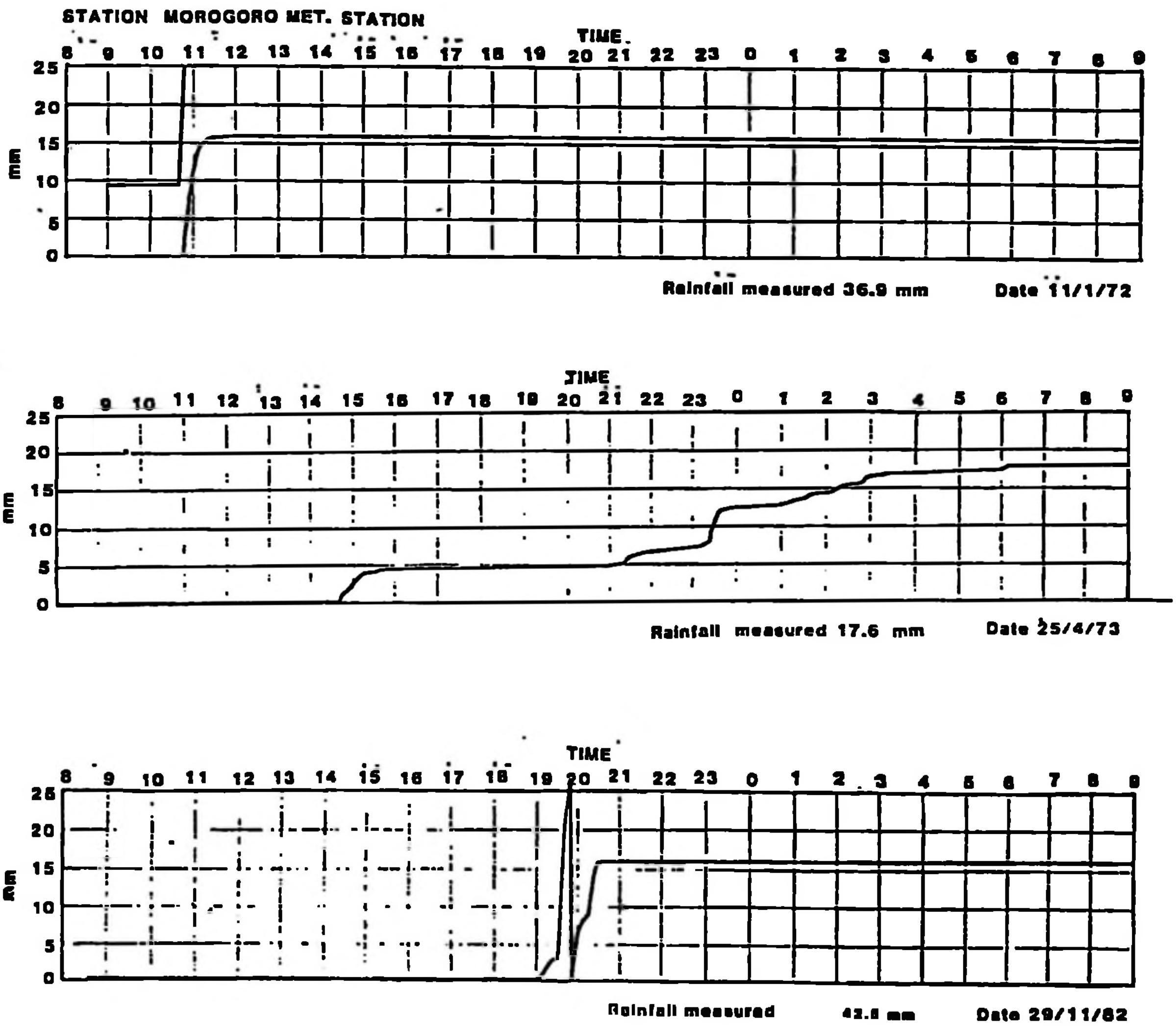


Figure 5.4 Examples of automatic raingauge charts.

The rain on 11/Jan./1972 is a typical storm which the trace rises quickly just after the onset of the rainfall, and lasts a very short period. This type of rainfall can be expected in both 'short' rain and 'long'. However, a rain type similar to the rain 25/April/1973 seldom occurs in a 'short' rain. From the point of view of soil erosion, an intense rain, such as on the 9/Nov./ 1982, which occurs at the beginning of the rainy season, is very serious. This is because vegetation (both natural and cultivated) is not developed enough to cover the soil surface. Thus much soil loss can be caused during a 'short' rain.

The highest rainfall intensity and the second highest intensity have been computed for each year of the data from Morogoro Meteorological Stations (table 5.2).

Table 5.2 Rainfall intensities of storms at Morogoro Met. Sts.

	Highest (mm/h)	Duration (minute)	Second highest (mm/h)	Duration (minute)
Nov.'70-Oct.'71	90	5	90	5
'71-'72	102	11	100	5
'72-'73	56	8	43	16
'73-'74	93	8	74	8
'74-'75	70	8	67	8
'75-'76	95	11	87	8
'76-'77	80	13	80	8
'77-'78	86	8	55	8
'78-'79	-	-	-	-
'79-'80	100	5	75	11
'80-'81	67	8	61	9
'81-'82	80	18	67	8
'82-'83	113	8	80	21
'83-'84	78	24	55	5
'84-'85	89	18	80	8
'85-'86	85	11	70	21

- : Lack of data

The rainfall intensities that are shown in table 5.2, are not calculated from complete data since some years lacks data, especially data for small amounts of rainfall. However, it is considered that the highest intensity at Morogoro Met. Sts. is not so high as in West Africa and Zimbabwe. Moore (1979) has reported that in general in East Africa, rainfall intesities greater than 75 mm/h (15 min.- period) may be expected a little apart from on the Uganda Plateau area where intensities greater than 100 mm/h are often recorded.

However, there is a problem which should be cosidered with respect to calculation of rainfall intensities in tropical countries. The rainfall (29/Nov./'82) shows a typical storm which was recorded in that period. The duration of the highest intensity lasted 8 minutes, however, calculation of a very short duration (one or two minuter) is almost impossible due to the scale of the horisontal axis (time). Assuming a point, a one- or two-minute duration of rain can go over the value that is shown in table 5.3. Conversely, when a rainfall is extended over a 30-minute period, low rainfall intensities are obtained as table 5.3 shows. The values that are given in table 5.3, are more accurate than the values in table 5.2. Because even if a small amount of rainfall which has a very high intensity, is lacking from the data, the intensity that is divided into a 30-min. interval gives a relatively low value of intensity.

Table 5.3 Rainfall intensity greater than 50 mm/h (30-min. period)

	Intensity (mm/h)
Nov.'70-Oct.'71	60
'71-'72	58, 53, 50
'72-'73	-
'73-'74	50
'74-'75	70
'75-'76	60, 55
'76-'77	66
'77-'78	-
'78-'79	-
'79-'80	57, 52, 50
'80-'81	-
'81-'82	72
'82-'83	56, 54
'83-'84	76, 52
'84-'85	66
'85-'86	66

- : rainfall intensity less than 50 mm/h

5.4 SOILS

5.4.1 Methods

The purposes of the soil survey were:
-to give basic information about the soil,
-to record soil properties that are important to erosion,
-to discover soil variations and hence variations of erodibility
-to detect previous erosion/sedimentation,
-to supply data for the construction of an erosion risk map (the map showing potential soil loss, appendix 5),
-to make it possible to compare the soil at Mazimbu to soil descriptions from other locations,
-to obtain information about nutrient conditions in the soil.

Soil profile sites and surface sample sites are shown on the map in appendix 4.

<u>Soil profiles</u>
Profile sites were selected on the basis that they should represent the various soil conditions at Mazimbu, and they shoul be easily accessible. 5 profiles were dug on a line along the slope and parallell to a farm road and electrical line on the western side of the railway. Two of these profiles (2 and 3) seemed to have the same visible properties, and only one of them (3) was described.

It is assumed that the variations in soil properties that are recorded from the four profiles along the slope give a picture o soil variation along the slope for the rest of the farm as well, at least for texture. Profile 7, the only profile on the eastern side of the farm, was dug because augering in the area showed soil properties that had not been discovered in the other profiles; light, coarse textured material with little/no clay content.

Soil profiles were not dug on the lower, gentle slopes of the farm. This means that soil properties on the lower parts of fiel

2, 3 and 10 and all of field 9 have not been recorded by this thorough examination. However, field registrations show that these soils are more clayey than on the higher parts of the farm. The high clay content and small slope means that these fields are less exposed to erosion, and detailed soil examinations were less important.

The profiles are described according to the FAO- guidelines for soil profile descriptions (FAO 1977). Soil classification is done according to the FAO-Unesco system (FAO-Unesco 1974). Revised standard soil color charts (OYAMA & TAKEHARA 1967) are used to determine soil colors.

Soil surface/field registrations

Initially this should have been a combination of a surface and subsoil survey, but very hard subsoil excluded the use of a soil auger. Subsoil examination was not carried out in most cases. At one place; site 6, subsoil samples were taken for analysis.

Properties of importance to erosion which were possible to record practically were selected.

Texture was determined in the field by working a soil sample with fingers.

Soil structure and consistence were described as for the profile descriptions (FAO 1977).

Types of erosion were classified as sheet, rill or gully, and intensity within each erosion type were given values from 1 to 4, with 4 as the most severe form.

Special factors including crusting, cracks, stones/rocks on the surface, special characteristics of plant cover etc. were recorded.

Efforts were made to describe representative sites. Samples from each textural group were taken for physical and chemical analysis.

Infiltration tests

Infiltration rate was measured with a double ring infiltrometer. Infiltration was measured at the profile sites and at field 15, site 6. Water level in cylinders varied between 8 - 12 cm. The measurements continued until little change was registered in infiltration rates and/or lateral flow was observed.

Soil analysis

Analysis were carried out at Landbrukets Analysesenter, Ås, and at the Department of Soil Science, AUN.

pH: pH was measured in a 1:10 soil/water suspension and a 1:10 soil/0.01M $CaCl_2$ suspension. A Metrohm 632 pH-meter with separate glass electrode was used.

Organic matter(O.M.): O.M. was found as % ignition loss when oven dry soil was heated to 550°C. Ignition loss was corrected for loss of water from the clay fraction as follows:

clay content (%)	reduction (%)
0-15	1
15-25	2
25-40	2.5
40-60	3.5

(Øien and Krogstad 1987)

Nitrogen (N): A modified macro Kjeldahl approach was utilized for determination of total N content. Soil was digested in sulphuric acid and a salt mixture of sodium sulphate and copper sulphate (Cheatle and Van'T Klooster 1984).

Available phosphorous (P): P was determined after a slightly modified version of the Bray and Kurz No 1. Soil was extracted in a solution of ammonium fluoride and hydrocloric acid. Addition of ammonium molybdate and ascorbic acid gives blue, reduced complexes. These are measured spectrophotometrically.

Cation exchange capacity: Ca, Mg, K and Na were extracted by 1M NH_4OAc at pH 7 and determined by atomic adsorption spectrophotometry (Øien and Krogstad 1987). Al was extracted by 1M KCl and determined by titration with NaOH (Cheatle and Van'T Klooster 1984). H was determined by titration in both the NH_4OAc and the KCl- extract.

Calculations:

Potential cation exchange capacity; CEC(NH_4OAc)
=Ca+Mg+K+Na+H (meq/100g)

Base saturation(NH_4OAc); BS
=(Ca+Mg+K+Na/CEC) x 100 (%)

Effective cation exchange capacity; ECEC
=(Ca+Mg+K+Na)NH_4OAc + (Al+H)KCl (meq/100g)
(Moberg et al. 1982)

Aluminium saturation; %Al
=(Al/ECEC) x 100 (%)

CEC/100g clay
=(CEC(soil) / %clay) x 100

The CEC, determined with NH_4OAc at pH 7, which is higher than natural pH in most soils, gives an overestimated exchange capacity of the soil. This is a result of pH-dependent charges on soil particles. The effective exchange capacity, ECEC, is a more realistic value for the actual soil conditions (Sanchez 1976). ECEC is normally determined with the extraction of soil in a neutral, unbuffered salt solution, f.ex. NH_4Cl. For the determination of "ferralic properties", CEC(NH_4Cl) / 100g clay is a criteria. Since this has not been determined, the calculated ECEC value is used (profile 1 and 4).

Particle size distribution: This was determined with the pipette method and wet sieving.

Some of the samples were overheated (>200°C) when drying the silt and clay fraction. This may have caused a loss of CO_2 from carbonates and of clay mineral water, hence an underestimation of the fine fraction. The influence of overheating depends on the type of clay mineral; gibbsite and allophanes loose water between 100 - 200°C, while other clay minerals loose water in the temperature range of 450 - 600°C. Except for sample 5.4, weight loss is still within an acceptable range (Krogstad, pers. com.).

5.4.2 Soil units

The classification of each soil profile, a brief classification and assumptions of soil unit distribution are given in this section. Soil data are insufficient to draw a soil map, mainly due to few subsoil examinations. The assumptions of soil unit distribution are based on exsisting soil data, field registrations, and topography.

Complete soil profile descriptions and analytical data are included in appendix 1 and 2.

Locations of soil profiles are given in appendix 4. Field numbers can be read from figure 5.5.

Ferralic Cambisol

Profile 1.
Location: 500 m above field 15, ca 10 m northeast of electrical line.
Deep, well-drained soil with sand in the upper horizon, increasing clay content and sandy clay loam as the dominating texture with depth. The soil has low base saturation and relatively high Al-saturation. pH decreases with depth, and varies from 5.4-6(H_2O) and 3.8-4.7($CaCl_2$).

Profile 4.

Location: Southern corner of field 5.

The soil is red, shallow and well drained. Most of the profile has fine texture, but there are no signs of clay illuviation. Cation exchange capacity is low, and base saturation < 50%. Al-saturation and pH are low.

Ferralic Cambisol presumably covers the lower parts of the uncultivated area, field 15 and the elevation on field 5,6,7 and 8. Field 13 could also be dominated by Ferralic Cambisol.

Chromic Cambisol

Profile 5.

Location: Southeastern corner of field 7.

Dark, well-drained soil, with sand overlaying sandy loam. Bottom of profile is a layer of stones. Base saturation is high, >50% except for the upper horizon. pH vary from 6.1-6.8(H_2O) and 5.1-6.1 ($CaCl_2$). Little aluminium is detected.

Chromic Cambisol probably covers the field below field 7, the lower part of field 6 and 7 and some of field 5.

Albic Luvisol (truncated Luvisol)

Profile 3.

Location: Northwestern corner of field 6.

Deep, well-drained soil that consists of a thick layer of sand over sandy clay loam/sandy loam. There are clear chemical differences between the sand layer and the subsoil; pH,cation exchange capacity and base saturation are low in the upper 40cm. Below 40 cm, the pH(H_2O) is >7 and base saturation is >50%. The high base saturation could be due to high Na content. Al-saturation in the topsoil is low.

Albic Luvisol is probably found mainly on parts of field 8 and field 14.

Albic Arenosol

Profile 7.
Location: The elevation of the northeastern side of field 12. The soil is light, coarse and somewhat excessively drained. Cation exchange capacity and pH are low. Al-saturation exceeds 40% in the AB horizon.

Albic Arenosol is probably limited to the elevation on the upper half of field 12.

Other soil units

The lowest parts of the farm on the eastern side of the railway, field 9, could probably be a Vertisol. This is based on the observation of a high clay content and, during the dry season, wide, deep cracks. Information from a NORPLAN hydrogeologist supports this assumption, as he stated that there should be "black cotton soil" near the Ngerengere river. Soils with high clay content on most of field 10 and 2, and the lowest parts of field 5 and 3 could be soils with vertic properties.

Mpepo (1984) has classified soil on the neighbouring farm. According to his classification, Ferralic Arenosol could have been expected in the area. The classification of soils at Mazimbu is based on analytical data that shows that the soils, except for profile 7, have too fine a texture to be classified as Arenosols. However, profile 3 is close to an Arenosol.

5.4.3 Soil texture and organic matter

Topsoil texture

Topsoil texture is shown in appendix 4. The main surface texture is sand and loamy sand, but also sandy loam and sandy clay loam is common. Soil surface texture seems to differ between the two sides of the railway. Sands dominate at the western side, while loams are more common east of the railway.

Clay in the surface is found mainly on the lower slopes, which means field 9 and parts of field 2, 10. Some clay in the surface is also found on the lower slopes of field 12.

Particle size distribution for soil surface samples are given in table 5.8.

Table 5.8. Particle size distribution and organic matter content for soil surface samples.

Texture	Sample	Particle size distr., weight %			O.M.
		Sand 2-0.06mm	Silt .06-.002	Clay <0.002mm	%
SAND	1.0	89	5	7	0.3
	3.1.a	88	7	5	0.2
	5.1	92	9	0	1.6
	6.1	89	10	1	0.8
	7.1	89	7	4	0.0
	24	89	7	4	0.0
	27	88	8	4	0.0
LOAMY SAND	14	82	9	9	0.6
	17	86	6	7	0.2
	36	86	8	6	0.0
	42a	84	10	5	0.9
	56	83	10	7	0.2
SANDY LOAM	4.1	77	9	14	2.5
	25	79	8	13	1.6
	26	68	16	16	1.2
	42b	78	12	10	0.6
	53	71	13	16	1.0
LOAM	45	50	29	21	3.9
SANDY CL. L.	13	64	15	21	1.6
	23	50	20	30	2.1
	44	53	14	33	3.3
CLAY	40	38	20	43	2.6
	43	13	28	59	5.3

Subsoil texture

Subsoil texture has to be considered based on soil profile descriptions and soil unit distribution. Table 5.9 shows texture throughout the soil profiles.

Generally the subsoil has a higher clay-content than the topsoil, but sand is still the dominating fraction. Sandy loam or sandy clay loam seems to be the dominant textural group. Exceptions are profile 4 and 7, which have sandy clay and sand in the subsoil, respectively.

Table 5.9 Particle size distribution in subsoil samples.

Soil sample and depth (cm)			Particle size distr., weight %		
			Sand 2-0.06mm	Silt .06-.002	Clay <0.002mm
Profile No. 1					
	Ah	0-20	89	5	7
	Bu1	20-39	77	7	16
	Bu1	39-75	70	7	23
	Bms1	75-110	71	7	22
	Bms2	110-130	65	7	28
	BC	130-210	46	5	49
Profile No. 3					
	Ap1	0-19	89	7	5
	Ap2	19-32	86	8	6
	E	32-40	92	6	2
	Bt	40-85	67	8	25
	Bm1	85-129	74	8	18
	Bm2	129-147	70	9	20
	Bm3	147-193+	77	4	19
Profile No.4					
	Ap	0-9	77	9	14
	B1	9-30	50	6	44
	B2	30-46	54	8	38
	BC	46-60	74	6	20
Profile No.5					
	Ap	0-27	92	9	0
	B1	27-61	84	10	5
	B2	61-115	74	7	19
	B3	115-152	68	11	21
Profile No.7					
	Ap	0-15	89	7	4
	AB	15-57	87	8	5
	Bu1	57-	88	7	5
Site No.6					
		10-15	90	10	1
		15-75	85	5	10
		75-105	77	5	18
		105-	77	8	15

Organic matter

Only the O.M. content in the surface soil will be discussed, as this influences soil erodibility. For sand and loamy sand O.M.

varies from 0 to 1.6 %, with most samples having less than 0.3 %. Mean O.M. content for sand and loamy sand is 0.4 %. Loam, sandy loam and sandy clay loam have from 0.6 to 3.9 % O.M., with a mean content of 2.6 %.

There are few analysed samples with clay topsoil, which makes it impossible to draw any conclusion, but it seems as if the O.M. content is higher in the clay soil than in the coarser soils. For the two analysed clay-samples, O.M. content is 2.6 and 5.3 %.

To conclude, it appears that O.M. content generally is very low in the topsoil. O.M. content is lowest in the sandy soils and increases with increased clay content. The O.M. content in clay soils could be overestimated due to the analytical method .

5.4.4 Topsoil structure.

Topsoil structure is of importance to the erodibility of the soil. General structure characteristics for the topsoil textural groups are shown in table 5.10.

Table 5.10 Topsoil structure.

soil texture	soil structure							
	str.less	weak		moderate		strong		
		1	2	1	2	1	2	3
SAND AND LOAMY SAND	+	+++	++	++	+	+	-	
SANDY LOAM LOAM SANDY CL.L.	-	-	++	+++	++	++	-	
SANDY CLAY CLAY	-	-	-	-	-	+++	+	+

1=blocky, 2=granular, 3=prismatic
- = not present, + = sporadic, ++ = common,
+++ = dominating

Weak, blocky structure dominates in sands. Improved structure, such as weak granular and moderate blocky are common in sands.

The weak structure in sand is probably due to the low content of organic material and clay.

The structural conditions for loams are better, with moderate, blocky as the main structural state. Weak and moderate, granular and strong, blocky are common structural states for loams.
Few descriptions of clay samples cause some uncertainty about the structural state for this texture, but it appears that strong, blocky is the dominating structure.

5.4.5 Infiltration rates

Infiltration rates vary from 5 cm/h to > 50cm/h (table 5.11), This means that the infiltrability of the soil is good, as is the case for many tropical soils (Greenland 1977).

Table 5.11 Infiltration rates for some soils at Mazimbu.

Infiltration rate, cm/h			
Site	Date	Final	Hours
Profile 1	14/7	30	5
Profile 1	28/7	20	4
Profile 3	20/7	18	5.5
Profile 4	22/7	6	2
Profile 5	24/7	6	2
Profile 5	24/5	5	2
Site 6	20/6	8	1.5
Site 6	25/7	29	2
Profile 7	30/7	57	2.5

The highest infiltration rates are found at profile 1 and 7,and could be explained by the natural conditions of profile 1 (uncultivated) and the coarse texture of profile 7. Infiltration rates are lowest at profile 4 and 5, which indicates that these soils are most exposed to runoff.

At site 6, the differences between the two tests could be due to surface properties, as the surface had a 2-3mm thick crust under the first test. The crust probably consists of fine, consolidated material with finer pores and lower saturated conductivity than the underlying soil, and thus reduces the infiltration rate. Before the second test at site 6, the crust was broken up by trampling animals.

The high infiltration rates that are found indicate that only very high rainfall intensities (>50mm/h) cause runoff, and that runoff should only occur on soils with the lowest infiltration rates. However, erosion features show that runoff occurs in most fields. It appears as if measured infiltration rates are higher than the infiltration rates under rainfall. This could be explained by the following:

- Measurements were finished before a true final infiltration rate was reached.
- There was lateral water movement in the soil during the test.
- Sites are not representative.
- The soil surface responds differently under natural rainfall than under a stable watertable as in the infiltration test.
- Surface crusting was detected in most fields, and the effect of this may have been omitted by the tests.

The high infiltration rates corresponds well with the drainage classes for soil profiles. Profile 1, 3, 4 and 5 are well drained, and profile 7 is somewhat excessively drained, which means that water is removed from the soil readily and/or rapidly.

5.4.6 Soil acidity, cation exchange capacity, base saturation and aluminium content.

pH, cation exchange capacity (CEC), base saturation (BS) and Al content are listed in table 5.12 for soil profiles. Table 5.13 includes pH, CEC and BS for topsoil samples.

Table 5.12 pH, cation exchange capacity, base saturation and Al-content in soil profiles.

Soil horizon	Depth(cm)	pH H_2O	pH $CaCl_2$	Ca	Mg	K	Na	H	CEC (sum)	BS (%)	Al	H	ECEC (sum)	Al.sat. (%)	Texture
				NH_4OAc extr.(meq/100g)							KCl-ex(meq/100g)				
Profile No.1															
Ah	0-20	6.0	4.7	0.67	0.51	0.33	0.02	7.0	8.53	17.9	0.00	0.14	1.67	0.0	S.
Bul	20-39	5.4	4.1	0.65	0.47	0.31	0.04	8.1	9.57	15.4	0.81	0.17	2.45	33.0	S.L.
-"-	39-75	5.4	4.0	0.38	0.58	0.26	0.07	9.2	10.49	12.3	1.25	0.14	2.68	46.6	S.C.L.
Bms1	75-110	5.7	3.9	0.20	1.03	0.35	0.27	9.6	11.45	16.2					S.C.L.
Bms2	110-130	5.9	3.9	0.30	1.43	0.45	0.59	10.1	12.87	21.5					S.C.L.
BC	130-210	5.4	3.8	1.26	3.53	0.81	1.86	9.9	17.36	43.0					S.C.
Profile No.3															
Ap1	0-19	5.4	4.4	1.15	0.61	0.27	0.03	11.5	13.56	15.2	0.19	0.07	2.32	8.2	S.
Ap2	19-32	5.1	4.4	1.23	0.63	0.19	0.04	7.2	9.29	22.5	0.19	0.07	2.35	8.1	S.
E	32-40	6.3	5.3	0.97	0.62	0.01	0.10	7.1	8.80	19.3	0.00	0.08	1.78	0.0	S.
Bt	40-85	7.7	6.1	2.95	4.82	0.17	1.58	8.2	17.72	53.7					S.C.L.
Bm1	85-129	9.5	7.9	4.58	3.90	0.29	2.10	6.3	17.17	63.3					S.L.
Bm2	129-147	9.6	8.0	7.24	4.71	0.33	3.08	4.3	19.66	78.1					S.L.
-"-	147-193+	9.5	8.0	3.12	3.36	0.27	2.95	4.9	14.60	66.4					S.L.
Profile No.4															
Ap	0-9	5.6	4.7	3.02	1.20	0.49	0.04	5.5	10.21	46.1	0.13	0.10	4.98	2.6	S.L.
Bs1	9-30	5.2	4.7	2.85	3.67	0.42	0.05	7.5	14.49	48.2	0.50	0.16	7.65	6.5	S.C.
Bs2	30-46	4.8	4.2	1.88	3.08	0.33	0.04	6.0	11.33	47.0					S.C.
BC	46-60	4.9	4.4	2.07	2.36	0.29	0.07	5.6	10.39	46.1					S.C.L.
Profile No.5															
Ap	0-27	6.8	6.0	2.46	1.08	0.80	0.02	5.6	9.96	43.8	0.00	0.05	4.41	0.0	S.
Bul	27-61	6.1	5.1	1.95	1.17	0.52	0.02	3.3	6.96	52.6	0.00	0.04	3.70	0.0	S.
Bt1	61-115	6.1	5.3	3.15	2.88	0.38	0.02	4.4	10.83	59.4					S.L.
Bt2	115-152	6.7	6.1	4.41	2.84	0.35	0.18	4.4	12.18	63.9					S.L.
Profile No.7															
Ap	0-15	5.5	4.4	0.37	0.13	0.11	0.01	4.5	5.12	12.1	0.13	0.13	0.88	14.8	S.
AB	15-57	5.3	4.4	0.21	0.12	0.11	0.01	5.2	5.65	8.0	0.38	0.08	0.91	41.8	S.
Bul	57-100	5.0	4.4	0.20	0.21	0.10	0.05	4.7	5.26	10.6					S.
Site No.6															
	10-15	6.1	5.1	1.26	1.69	0.45	0.03	5.8	9.23	37.2	0.00	0.08	3.51	0.0	S.
	15-75	5.8	4.9	0.66	2.25	0.14	0.10	5.2	8.35	37.7	0.06	0.13	3.34	1.8	L.S.
	75-105	5.6	4.5	0.63	1.82	0.17	0.08	4.8	7.50	36.0					S.L.
	105-	6.6	5.2	1.14	1.98	0.10	0.35	4.1	7.67	46.5					S.L.

pH is generally acidic, exceptions are the topsoil of profile 3 at field 6 and topsoil sample 43 and 45 (field 9 + 10). Schroeder (1984) has given the following descriptive terms to soils of different pH($CaCl_2$): Weak acidic (7-8), weak sour (6-7), medium sour (5-6), strong sour (4-5), very strong sour (3-4). According to this description, topsoil is mainly medium and strong sour. pH in the subsoil varies from very strong sour to weak acidic.

Table 5.13 pH, cation exchange capacity, base saturation and Al-content in topsoil.

Sample No.	Depth (cm)	pH H_2O	pH $CaCl_2$	Ca	Mg	K	Na	H	CEC (sum)	BS (%)	Texture
				NH_4OAc-extr.cat.(meq/100g)							
13	5-15	6.3	5.9	6.04	2.35	0.76	0.04	4.0	13.19	70	S.C.L.
14	0-20	5.7	4.5	1.04	0.52	0.27	0.10	4.5	6.43	30	L.S.
17	0-10	5.8	4.7	1.08	0.60	0.33	0.01	4.5	6.52	31	L.S.
23	0-15	6.1	5.2	6.18	4.38	0.55	0.30	6.7	18.11	63	S.C.L.
24	0-20	5.0	4.3	0.63	0.31	0.19	0.02	4.7	5.85	20	S.
25	0-20	6.1	5.6	5.38	1.79	0.74	0.03	4.2	12.14	65	S.L.
26	0-7	6.6	6.0	6.07	2.00	1.06	0.02	4.1	12.25	69	S.L.
27	0-15	5.2	4.2	0.56	0.22	0.13	0.01	5.4	6.32	15	S.
36	0-15	6.1	4.9	0.66	0.43	0.37	0.01	5.1	6.57	22	L.S.
40	0-8	6.3	5.3	9.89	5.58	1.40	0.13	5.8	22.80	75	L.
42a	0-15	5.4	4.3	0.51	0.28	0.19	0.01	3.3	4.29	23	L.S.
42b	0-13	5.9	4.6	0.96	0.74	0.42	0.21	8.8	11.13	21	S.L.
43	0-7	7.0	6.3	16.7	11.2	1.98	0.77	6.1	36.75	83	L.
44	0-10	6.5	6.0	9.42	3.46	1.56	0.06	4.4	18.90	77	S.C.L.
45	0-15	8.0	7.3	17.2	2.27	2.19	0.04	4.1	25.80	84	L.
53	0-13	6.8	6.4	6.89	1.55	0.67	0.03	4.5	13.64	67	S.L.
56	0-13	5.9	4.7	1.30	0.89	0.52	0.01	3.7	6.42	42	L.S.

pH is of importance for nutrient availability and aluminium toxicity. Nutrient availibility is highest in pH range 6-7.5, while aluminium becomes more soluble with decreasing pH, hence the risk of aluminium toxicity increases. Msunza et al, ref. Svads (1983) found that for Zambian soils, pH($CaCl_2$) of < 4.7 for subsoil and < 4.4 for topsoil was critical for high aluminium saturation. According to these values, the risk for Al-toxicity at Mazimbu seems to be generally low in the topsoil, but there could be some risk for Al-toxicity in some subsoils.

<u>Cation exchange capacity</u>

Due to the analytical method of measuring CEC; extraction with NH_4OAc at pH 7, the potential CEC is measured for most samples, since soil pH is below 7. The potential CEC is higher than the effective cation exchange capability (ECEC) and the difference between them is due to pH-dependent charges. Detemination of the potentional CEC makes it complex to discuss the exchange conditions in the soil, since this value is not the real value. Therefore, an estimation of ECEC has been made for those samples where Al and H have been measured in a neutral KCl-solution. The values reached for ECEC are strikingly lower than those for CEC, and vary between 0.88 - 7.65 meq/100g. Sanchez (1976) suggests that ECEC values higher than 4 meq/100g are sufficient to prevent serious leaching losses. Most ECEC values at Mazimbu are below 4 meq/100g. This means that the soils capacity to retain cations, for example nutrients, is low, especially in sandy soils. Moberg et al. (1982) have investigated soils in the Morogoro area, and they state that most soils had low ECEC. An ECEC-value below 10 meq/100g seems to be low by their considerations, thus it seems the soils at Mazimbu have low ECEC.

Birchall et al. (1979 ref. FAO 1983) give the following nutrient status classes with relevance to CEC: High > 20, moderate 12-20, low 6-12, very low 3-6, extremely low < 3 (all in meq/100g).

According to this, most topsoils at Mazimbu have low to moderate CEC. The CEC of some subsoils are slightly better, due to clay content. Only soils with a high clay content have a high CEC. The low CEC of soils are due to coarse material and low OM content.

Base saturation

Base saturation (BS) is generally low for the coarse-textured soils, and high for soils with a high clay content. Since calculation of BS is based on the NH_4OAc extracted cations at pH 7, the calculated BS can be lower than the actual BS; at soil pH (Sanchez 1976). This is due to pH-dependent H^+ that may be revealed from the soil to the solution when soil pH is lower than pH in the solution.

Aluminium

Al-saturation is low, except for profile 1 and 7, which exceed 40 % Al-saturation in the topsoil. This corresponds well with the results of Moberg et al 1982, who found low Al-saturation in most of the investigated soils in Morogoro area.

5.4.7 Phosphorus and nitrogen content.

Total N content in the analysed soils varies from 0.03 to 0.08 %. The content of available P is highest in the upper layer of the cultivated soils (table 5.14). This is probably due to fertilization. A P-content in the topsoil of more than 20 mg/kg is common, while available P in the subsoil is less than 10 mg/kg. Both N and P-content are low in the sandy soil of profile 7.

Table 5.14 Nitrogen and phosphorus content in some soils at Mazimbu.

SOIL PROFILES				TOPSOIL		
Horizon and depth(cm)		Total N %	Avail.P mg/kg	Soil sample	Depth(cm)	Avail.P mg/kg
Profile no.1:				13	5-15	10
Ah	0-20	0.04	4	14	0-20	16
Bul	20-39	0.04	3	17	0-10	19
Bul	39-75	0.04	1	23	0-15	8
Profile no.3:				24	0-20	32
Ap1	0-19	0.05	12	25	0-20	21
Ap2	19-32	0.04	3	26	0-7	28
Profile no.4:				27	0-15	16
Ap	0-9	0.08	60	36	0-15	27-31
Bs1	9-30	0.08	2	40	0-8	30
Bs2	30-46	0.05	1	42a	0-15	17
Profile no.5:				42	0-13	47
Ap	0-27	0.06	40	43	0-7	19
Bul	27-61	0.04	7	44	0-10	58
Profile no.7:				45	0-15	33
Ap	0-15	0.04	4			
A/B	15-57	0.03	1			
Auger hole(6):						
	0-15	0.04	20			
	15-75	0.03	5			

It must be noted that since soil samples were taken short before or just after harvesting, N content and P content may change before next planting. Organic matter containing N and P are added to the soil as plant residues. As the residues are destructed, N and P are added to the soil.

The N and P content can be compared to N- and P-fertility classes for soils in Morogoro Region, developed by Singh and Uriyo (1980), table 5.15. All the analysed soils of Mazimbu are in the Low-N class, which corresponds well to the low organic matter content. Many soils have a very high P-content. Few soils have low P-content. The very high P-content in soils could be a sign of too high fertilization rates.

Table 5.15. N- and P-fertility classes. After Singh and Uriyo, (1980).

N-class	Total soil N %	P-class	Available soil P mg/kg
Low-N	0.10	Low-P	<15
Medium-N	0.1-0.15	Medium-P	15-25
High-N	0.15	High-P	25-30
		Very high-P	>30

5.5 THE FARM

In 1987, crop production covered approximately 450 hectares, not including horticultural crops. Northwest of the cultivated land, towards the Lugala Mountains, there are approximately 440 hectares of steeper, mainly uncultivated land with the exeption of some fields cultivated by Tanzanians. Parts of the uncultivated land is used for grazing of goats and cattle (see figure 5.5).

Farm information is primarily from personal communication with farm personell, although some information is found in the Norplan report (Kolshus et al. 1986). The rather detailed descriptions are required since the soil conservation plan affects farm management.

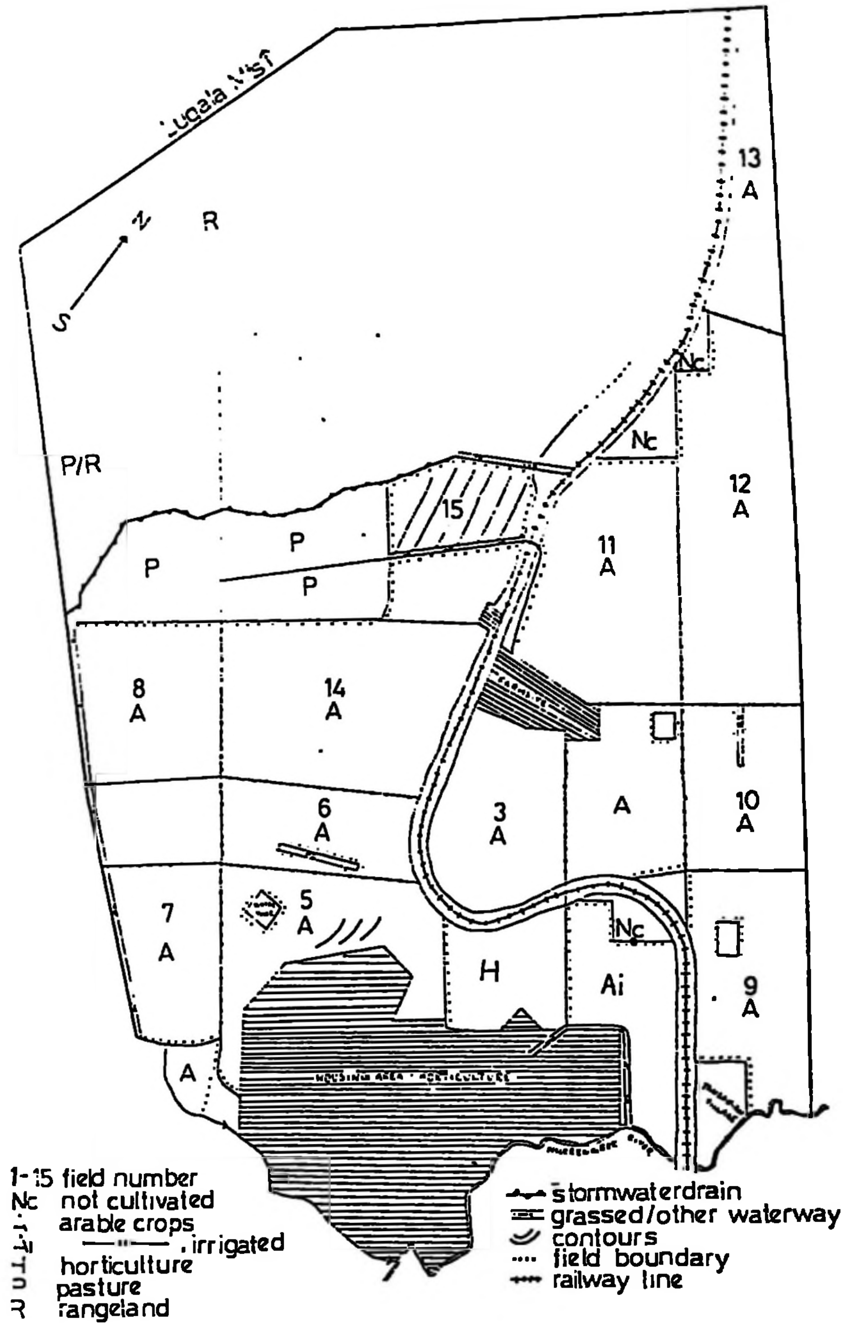


Figure 5.5. Land use and some conservation measures at Mazimbu, June/July 1987.

5.5.1 Plant production / Field section

The agriculture crops cultivated are maize (*Zea mays* L), sorghum (*Sorghum vulgare*), sunflower (*Helianthus annus*), beans (*Phaseolus* vulgaris L) and pasture (Chloris gayana). Lucerne (Medicago sativa) was cultivated on one field in 1986, but due to the unavailibility of seeds it was not cultivated in 1987.

Crop rotations: Crop rotations practiced in 1982 - 1987 are shown in table 5.5. The table shows that maize covers most of the fields, and that grass was introduced in 1986.

Table 5.5. Crop rotations practiced in 1982 - 1987 at Mazimbu.

Field	1982	1983	1984	1985	1986	1987
1	Maize	Sunflower	Sorghum	Beans	Lucerne	Sorghum
2	Maize	Maize	Sunflower	Beans	Maize	Sunflower
3	Sorghum	Maize	Beans	Maize	.Maize	Sorghum
4	Maize	Beans	Maize	Maize	Orchard	Orchard
5	Beans	Beans	Maize	Sorghum	Maize	Sunflower
6	Beans	Maize	Maize	Maize	Beans	Maize
7	Maize	Sorghum	Maize	Maize	Maize	Sorghum
8	Sunflower	Maize	Sorghum	Beans	Maize	Maize
9	Sunflower	Maize	Maize	Sunflower	Sorghum	Maize
10	Sunflower	Maize	Maize	Maize	Maize	Maize
11	0	Maize	Maize	Maize	Pasture	Pasture/ Sunflower
12	0	Maize	Sorghum	Tanzanians	Sorghum	Maize
13	0	0	0	Sorghum	Sunflower	Maize
14	0	0	0	Maize	Maize	Maize
15						Beans

Yields: Normal yields (seeds) are: Maize 2 - 2.8 t/ha, sorghum 2.5 t/ha and sunflower 0.3 - 0.6 t/ha. In 1987, maize yields were reduced some places due to drought, and they varied from 0.7 to 2.9 t/ha. Maize yields for specific fields in 1987 are listed in table 5.6. Yields for beans were 0.7 t/ha in 1984.

Tillage: Tillage operations are the same for all crops. The fields are ploughed with a diskplough every year during the dry season. Ploughing is usally done across the slope, at least this is the intention. This is difficult to accomplish, as the slope is not always uniform, and it is difficult to visually determine the slope direction in the field. Plant residues and weeds are mixed with soil during ploughing. The fields are harrowed one or two times with a diskharrow before planting.

Table 5.6. Maize yields for specific fields in 1987.

Field no.	Yields (t/ha)
6	0.7
8	1.2
9	1.2
10	1.6
12	2.4
13	2.9
14	1.4

Planting: Planting is done at the beginning of the rainy season, normally in February. Variations in the time when the rain starts, and the "false" start of the rainy season can create uncertainty in determining optimal planting time. Seed rates are given in table 5.7. No reason is given for the variations in seed rates for maize. According to Kolshus et al. (1986), 20 kg/ha are used for grain production of maize.

Crop cover: Distance between the rows are 70 - 75 cm. Spacing between plants is 30 cm in maize and 7 - 8 cm in sorghum and sunflower.

Weed control: Weeds are controlled with Primagram, 4 - 6 l/ha. In sorghum, 4 l/ha of Gesaprim are used, and in sunflower, 8.6 l/ha of Gesagard. Herbicides are applied at the pre-emergence stage. Two weedings before the crop canopy closes are recommended for beans (Kolshus et al. 1986). Despite of the use of herbicides, weeds are common in some fields during the dry season, particularly where the growth of the cultivated plants is weak.

Fertilization: According to Kolshus et al. (1986), fertilizer rates at Mazimbu are as follows: Maize: 200 kg/ha NPK (6-20-18) + 100 kg/ha CAN. Sorghum: 0 - 190 kg/ha NPK (6-20-18) + 0 - 68 kg/ha UREA. Sunflower: 100 kg/ha NPK (20-10-10) + 100 kg/ha TSP. Table 5.7 shows that the different maize fields recieved various amounts and types of fertilizers in 1986.

Table 5.7. Fertilizer rates and seed rates in Mazimbu in 1986.

Field	Crop	Seeding rate (kg)	Fertilizer rate (kg/ ha) NPK	CAN	TSP	SA	UREA
2	Maize	29	217	108			83
3	Maize	19	88				
5	Maize	5	30	15			
7	Maize	17	229	115			83
8	Maize	6	109	54			18
9	Sorghum	10					41
10	Maize	18	173	86			
11	Sunflower	21		36	107	36	
11	Grass	13			186	186	
12	Sorghum	14	190				68
14/15	Maize	15					34

Harvesting: Maize for grain production is harvested by hand approximately three months after planting, when the moisture content in the grains is 19 - 20 %. The cobs are harvested and the remainder of the plant is cut down and left in the field for grazing. Sorghum is harvested with a combine harvester. Sunflower is harvested by hand. After harvesting, weeds grow to a heigth of 30 - 60 cm. Plant residues are to a high degree destroyed by termites. Some of the grass is cut with a cutting machine, and some is grazed.

Existing conservation work: Some grass-covered contours have been made on field 5. There are some waterways along the farm road entering from field 5 to unit 4 (housing). In June/July 1987 a stormwater drain was constructed northeast of the cultivated area, to prevent inflow from the catchment. A grassed waterway (A) at the southeastern boundary was nearly completed. The waterway is supposed to drain some of the collected water from the storm waterway and the runoff from neighbouring fields. Another grassed waterway (B) was partly constructed by NOR-EMCO/NORPLAN. Contours and a grassed waterway were constructed on field 15. Existing conservation work is shown in figures 5.5, 5.6, 5.7 and 5.8.

Irrigation: An irrigation system makes it possible to irrigate a small part of the farm (field one). Irrigation at a higher elevation is impossible because of the low pump capacity.

Figure 5.6. Construction of the embankment of grassed waterway A

Figure 5.7. Contours on field 15.

Figure 5.8. Construction of a grassed waterway to drain water from the contours on field 15.

5.5.2 Animal husbandry

This section of the farm includes dairy, grazing animals, pigs and poultry.

Dairy section: In June 1986, the dairy section included 18 cows, 2 serving bulls, 16 heifers and 2 bulls over 6 months and 12 calves. This section is located at the farm site, and the animals are mainly fed inside the dairy barn.

Piggery: The piggery is planned to accomodate an adult population of 1000 animals (ANC SOMAFCO 1985).

Grazing animals: Approximately 500 goats and 50 beef cattle are grazing on the area northwest of the farm.

Feeding: Feeding is mainly based on pasture, maize, sorghum and sunflower produced at the farm. Fish meal, cotton cake, mineral salt etc. are bought.

Manure: Manure from the dairy section is mixed with sawdust and forage leftovers and than stored in piles on an uncultivated field. The urine is spread on the fields. There is manure storage from the piggery, but it is inadequate. Manure is leaching from the storage site, causing a wet, fertile waterway on field 3. Some manure is utilized in horticulture.

Little manure is collected from the beef cattle, as they graze during the day and they are in a corral during the night. Manure is collected during the night from the goats while they stay in a barn. The collected manure from the goats is not spread on the fields.

5.6 CURRENT EROSION

Considerations of the current state of erosion at Mazimbu is based on field registrations and visible signs of erosion. Measurements of the rate of erosion have not been done.

5.6.1 Field erosion

Within most fields there is a crust on the soil surface (figure 5.9).

Concentrations of coarse fragments (coarse sand/gravel) on the soil surface are also common. The crusting and the coarse fragments are signs of rainsplash and inter-rill erosion.

Rills are observed several places, especially on steeper parts of the fields. This may be close to sudden depressions such as waterways and roads. Figure 5.10 illustrates rills within a field. Local development of rills within maize rows resulted in lodging. This was observed in field 12.

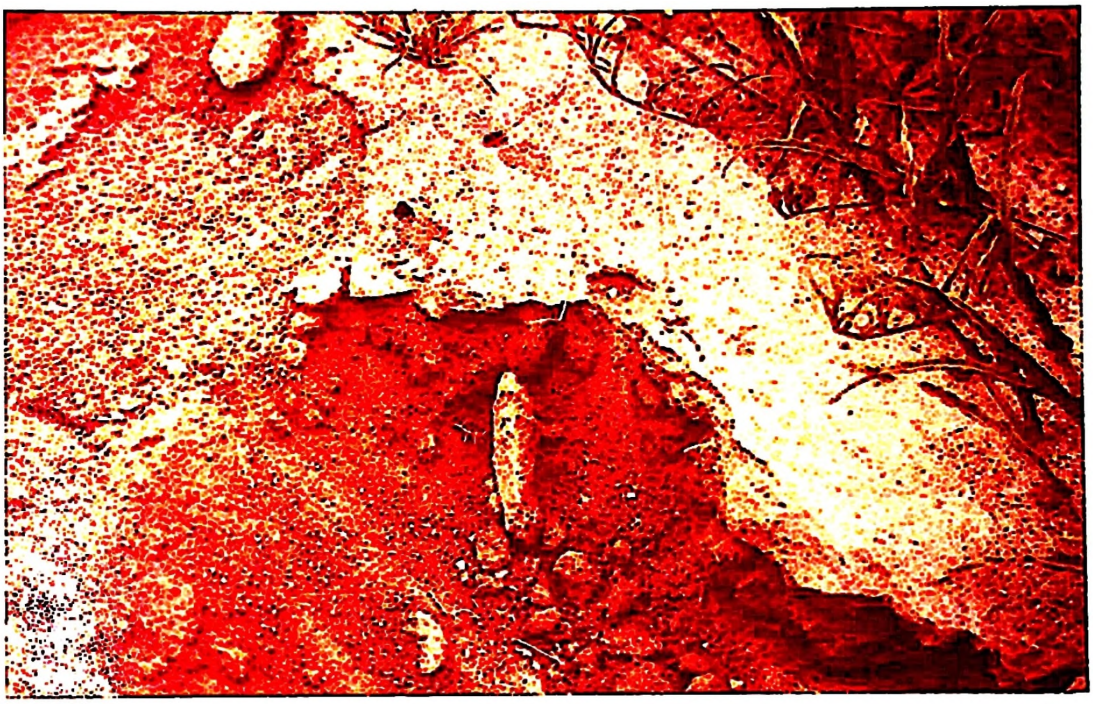


Figure 5.9. Surface crusting.

Figure 5.10. 45 cm deep rills in a maize field.

Larger rills and gullies occur along depressions in most fields and in the grazing area. These could be more than 50 cm deep and of various width up to more than 100 cm (figure 5.10 and 5.11).

Sedimentation in the fields is common where the slopes become nearly level, for example in the ends of waterways or below steeper slopes. Plant growth is often reduced due to sedimentation, (figure 5.13).

Figure 5.11. Sedimented gully, field 6.

Figure 5.12. Severe erosion in clay soil, field 9.

5.6.2 Other results of erosion

Erosion and sedimentation of farm roads causes damage. Sedimentation reduces the capacity of drains and culverts. Large amounts of runoff sometimes leads to flooding of parts of the housing area.

Figure 5.13. Sedimentation in the fields causes reduced growth of maize.

6 SOIL EROSION RISK ASSESSMENT AT MAZIMBU

Evaluation of the soil erosion risk at Mazimbu is based on USLE (chapter 3.2.1). Values for erosivity, erodibility, the topography factor and the cropping and management factor have been estimated. No conservation practice factor is included in the assessment, as the purpose is to assess the potential soil loss when no conservation practices are implemented.

6.1 RAINFALL EROSIVITY (R)

The Wishmeier's-index R was chosen for evaluating the erosivity at Mazimbu because the USLE-model will be used for the erosion risk analysis. R-index was originally calculated from data which was recorded by automatic rain recorders. However, there are several problems in calculating the R-index from rain chart in this case. First, it will require a large amount of time to compute EI_{30}-values for several years. Secondly, the use of automatic rain gauge charts from Morningside and Morogoro Meteorological Station is not suitable, because, annual rainfall at Morningside is so high that it can not be used for the calculation of the R-index for Mazimbu. Rainfall data from Morogoro Met. Station would be more suitable for Mazimbu, but, it can still be inaccurate to use this data as is shown in chapter 5.3, because annual rainfall at Mazimbu may be more or less than the annual rainfall at Morogoro Met. Station. A third problem, which is the most important problem, is that the rain charts from Morogoro Met. Station can not be obtained in enough quantity.

However, various researchers have proposed to calculate R-values (or EI_{30}-values) from non-automatic raingauge data. Hence, the following equations will be discussed to determine a R-value for Mazimbu:

Roose's method (1977)

$$R_{us} = P \cdot 0.5 \qquad \text{----------(1)}$$

where

R_{us} : mean annual rainfall erosivity (US units)

P : mean annual rainfall (mm)

Arnoldus' method (1980)

$$R_{us} = 4.17 \sum_{1}^{12} \frac{p^2}{P} - 152 \qquad \text{----------(2)}$$

$$R_{us} = 5.44 \sum_{1}^{12} \frac{p^2}{P} - 416 \qquad \text{----------(3)}$$

where

p : monthly rainfall (mm)

P : annual rainfall (mm)

* the equation (2) is obtained using 162 stations in the USA plus 14 stations in West-Africa
* the equation (3) using 14 stations in West-Africa

Rainfall erosivity in Zimbabwe by Stocking and Elwell (1976)

EI_{30} = 26.2·P - 8112 (Highveld) -----------(4)

EI_{30} = 49.7·P - 22305 (Middleveld) -----------(5)

EI_{30} = 26.7·P - 5961 (Lowveld) -----------(6)

EI_{30} = 21.5·P - 5111 (Combined) -----------(7)

where

EI_{30} : rainfall erosivity ($J \cdot mm/m^2/hr$)

P : mean annual rainfall (mm)

Rainfall erosivity (KE>25) in Zimbabwe by Elwell (1976b)

KE = 17.368·P (Southern Zimbabwe) -----------(8)

KE = 18.846·P (Northern Zimbabwe) -----------(9)

where

KE : annual kinetic energy (J/m^2)

P : mean annual rainfall (mm)

Rainfall erosivity in East Africa by Moore (1979) and Wenner (1977)

KE_{15} = 11.46·P - 2226 (combined) -----------(10)

KE_{15} = 22.82·P - 15795 (coastal) -----------(11)

KE_{15} = 11.36·P - 701 (inland<1250meter) ------(12)

KE_{15} = 3.96·P + 3122 (inland>1250meter) ------(13)

where

KE_{15} : annual kinetic energy at intensities greater than 25mm/hr, based on 15 minute periods (J/m^2)

P : mean annual rainfall (mm)

The regression equation (12) applies to Dodoma, Kigoma, Mwanza and Tabora in Tanzania.

A regrassion equation was presented by Wenner (1977) (described by Moore 1979) to convert kinetic energy to Wishmeier's index R in Kenya.

$$R_{us} = 0.029 \cdot KE - 26 \qquad \text{----------(14)}$$

where

R_{us} : rainfall erosivity

KE : annual kinetic energy (J/m^2)

Result:

Table 6.1 Several values of rainfall energy

	equation	EI_{30}	KE>25	R_{us}	comments
Roose	(1)			370	
Arnoldus	(2) (3)			299 164	
Stocking and Elwell	(4) (5) (6) (7)	11249 14423 13770 10777		661 847 809 633	$R_{us}=EI_{30}/17.02$
Elwell	(8) (9)		12834 13927		
Moore	(10) (11) (12) (13)		6243 1069 7694 6048	155 5 197 149	R_{us} are calculated using equation (12)

The unit of EI_{30} is $J \cdot mm/m^2/hr$ and KE>25 is J/m^2.

The unit of R_{us} is:

one hundredth of a foot-tonf·inch/acre/hour/year (Foster et al. 1981).

The mean annual rainfall (739 mm) which is used for the calculations, was observed at Morogoro Water Department (Maji).

The R-value for USLE at Mazimbu will be approximated to 197 (US units) since the regression equation of KE>25 is based on data from inland Tanzania and Kenya, and for further calculations of R_{us} were used the equation derived by Wenner (equation (12)).

Rapp et al. (1972) calculated rainfall erosivity at Morningside, Morogoro. They obtained a mean R-value 700 (EI_{30}=70000) (US units) and KE>25 was 12000 (J/m^2). Annual rainfall at Morningside is 2392 mm (year 1961-'70). The R-value at Morningside is about 3.5 times larger than the value at Water Dep., in Morogoro. However, the KE>25-value at Morningside is only 1.5 times larger than the value at Water Dep. This means that a large amount of rainfall at Morningside is considered as moderate precipitation.

Moore (1979) calculated the annual amount of storm rainfall greater than 25 mm/hr. At the stations that are lower than 1250 meter in Tanzania, 38 to 43 percent of the annual rainfall are higher than 25 mm/hr. If it is assumed that the rainfall characteristic at Mazimbu is similar to inland Tanzania, a relatively large part of the annual rainfall will cause soil erosion due to the high rainfall intnsities. He has mentioned that the erratic starting of the rainy season in Tanzania can cause severe soil erosion at the onset of the rainy season owing to the sparse vegetation in November.

Arnoldus' regression equation which is derived using data from West Africa gives a close value of the R-index.

The regeression equations from Zimbabwe show very high values compared with the equations from East Africa. This means that rainfall in Zimbabwe is obviously much more erosive than rainfall in East Africa. One reason can be that Hudson's KE>25-index gave the best correlation to soil losses in Zimbabwe though several results (Lal 1976, Ulsaker et al. 1983) showed lower correlation coefficient of the KE>25-index.

6.2 SOIL ERODIBILITY (K)

6.2.1 Erodibility factor in USLE

US units for K are used if not otherwise specified. The soil erodibility factor in USLE is the average soil loss per unit of erosivity for the standard plot of 22m, 9% slope, in tilled, continuous fallow. The nomograph (figure 2.3) gives K-values of 0-0.7, with the highest value for the most erodible soils. K has been predicted from the nomograph for all soil samples at Mazimbu. K-values and the factors used to predict K are shown in table 6.2.

Table 6.2 K-values and factors used to predict K for soils in Mazimbu.

Site	Silt+v.f.sand (%)	Sand (%)	O.M. (%)	Structure **	Perm. **	K
SAND						
Profile 1 *	11	83	0.3	2	1	0.04
Profile 3 *	15	80	0.2	3	1	0.10
Profile 5 *	19	82	1.6	4	2	0.17
6	19	80	0.8	4	2	0.18
Profile 7 *	15	81	0.0	4	1	0.13
24	17	80	0.0	4	2	0.18
27	16	80	0.0	4	1	0.15
LOAMY SAND						
14	18	73	0.6	4	2	0.17
17	14	79	0.2	4	1	0.13
36	19	76	0.0	3	2	0.15
42a	20	75	0.9	3	1	0.12
56	37	56	0.2	4	1	0.31
SANDY LOAM						
Profile 4 *	20	66	2.5	3	2	0.11
25	18	70	1.6	3	2	0.12
26	26	58	1.2	4	2	0.22
42b	15	75	0.6	3	2	0.11
53	24	60	1.0	4	2	0.18
LOAM						
45	39	40	3.9	4	2	0.20
SANDY CLAY LOAM						
13	23	57	1.6	4	2	0.16
23	27	43	2.1	3	2	0.13
44	20	47	3.3	4	4?	0.16
CLAY						
40	30	27	2.6	4	5	0.20
43	32	9	5.3	4	5	0.17

* Predicted K for profiles are for topsoil.
** See figure 2.3 (nomograph) for explanation of codes.

Main predicted K at Mazimbu fluctuates between 0.10-0.22. Average values are 0.15 within both sands and loams. K-values are slightly higher for clay. Vaneslande et al. (1984) measured K-values in Nigeria, and states that values of 0.02-0.04 in SI-units, which corresponds to 0.15-0.30 in US-units, indicate low erodibility. According to Lal (1984), soils with K-values of 0.20-0.40 are highly erodible. Even if there is some disagreement between these authors about K-values and erodible soils, the predicted K-values of soils at Mazimbu indicate that the soils are not highly erodible.

The low predicted K-values are mainly due to low content of the most erodible fraction, silt and very fine sand.
Two K-values, those for profile 1 and for site 56 need further comments. The very low K-value of profile 1 (K=0.04) is due to the low content of silt + very fine sand, granular structure and good permeability. It is interesting to note that this soil, which is uncultivated, has a lower erodibility than estimated for any other soils in the area. Sample no. 56 has an estimated K-value of 0.31, which is the highest K-value in the area. This soil has a high content of silt + very fine sand, which could be transported from the surrounding area. The K-values of profile 1 and site 56 probably represent a part of the variation in K over the area.

6.2.2 Discussion of the predicted K

The following factors lead to the assumption that the predicted K has limited value:

1) There is limited application of the nomograph for tropical soils.
2) Soil erodibility changes with time.
3) Soil permeability for many sites is based on assumptions.
4) O.M. content could be overestimated for soils with high clay content due to the analytical method.

The real value for K can only be determined from field plots. For tropical soils it is questionable to predict the erodibility by the nomograph, since the nomograph is based on the behaviour of soils in temperate climates (Lal, 1984). Several authors have found differences between predicted K and K from field tests, and ask for appropriate modifications of the nomograph for tropical soils (Ngatunga et al. 1983, Vaneslande et al. 1984). For Hawaian soils, El-Swaify and Dangler (1977) found low correlation between O.M. content, structural and permeability classes and predicted K. He concludes that the nomograph has a limited validity for tropical soils.

The prediction is based on soil properties before harvesting. Erodibility is a dynamic property and changes over the year as a result of cultivation practices, which influence structure and O.M. content (Lal 1984). Hence, the predicted K values would probably have been different if they were based on soil properties before planting.

Except for profile sites, assessment of permeability is based on topography, soil type distribution, site location and soil infiltration. This may have caused either an overestimation or an underestimation of soil permeability.

Due to the analytical method, the given O.M. content could be too high for soils with high clay content. In this case, the predicted K is too high for these soils.

The questionable validity of the nomograph for tropical soils, the lack of field measurments for K, and the other previous mentioned factors, make it difficult to evaluate the predicted erodibility for soils at Mazimbu. Due to the signs of erosion that are evident, it was expected that the soil was highly erodible. Factors like low O.M. content, surface crusting weak structure, low base saturation and cation exchange capacity could lead to the assumption that the soils are highly erodible.

However, the soils are mainly deep, well drained with coarse textured topsoils. The soil profiles also indicate a relatively coarse subsoil, with high infiltration rates. Based on these factors, the predicted low erodibility could be close to the real K values. A soil with low erodibility factor may show signs of erosion when it occurs on long slopes/steep slopes in localities with high intensity rainstorms (Wischmeyer and Smith 1965).

Despite of the factors that are limiting for the validity of the predicted K, it is believed that the erosion at Mazimbu is not caused by highly erodible soils.

6.3 TOPOGRAPHY (LS)

The topographic factor (LS) is determined by the use of the following equation which was derived by Morgan (1986) or which can be read from a nomograph (Hudson 1986).

$$LS = \frac{L}{22.13} \cdot (0.065 + 0.045 \cdot S + 0.0065 \cdot S^2)$$

Where

LS : topographic factor, a value 1.0 corresponds to the standard plot (9% slope, 22.6 m long)

L : slope length (m)

S : slope steepness (uniform slope) (%)

The application of the equation to extremely long slopes would be uncertain since the equation was derived from a short length of the standard plot, and topography can feature irregular long slopes. However, in the calculation of LS-values it was assumed that the equation can be employed for slope lengths over 600 meter. The values of slope length and steepness were read from the map of Mazimbu (1:5000 scale). The slope lengths were chosen as straight line from the top to the toe of the slope so that a uniform gradient could be obtained, i.e. a slope line intersects at as right an angle to the contour lines as possible. The values for each field are shown in table 6.4.

The LS-value represents the maximum value for each field so that a maximum potential of soil loss from the field could be calculated. Often, the longest slope of the field provides the highest value of LS-factor.

The value for field 9 was not calculated since the situation in field 9 did not fit the criteria of USLE (predicting soil loss caused by rill and interrill erosion). A large part of the field was waterlogged during the rainy season as much runoff water was concentrated to the area and stagnated due to the flat topography. Also, drainage of the water was delayed.

6.4 CULTIVATION PRACTICES AND CROP COVER (C)

The crop and soil management practiced at Mazimbu are some of the factors causing accelerated erosion. The most negative effects of these practices are discussed here. The discussion is based on farm information (section 5.5), soil properties (section 5.4), and the theory presented in previous chapters.

6.4.1 The effects of current soil and crop management on erosion

Cultivated crops and crop rotation.

The main cultivated crops are row crops: Maize, sunflower and sorghum (table 5.5). These crops provide little vegetal cover, especially at the beginning of the rainy season. Beans probably offer slightly better cover, and are cultivated on smaller parts of the area during most years.

Maize is usually grown 2-3 continous years, often after or prior to sorghum or sunflower. At field 10, maize has been grown continuously for 5 years.

The practice of growing row-crops to such an extent; of growing maize 2-3 and up to 5 years, and of having no grass or close growing legumes in the rotation is not very appropriate when related to soil erosion risk. Under this form of land-use the soil has to be tilled every year. No build up of organic matter or soil structure are promoted. All of the area is exposed to the erosive rain.

Soil management

Use of diskplough and diskharrow may be necessary to cut through the hard soil. These implements tend to overwork the soil, which means that the soil becomes very fine powdered after tillage operations. Most soils at Mazimbu have weak to moderate structure, and soil aggregates are easily broken by the disking. The implements bury plant residues. The negative effects increase with the amount of tillage operations.

A smooth, pulverized soil surface that is almost free from mulch is highly exposed to erosion. The pulverized soil easily crusts and thus infiltration rate decreases. The smooth soil surface gives few pits to store surface water, or clods to reduce runoff velocity. There are no plant residues to protect the soil. The tillage operations practiced at Mazimbu lead to such conditions, and are therefore enhancing erosion risk. The same conclution on the effects of disking was drawn by Macartney et al. (1971), who compared several tillage systems on soils in Kongwa, Tanzania.

The combination of heavy machinery, many tillage operations, and other nessecary traffic in the fields can lead to soil compaction. This results in decreased infiltration rates, and can impede root movement.

Fertilization

Proper fertilization is important for vigour plant growth, good yield and the production of plenty of plant residues. Although the information about practiced fertilization for the main crops is sparce, some comments on it can be made. The amounts of N, P, and K removed by the main crops, and the fertilization rates practiced at Mazimbu are listed in table 6.3.

Table 6.3. N, P and K removed by some crops. Fertilization rates at Mazimbu.

Crop	Yield (kg grain/ha)	Removed nutrients (kg/ha)*			Added nutr. in Maz. (kg/ha)**		
		N	P	K	N	P	K
Maize	2000	100	18	67	36	40	36
Sorghum	2500	75	14	73	0-43	38	34
Sunflower	580	23	2	36	20	32	10
Beans	1000	93	16	115			

* Calculated for normal yields at Mazimbu; based on Agricultural Compendium (ILACO 1981).
** Calculated from fertilization rates given by Kolshus et al. (1986).

Nitrogen: According to table 6.3, low rates of N are added for maize and sorghum. Table 5.7 shows that some fields received higher N-rates, but generally low N-rates are added. FAO (1972) states that economic optimum rates of N for maize are 150-250 kg/ha. This is confirmed by Singh and Uriyo (1980) who found in fertilizer trials in the Morogoro region that maize on soils in the low-N class, as the soils at Mazimbu, gave response on fertilizer-N up to 200 kg/ha. The economic optimum rates of N for sorghum is 147-162 kg N/ha. But sorghum responds to fertilizers only when there is sufficient water.

Phosphorus: The surplus of phosphorus added to maize and sorghum compared to what is removed by the crops is acceptable when the strong fixation of P in soils is considered. In maize, 25-30 % of applied P is recovered in the first crop (FAO 1972). Even if this fixation effect also occurs for sunflower, it is too excessive to add 32 kg P/ha.

The analytical results of soil samples can be compared to fertilizer trials with maize in the Morogoro region (Singh and Uriyo 1980). These trials showed that for soils with more than 25 mg P/kg (High-P and Very high-P) there were very low or negative effects of adding more than 40 kg P/ha. Many soils at Mazimbu have >25 mg P/kg. For these soils, and especially those in Very high-P, P-fertilization could be reduced.

Kalium: The added rate of K is lower than what is removed by the crop. But the situation for K is special, since it can be supplied from the soil. Most soils at Mazimbu are rather coarse, with low CEC and a low content of exchangeable K. Hence it is not probable that these soils are self-sufficient with K. It may be profitable to raise the K-rates.

6.4.2 Cover and management factor in USLE

The cover and management factor (C) in USLE is the ratio of soil loss from cultivated land under given conditions compared to the soil loss from bare fallow (section 3.2.1).

For the calculation of potentional soil loss at Mazimbu, a C-value of 0.82 has been used. This is the mean value over four seasons for maize with mouldboard ploughing on a Luvisol in Kenya (Onstad et al. 1984). Roose (1977) indicates that maize and sorghum have annual average C-values ranging from 0.4 to 0.9. The C-value for maize found in Kenya is very high. This means that the growing of maize on mouldboard ploughed soil is an erosion promoting practice. In the case of diskploughing and disk harrowing, the situation is probably similar or even worse, since the disks pulverize soil more than the mouldboard plough.

The C-value for maize is selected because maize is the main crop cultivated at Mazimbu. Estimation of soil loss when maize is cultivated without any conservation practices gives an indication of the soil loss for the worst management practice; similar to the situation today. This is the basis for calculations to find acceptable conservation measures.

6.5 POTENTIAL SOIL LOSS (AP)

Potential soil loss is defined as the maximum soil loss that is expected from a field under present crop management i.e. growing maize without any practice of soil conservation. The potential soil losses are calculated by the use of the USLE equation as follows;

A_p =2.24·R·K·LS·C

Where

A : potential soil loss (ton/ha/year)

R : rainfall erosivity factor (U.S. customary units, see chapter 6.1)

K : soil erodibility factor (U.S. customary units)

LS : topographic factor (dimensionless)

C : cropping management factor (dimensionless)

2.34 : conversion factor from U.S. units to metric units (Foster et al. 1981)

Table 6.4 Potential soil loss (Ap)

	L (m)	S (%)	LS	K	A_p (t/ha/yr)
Field 1	450	1.33	0.62	0.20	45*1
Field 2a	610	2.38	1.10	0.19	76
2b	480	2.50	1.02	0.19	70
Field 3a	510	1.96	0.86	0.13	40
3b	640	1.69	0.86	0.13	40
Field 4	490	1.53	0.70	0.20	6*2
Field 5a	320	4.22	1.41	0.13	66
5b	260	5.77	1.85	0.15	100
5c	430	3.84	1.47	0.16	85
5d	270	3.15	0.95	0.11	38
5e	520	1.63	0.76	0.16	44
Field 6a	35	11.43	1.80	0.14	91
6b	115	4.35	0.87	0.14	44
Field 6c + Field 14a	1135	2.25	1.42	0.12	62
Field 7a	80	1.88	0.33	0.17	80
7b	280	3.57	1.10	0.11	44
7c	480	3.13	1.25	0.14	63
7d	140	3.21	0.70	0.11	28
Field 8a	190	2.90	0.73	0.11	29
8b	75	4.67	0.77	0.11	31
8c	300	2.73	0.87	0.11	35
8d	110	3.18	0.61	0.11	24
8e	690	2.32	1.14	0.11	46
8f	185	2.97	0.74	0.11	29
Field 10	610	1.39	0.74	0.20	54
Field 11a	450	2.56	1.00	0.18	65
11b	570	2.19	0.99	0.22	79
Field 12a	270	2.96	0.89	0.15	48
12b	520	2.21	0.95	0.15	48
12c	260	6.15	2.02	0.15	110
12d	280	2.68	0.83	0.15	45

A_p =2.24·R·K·LS·C

Where

A : potential soil loss (ton/ha/year)

R : rainfall erosivity factor (U.S. customary units, see chapter 6.1)

K : soil erodibility factor (U.S. customary units)

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Field 4	490	1.53	0.70	0.20	6*2
Field 5a	320	4.22	1.41	0.13	66
5b	260	5.77	1.85	0.15	100
5c	430	3.84	1.47	0.16	85
5d	270	3.15	0.95	0.11	38
5e	520	1.63	0.76	0.16	44
Field 6a	35	11.43	1.80	0.14	91
6b	115	4.35	0.87	0.14	44
Field 6c + Field 14a	1135	2.25	1.42	0.12	62
Field 7a	80	1.88	0.33	0.17	80
7b	280	3.57	1.10	0.11	44
7c	480	3.13	1.25	0.14	63
7d	140	3.21	0.70	0.11	28
Field 8a	190	2.90	0.73	0.11	29
8b	75	4.67	0.77	0.11	31
8c	300	2.73	0.87	0.11	35
8d	110	3.18	0.61	0.11	24
8e	690	2.32	1.14	0.11	46
8f	185	2.97	0.74	0.11	29
Field 10	610	1.39	0.74	0.20	54
Field 11a	450	2.56	1.00	0.18	65
11b	570	2.19	0.99	0.22	79
Field 12a	270	2.96	0.89	0.15	48
12b	520	2.21	0.95	0.15	48
12c	260	6.15	2.02	0.15	110
12d	280	2.68	0.83	0.15	45

(Fig.6.4 cont.)

Field 13a	240	3.96	1.14	0.15	62
13b	210	2.86	0.76	0.15	41
13c	390	3.33	1.21	0.15	66
13d	180	3.33	0.82	0.15	45
Field 14b	400	2.75	1.01	0.10	37
Field 15	580	1.90	0.89	0.18	58
Average	313	2.14	0.87	0.14	53

Field 1 is irrigated by sprinkler so that the USLE model does no apply to that field. Sprinkler irrigation is rather a god method for reducing erosion because it can improve vegetative cover in any time independent of rains.

The C-value (crop management factor) at field 4 assumed to be 0.10. This corresponds to the value of grass covered orchard (assumed ca. 50 % of the ground covered) given by Wischmeier et al. (1978). The potential soil loss at field 4 is reduced greatl owing to the effective cover function achieved by grass.

Each factor is obtained in the previous chapters. Because it is intended to assess the potential soil loss for Mazimbu, the highest the LS-values were chosen. For the determination of a K-value for a field, the predicted value in chapter 6.2 was used i cases where the value was representative of the field. In other cases, several adjacent values are combined on the basis of the soil calssification. The results are presented in table 6.4 and appendix 5.

Average values which are given in table 6.4, are arithmetic means. A mean value of potential soil loss (A_p) of 53 t/ha/y under cultivation of maize and sorghum, is obtained. Some potential soil loss is lower than the mean value mainly due to shorter slope length. The mean A_p-value (53 t/ha/y) will be used for further discussion of the soil loss at Mazimbu as comparing to some value of soil loss observed in Tanzania.

The estimated values of potential soil loss at Mazimbu are high compared to soil loss tolerance which is mentioned in chapter 2.3. The tolerance value should be kept under 5 t/ha/y for sustaining crop productivity. Thus, it is necessary to reduce the potential soil loss below 5 t/ha/y by the use of mechanical practices and soil and crop management.

For comparing the predicted value at Mazimbu to values observed elsewhere in Tanzania, the topographic factor has to be modified to the same situation. If the mean topographic value (LS=0.87) at Mazimbu is changed to the value of a standard plot (LS=1.0), the mean potential soil loss (53 t/ha/y) will correspond to a soil loss of 61 t/ha/y. In earlier erosion experiments at plot scale in Mpwapwa, Tanzania, (Staples 1936; described by Temple 1972, Rensburg 1955) several values of soil loss were observed under different conditions of crop and soil management. Under cultivation of sorghum and millet at the plots (3.5 % slope, 27.7 m long, LS=0.65), they measured 68 t/ha/y (2 years average) and 48 t/ha/y (8 years average) of mean soil losses respectively. The observed values are converted to values of the standard plot by dividing with 0.65. The calculation results in soil loss of 105 t/ha/y and 74 t/ha/y. The estimated A_p-value at Mazimbu is relatively close to the soil losses measured in Mpwapwa. It is assumed that the estimated values of potential soil loss are reasonable. Thus, the values are acceptable to use USLE in soil conservation planning for Mazimbu.

7 SOIL CONSERVATION PLAN FOR MAZIMBU

This soil conservation plan consists of:

(a) Recommendations for soil and crop management (mainly crop rotations, tillage practices, crop nutrition).

(b) Recommended mechanical practices (grass buffer strips, waterways, drainage systems).

The mechanical practices (b) can be considered as an alternative to the "Plan for physical conservation at ANC farm Mazimbu" by Bergedalen, Hauken and Kosaka (1987). The mechanical practices are partly based on the plan by Bergedalen et al.. The recommendations for soil and crop management (a) is a complement to the plan by Bergedalen et al., as agronomical aspects were not described in that plan.

Since the parts (a) and (b) constitute one unit, modifications of part (a) are needed if the physical plan by Bergedalen et al. is adopted.

It has not been possible to coordinate the soil conservation plan with the actual farm planning. Such a coordination would have been prefered, since the conservation plan interferes with production characteristics i.e. production levels, sort of products. The evaluation of potential soil loss and the reasons for erosion at Mazimbu revealed that current soil and crop management are main factors causing erosion, and it has been found necessary to alter these practices. Soil protective crops (cover crops; grass/legumes) are introduced in the rotation. This may be a reason for raising the number of cattle/goats, as the soil protective crops can provide fodder. This will have to be further discussed by farm and administration personell at Mazimbu.

The following assumptions have been the basis for the plan:

1) Implementation of the plan should be possible within a short time.
2) Primarily farm machinery should be used for construction.
3) The financial costs should be low.
4) The conservation plan should not interfere (too much) with existing farm roads and field layout.
5) Production characteristics should be maintained.
6) Minimum expertice from outside Mazimbu should be required for the implementation of the plan.

It has not been possible to meet all of the assumptions. One main point that had to be altered concerns production characteristics, since the introduction of cover crops and permanent grass leads to reduced area for the other cultivated crops.

The conservation plan is based on the litterature and the soil erosion risk assessment at Mazimbu, as described in previous chapters. Special references are listed after some chapters. The plan is described in the following text, and main elements are shown on the map in appendix 6.

7.1 PLANNING OF EROSION CONTROL PRACTICES BY USE OF USLE

The potential soil losses under present cultivation (maize) have been presented in table 6.4. It is necessary to reduce the soil losses below the tolerance value (5 t/ha/y) for maintaining favorable conditions for crops. The USLE equation (see chapter 3.2) can be used to select the crop management system and the surporting practices necessary to keep soil losses below the tolerance value. The crop management and soil management system (see chapter 4.1 and 4.2) affect the C-value of the equation, and the supporting practices (see chapter 4.3) affects the P-value and LS-value (some supporting practices do not affect the LS-value). The R-value (see chapter 6.1) and K-value (see chapter 6.5) are assumed constant since those values are calculated as a mean value over a long period. The plan for erosion control practices for Mazinbu is that the fields will be protected from erosion by the introduction of mulching and strip-cropping (narrow grass buffer strips). Because these methods are assumed to be cheapest, most effective and the simplest among the several methods available.

Onstad et al (1984) obtained a mean value of C=0.23 for the crop management factor under culivation of maize with 3 t/ha of mulching. The effect of the mulching in the above case seems to be relatively low (high C-value) compared with data obtained by Lal (1979) or Valentin et al (1981). Roose (1977) reported P-values for buffer strips cultivation ranging from 0.1 to 0.3. The introduction of buffer strips may not change the length of slope as terraces do. Here the soil loss will be estimated when C-value (0.23) and P-value (0.3) are used.

According to the caluculation, a field that has a potential soil loss higher than 60 t/ha/y can not have its soil loss reduced to below the soil loss tolerance (5 t/ha/y) even though mulching and buffer strips are practiced. Thus either the crop management or the supporting practices have to be modified so that the soil loss will be less than 5 t/ha/y. The parmanent methods are certainly efficient in reducing soil loss. However, from an economical point of view, buffer strips which are placed at a slight gradient may function as efficiently as terraces, with time. This is because the zone of buffer strips gradually become higher embankments as deposition of soil materials modifies the soil surface. Thus fields where one would expect large amounts of potential soil loss, are protected enough by the use of the buffer strips instead of terraces. It will take 3 or 4 years before the grass strips will work as terraces. In case that the grass strips will not act on as one has expected, other permanent practices can be considered for instance terraces. The construct-ion of terraces will not be difficult since the grass strips will have been laid out at a gentle slope.

7.2 SOIL AND CROP MANAGEMENT

In section 6.4, it was concluded that several management factors enhance the risk of erosion. The main cultivated crops are row crops that provide minimal soil protection against the rain. The crop rotations have continous years with row crops, and include almost no use of cover crops (grass). Diskploughing and disk-harrowing bury plant residues and pulverize the soil. Thus a clean, smooth soil surface remains for the rain and runoff to attack.

The aim of the recommendations for soil and crop management are to improve the management that has been practiced to date. In short, the recommendations are:

a) To improve the rotations by including cover crops,
b) to cultivate permanent grass on some of the fields with the highest erosion risk,

c) to provide adequate crop nutrition to ensure vigourous plant growth, healthy plants and good yields,

d) to introduce conservation tillage to provide a soil surface resistant to erosion.

7.2.1 Crop rotations

Proper crop rotations must be planned for all fields. Recommended rotations are listed below. Some general principles for planning are also given. These should be the basis for any other rotations if the recommended crop rotations are not practiced.

Recommended rotations

Field No.		Rotation
1(irrigated)	A:	2-year rotation with two crops every year; silage-silage / silage-beans.
5a and 7a		Permanent grass (pasture)
9	B:	4-year rotation; maize / maize / sunflower / cover crop
3, 7b, 12a, 10 and 14b	C:	4-year rotation; maize / maize / sunflower / cover crop
6, 13, 5b, 8b and 15	D:	4-year rotation; maize / sorghum / sorghum / cover crop
12b, 8a, 14c, 11a, 14a, 2 and 11b	E:	4-year rotation; maize / beans / maize / cover crop

A detailed plan for the crops on individual fields over 4 years is given in table 7.1. After the fourth year, the rotations are repeated. Field numbers are shown in appendix 6.

Descriptions

a) Rotation practices

There are two alternative ways of practicing rotations C, D and E

Alternative 1: Rotation on strips

Different crops are cultivated between the grass buffer strips. Crop sequence for the strips on one field is as crop sequence wit time on the same field, see figure 7.1. As opposed to growing one crop over the whole field, rotation on strips is more effective i erosion control since every fourth strip is with cover crops. Rotation on strips are not suggested for the rotations A and B since they cover fields without grass buffer strips.

Alternative 2: Normal rotation

One crop is grown on each field.

Alternative 1 is recommended. If this is practiced, the cover crops cannot be grazed due to the risk of grazing the buffer grass-strips and the neighbouring strips.

Table 7.1 Detailed plan for crop rotations.

Field No.	Area(ha)	1989	1990	1991	1992
1	23	Si-Si	Si-B	Si-Si	Si-B
9	33	M	M*	Su	C
3	28	M	M	Su	C
7b+12a	31	M	Su	C	M
10	26	Su	C	M	M
14b	35	C	M	M	Su
6	23	M	So	So	C
13	21	So	So	C	M
5b+8b	28	So	C	M	So
15	15	C	M	M	So
12b	35	M	B	M	C
8a+14c	39	B	M	C	M
11a+14a	33	M	C	M	B
2+11b	44	C	M	B	M**
5a+7a	38	G	G	G	G

Si = Silage, Su = Sunflower, M = Maize, B = Beans, So = Sorghum, G = Grass, C = Cover crops (see descriptions; b) * Maize for silage if needed. ** Maize for silage on field 2 if needed.

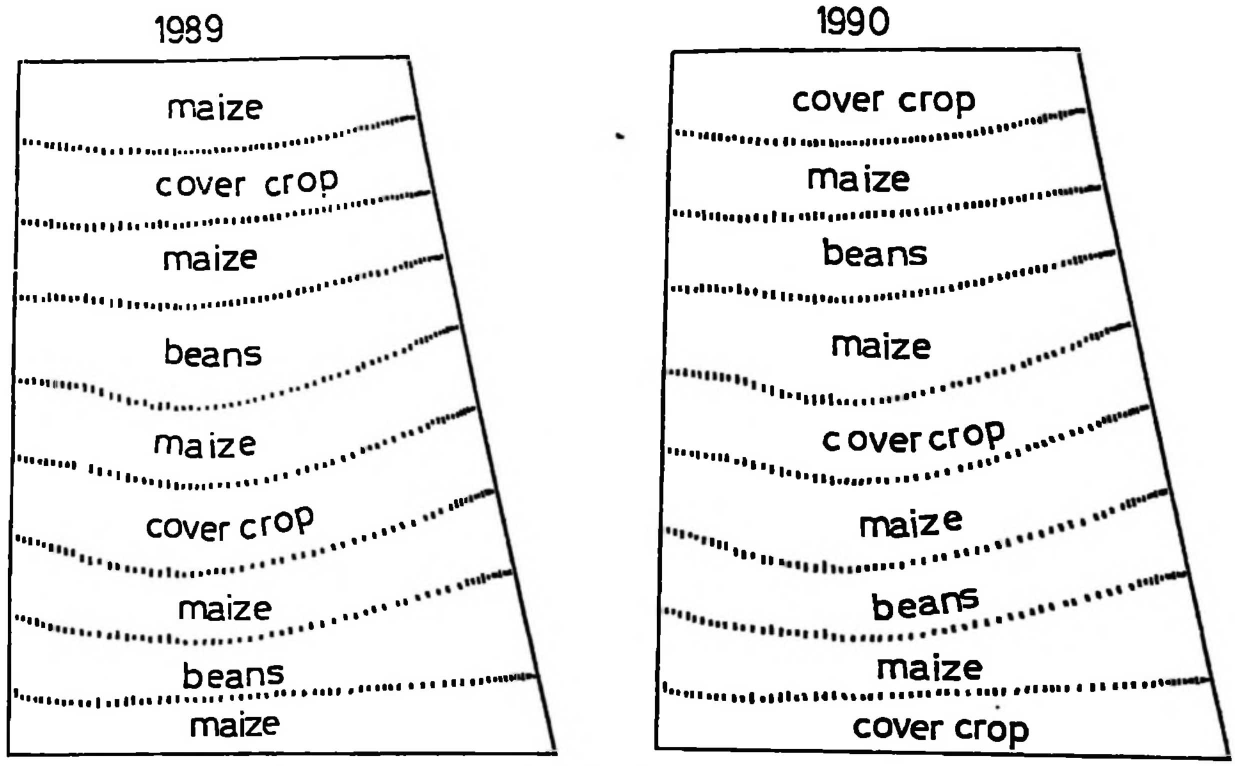

Figure 7.1. Crop rotation on strips. Rotation E.

b) Cover crops

Species: Any close growing crop, mainly grasses, legumes or grass/legume mixtures can be sown as a cover crop. In the case o grass/legume mixtures, a short growing legume should be grown together with tall grass(es). Legumes fix N from the air and thu enhance the N-content of the soil, which is beneficial for the grasses and the following crops.

Actual grass/legume mixtures are:

- -Chloris gayana + Medicago sativa,
- -Panicum maximum + Centrosema pubescens,
- -Panicum maximum + Medicago sativa.

A pure grass mixture as discussed in c) can also be sown. Other actual grass and legume species are listed in table 7.2.
The selected plant species depend on availability of seeds and plant suitability for the local conditions.

Management: Cultivation is discussed in section 7.2.2. Secondary tillage should be, as in alternative 2, full width tillage, as zonal seedbed preparation leaves too much space between crop rows. Seeding may be done in good time before the onset of the rain; preferably by drilling, eventually broadcast sowing. Practical experience must be the basis for evaluation of seeding time and method.

Harvesting: The cover crops should normally not be harvested, but left in the field as mulch. If needed, the crops may be cut for fodder or grazed. Regrowth should then be allowed before fallowing.

Fallowing: A burndown herbicide (glyphosate or paraquat) is applied prior to tillage. Cutting of plant residues (see 7.2.2.) is probably necessary to prevent clogging of tillage equipment.

c) Permanent grass (pasture)

Species: Grass species suitable for the area should be sown. A mixture of grasses provides better cover and gives better forage quality than one single species. The following grass mixture has proven useful in Kongwa and should be tried at Mazimbu (Brzostowski and Owen 1964).

- 60% Cenchrus ciliaris
- 30% Chloris gayana
- 10% Cynodon dactylon

Table 7.2 includes other grasses and legumes that could be suitable.

Harvesting: The grass can be cut for hay, fed fresh or grazed. Fencing might be necessary in the case of grazing. Overgrazing and development of paths should not be allowed as this enhances erosion risk. The frequency of grazing and/or cutting should not be too often, as the plants need time for revegetation.

Reseeding: Reseeding and tillage may be necessary if weeds take over or the content of desired species decrease.

Table 7.2 Grass and legume species for pasture establishment in sub-humid to semi-arid ecological zones in Tanzania (after Lwoga et al. 1985).

Grasses	Legumes
Cloris gayana	Medicago sativa
Setaria anceps	Neonotohia wightii
Panicum coloratum	Clitoria ternatea
Panicum maximum	Dolichos formosus
Panicum antidotale	Rynchosia sennaarensis
Cenchrus ciliaris	Lotononis bainesii
	Desmodium sandwicense
	Desmodium uncinatum
	Desmodium intortum
	Stylosanthes guianensis
	Centrosema pubescens
	Macroptilium atropurpureum

General principles for crop rotation planning

a) Maize should always be first in the rotation (after cover crops).
b) Maize does well after leguminous crops.
c) Crops with common diseases should not be sown in succession (ex. maize and sorghum, sunflower and luzerne).
d) Sunflower should not be grown more than once every fourth year in the same field.
e) Sunflower utilizes ground water and nutrients well. This may affect the succeeding crop.
f) Leguminous crops should not be grown in sequence.
g) Beans are very sensitive to waterlogged soils.
h) Two years of continous crops should be avoided (except for grasses).

Comments

In order to maintain a high production of the main crops, these still occupy large parts of the fields. Thus, many of the general principles for rotations have been omitted in the recommended rotations. As a result, this is not the best rotations from an agronomical view, but it greatly improves the practice at present.

The value of the rotations must be considered together with the other practices for erosion control, especially conservation tillage. Crop rotations are important in the control of weeds and pests under conservation tillage.
Litterature: Owen and Brzostowski 1967, Okigbo and Lal 1977, Humphreys 1978, Lwoga et al.1985

7.2.2 Conservation tillage

A system of chisel ploughing + zonal secondary tillage (strip tillage) at planting is recommended. Cultivation will be done on the contour, as the grass buffer strips are laid out on the contour.

Conservation tillage is to be practiced on all fields included in the crop rotations except for the fields No. 1 and 9. Fields No. 1 and 9 have clayey soils and are almost flat. They are cultivated as they have been so far; with disk implements.

The recommended tillage practices may be tried out on some fields before tillage is altered over the whole farm. This results in experience about the most beneficial tillage practices. The recommendations must be evaluated continously, and adjusted if weak points are discovered.

Description of operations

a) Cutting of plant residues

Crop residues have to be chopped and spread uniformly on the soil surface. Chopping of residues prevents clogging of tillage equipment, and spreading of residues over the fields provides protective mulch. There should be no grazing on crop residues since they are needed to provide mulch.

Equipment: A combine harvester can be used for sorghum if the combine in use cuts enough. A forage harvester should be used for the residues from maize, beans, sunflower and grass, eventually for sorghum if the combine does not cut enough.

Timing: After harvest (at harvest with the combine). If weeds seem to disturb chiseling, a cutting operation of weeds might be advisable prior to tillage.

b) Primary tillage

Equipment: Chisel plough with sweeps. One chiseling, 20-25 cm deep is recommended.

Timing: Timing of the operation depends on soil properties. The chisel plough is most effective on dry soil since dry soil cracks more easily than wet soil. As dry soil often is hard and difficult to till, it could be preferably to till after short rain-showers. Since most fields at Mazimbu have hard soils, ploughing should be accomplished during/after the short rains, but not on too wet soil. If experience shows that chiseling can be accomplished without pre-wetting of soil, primary tillage can be accomplished when it is practical during the dry season. All fields must be chiseled in good time before the onset of the long rains, as the tillage increases infiltration and reduces runoff. Planting must be done as soon as possible in the beginning of the rainy season.

c) Secondary tillage and planting

Alternative 1: Zonal seedbed preparation

Equipment: Rotary tiller with row space (70 cm) between knives; remove surplus knives. A standard planter can be attached to the tiller, thus cultivation and planting are than done in one operation. Eventually, a rotoseeder can be used.

Tillage zone: Appr. 20 cm wide, 5-10 cm deep.

Timing: At normal planting time. Combined secondary tillage and planting reduce field operations and shorten the planting period.

If weeds are a serious problem, one harrowing with a cultivator or one shallow operation with the chisel plough is recommended prior to planting.

Alternative 2: Full width tillage

Equipment: Field cultivator. The cultivator may have sweeps for better weed control. The chisel plough may substitute the cultivator if chiseling is done on the soil surface. Planter for planting in crop residues may be necessary if there is a surplus of residues on the soil surface. Rolling coulters in front of the furrow opener of the planter cut through plant residues.

Timing: One shallow operation with the cultivator/chisel plough when soil moisture is appropriate (after some rain). If there is an abundance of weeds and the soil is compacted, two operations can be accomplished. Cultivation should be done close to planting. If the time between primary tillage and secondary tillage is too long, weeds can become a problem for the seedlings.

Alternative a) is recommended, as this leaves most residues on the soil surface and saves time. Alternative b) provides better mechanical weed control. This can be advantageous, especially if the required herbicides are unavailable.

Litterature: Wilkinson and Braunbeck 1977, Unger and McCalla 1980, Throckmorton 1986, Macartney et al. 1971.

d) Weed control

Adequate weed control is important since weeds compete with the crop for nutrients, water, space and light. In the conservation tillage system, weeds are controlled by crop rotations, mulch, and herbicides. Tillage for weed control is accomplished in special situations. Mulch is a means of controlling weeds since it prevents weed seeds from germinating. Herbicides are the main method of weed control.

Herbicide types: Herbicides that are taken up via the leaves (foliar application) must be used since they are not cultivated into the soil. A burndown herbicide that kills all vegetation, f.ex. glyphosate or paraquat is applied prior to planting. This is a substitute for disking. After planting, the pre-emergence herbicides already in use at Mazimbu can be sprayed out. These are Primigram for maize, Gesaprim for sorghum and Gesagard for sunflower. Alternating the herbicide types may be necessary to avoid that weeds develop resistance.

Application rates: Application rates depend on weed dominance. If there are few weeds, low rates can be used. General rates are: Paraquat 0.25-0.5 kg/ha, glyphosate 1.0-4.0 kg/ha. High application rates may be necessary since mulch can reduce the herbicide effect.

Application time: the burndown herbicide should be applied in good time, f.ex. 10-14 days before planting. Pre-emergence herbicides are sprayed out just after planting. If needed, herbicides may be applied 1-2 more times. Follow recommendations on the label for both application time and rates.

Cultivation: Cultivation for weed control should normally not be used. It must be used if herbicides fail. This may be the situation for difficult weeds on some fields. Shallow chiseling or cultivation can be done to control weeds during the dry season and between crop rows in young plants. It may be necessary to introduce disking after one of the crops in the rotations for the control of problematic weeds. This has to be evaluated after some experience with the new tillage system.

Litterature: Kells and Meggitt 1985, FAO 1984, Unger and McCalla 1980.

7.2.3 Crop nutrition

Mazimbu farm covers a large area, and the soils differ between fields and even within fields. Due to the large area, it is economically important to add suitable amounts of nutrients to the plants. Over-fertilization means unnecessary costs, while under-fertilization means lost income. It is therefore vital to adjust the fertilization rates to the requirements.

General guidelines for fertilization practices

Soil analysis shows that the following main points should be considered under fertilization planning:

- The N-content and organic matter content in the soils are generally very low. This means that little N can be supplied from the soil, and high fertilization rates seem necessary.
- The P-content is generally high. This indicates that it should not be necessary to add the same excesss of P that has been applied thus far. Maintenance of the P-status should be aimed for some years. After that, P-rates can be increased to today's level.
- The soils have low ability to retain cations (low CEC). This means that K can be lost by eluviation, and sufficient K must be applied. An increase of the K-rates supplied at present is recommended.

It might be necessary to substitute NPK 6-20-18 with NPK 20-10-10 to reduce phosphorus rates. Potassium fertilizers such as muriate of potash (KCl: 48-62 % K_2O), or potassium sulphate (K_2SO4: 48-52 % K_2O) is then necessary for K-supply.

Band application of fertilizers for the row crops are to prefere since broad strips between crop rows are left uncultivated and mulched.

Fertilizer recommendations

Due to the large farm area, few soil analysis and limited knowledge of crop response to fertilization at Mazimbu, only tentative recommendations for fertilization rates can be given. Present fertilization rates, and the amounts of nutrients removed by the crops can be found in table 6.3.

Fertilization rates have to be adjusted to the individual fields and expected yields. They should be based on local experience, soil analysis and field trials.

a) Maize

-Increased N rates up to 100 kg/ha (150 kg/ha) can be tried. Highest rates are supplied for fields that normally have high yields.

-Maintenance fertilization of phosphorus for some years.

-Increased K-rates could be tried, especially on the coarse soils.

b) Sorghum

-It is difficult to give specific recommendations for sorghum, since the crop responds to fertilization only when moisture conditions are good. Increased N rates may be tried. Phosphorus rates can probably be rduced for some years.

c) Sunflower

-Minimum rates of P or no P could be added since sunflower requires little P.

-The plant uses large amounts of K and Ca. A surplus of K should be added. N and Ca can be added as CAN.

-N fertilization at present (20 kg/ha) is probably suitable.

d) Beans

-Nitrogen (15-20 kg) should be added before planting to stimulate early growth.

-Phosphorus should be added before planting and as top dressing.

e) Cover crops

It is recommended that the cover crops are left on the field as mulch. This returns nutrients to the soil and fertilization is, therefore, normally not neccesary. If the cover crops are harvested or grazed, fertilizers should be added to avoid depletion of nutrients. Fertilization rates depends on species. If a grass/legume mixture is used, little fertilizer N is needed, as the legumes fix N from the air.

f) Permanent grass and pasture

Fertilization of pasture may be considered after grazing or during the long rains. This can improve fodder quality and yields. But pasture fertilization is often not economical.

Use of manure

Manure is a valuable nutrient source and it improves soil structure. The manure from all animals should be collected and utilized in plant production. Much of the manure at Mazimbu is supplied to horticultural crops. Maize utilizes manure well, and it would have been very valuable for the arable crops if they received manure. As a general principle, manure can be supplied to the first arable crop in the rotation.

Further fertilizer planning

Representative soil samples from every field should be analysed for N, P and K, micronutrients and pH. Results can be compared to the soil analysis results given in this thesis. Interpretation of the results gives a detailed knowledge of the nutrient conditions of the soils, and are the basis for further fertilizer planning.

Soil sampling should be done in cooperation with the staff from Sokoine University. Soil analysis can be accomplished at the University. Recommendations for fertilization rates based on soil analysis and climate should be available at the same place.

7.3 MECHANICAL PRACTICES OF SOIL CONSERVATION

Mechanical practices mean that the movement of water is controlled by the use of engineering works, as outlined in chapter 4.3. At first, general disposal of runoff water will be mentioned, and then, mechanical practices on arable land will be discussed on the basis of potential soil loss. By the way, it should be noted that this is one of the proposal plans so this proposal may differ from the earlier report that was prepared by J. Bergedalen, M. Hauken and S. Kosaka. The decision as to which method will be adopted, depends on several factors such as economy, crop management, appropriate staff, etc.. The conveyance of runoff water which comes from outside of arable land, is done by the use of the same structures (stormwater drains and grass waterways A) as outlined in the earlier report. Consequently, this report does not deal with these structures.

7.3.1 Layout of drainage systems

The water movement in the field and the layout of waterways is presented in appendix 6. The water movement was decided according to the topographic map of Mazimbu (scale 1:5000). The difference of this layout from the early report is that this plan is based on the introduction of agronomic management so that the general view of communicating roads will be same as with the present system (see appendix 6). The storm runoff that flows down to the arable land, is intercepted by the stormwater drains so that no runoff flows into the arable land. The runoff diverted by the stromwater drains is drained away by the artificial grass waterway A and the existing waterway C. The important and skilled part of construction works of the stromwater drain and the grass waterway A was carried out whilst the writers were in resident in Mazimbu. The construction will be carried out according to the earlier report, thus nothing of this is presented in this report. In the arable land drainage water in conveyed by artifical and natural waterways. In view of the fact that the area adjoining field 6 and field 14 has a large amount of potensial soil loss (62 t/ha/y), an artifical grass waterway (field grass waterway a) should be constructed in order to reduce the slope length. The drainage water that comes mainly from the fields 6,8,14 and the area between the arable land and the storm waterdrain, will be carried by a constructed grass waterway B. The waterlogging problem at the residence area will be solved by diversion drains covered by grass.

As is shown on appendix 6, runoff water which would flow towards roads, will be caught by zones of vegetations and small drains so that runoff water never flows out from arable land to the roads. The vegetative zones will easily be established if the zones remains unploughed. Alternatively, useful types of grass which can be used for forage, can be planted (or sown) in the zones.

For the type of grass which can be used, please refer to chapter 7.2 and 7.3.3.

The location of natural waterways in the field is based on the map of Mazimbu. Small natural waterways may not exist any longer because of continous tillage. However, the area that shows the influence of erosion (both erosion and deposition), will never be cultivated so that the natural depressions (waterways) may act as a trap of soil materials.

The impact of erosion on the road has been recognized and as a serious problem at the Mazimbu farm. The surface of road is very susceptible to erosion by water because vegetation can seldom grow on the road due to disturbance and compaction by traffic. The roads seriously affected by erosion are the roads along field 12,13 and along the electric power lines (between field 6 to field 8). The road along the power lines has already been eroded tens of centimeters down compared with the field surface. The most serious problems caused by erosion will be solved by the introduction of a vegetative zone along the road (inside of the cultivated area). Also the road itself should be repaired as a example shows (figure 7.2).

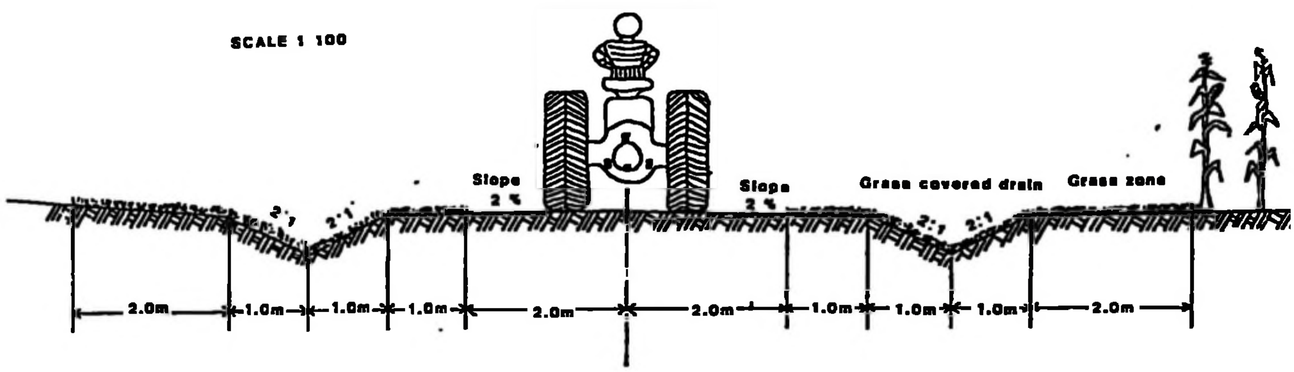

Figure 7.2 An example of a cross section of a road.

Estimation of runoff

During storm rains, the peak rate of runoff, is the basis that determines the dimensions of artifical waterways. For predicting a design peak runoff rate, the following equation, is used.

$$Q = \frac{C \cdot I \cdot A}{360}$$

where
Q : the design peak runoff rate (m^3/sec)
C : the runoff coefficient (dimensionless)
I : rainfall intensity in mm/h for a duration equal to the time of concentration of the runoff
A : the watershed area (ha) (Schwab et al. 1981)

Runoff coefficient (C) is defined as the rate of runoff to the rate of rainfall (Hudson 1986). The C-value is dependent on the catchment characteristics such as surface cover, soil characteristics (mainly infiltration), topography (slope) and rainfall characteristics (mainly intensity). Several values of the runoff coefficient are shown in table 7.3 for the decision of the C-values for Mazimbu.

Table 7.3 Runoff coefficient.

	C-value	Vegetation	Comments
Schwab et al. (1981)	0.30 0.10 0.10	cultivated pasture woodland	for general purpose sandy loam 0-5% slope
Staples (1936) (described by Temple 1972)	0.23-0.29 0.01-0.03 0.01-0	sorghum grass thicket	experimental plots Mpwapwa, Tanzania 3.5%, 4.5% slope
Rensburg (1955)	0.09-0.29 0.10-0.21 0.04-0.19 0.01-0.07	sorghum cultivated plot+narrow grass strip cultivated (50%) + grass (50%) grass	experimental plots Mpwapwa, Tanzania 3.5% slope

The C-values of each field were decided on the basis of the crop management. The following values were chosen for the calculation of the peak runoff at Mazimbu.

C = 0.21 (cultivated maize + narrow grass strip)

C = 0.19 (unculivated area for grazing)

C = 0.07 (grass land)

The runoff coefficient of a area covered by grass or trees is very low compared to cultivated land, owing to the different effect of vegetation which increases infiltration and intercepts rainfall.

Rainfall intensity (I)

The period of rainfall intensity corresponds to the time of concentration of runoff for the watershed. It is possible to calculate the time of concentration using the following equation

$$T_c = 0.019 \cdot L^{0.77} \cdot S^{-0.385} \quad \text{(after Schwab et al 1981)}$$

Where

T_c : time of concentration (minutes)
L : maximum length of flow (m)
S : gradient of the watershed from the outlet to the most remote portion.

For the determination of the design intensity, the time of concentration refers to the rainfall intensities observed at Morogoro Met. Sts. (see table 5.3 and 5.4).

7.3.2 Design of grass waterway

The cross-sectional shapes and the dimensional characteristics o a waterway has been presented in figure 4.7. The choice of the shape is dependent on a number of factors such as construction and maintenance equipment, hydraulic characteristics, etc.. The calculation of the channel dimensions is based on the parabolic cross section, because artificial cross sections will become parabolic in time. However, under construction trapezoidal cross section can be selected in dependeng on the type of equipment used, such as bulldozer, scraper or motor grader.

Design velocity is the mean velocity of flow which does not produce erosion. It should be decided depending on the soil type the condition of vegetation in the channel, topography, etc.. Hudson (1986) recommends a maximum design velocity ranging from 1.7 m/sec (clay loam) to 0.9 m/sec (light loose sand) under medium cover of grass. For the calculation and determination of channel dimentions please refer to books (for example, Schwab e al. 1981, Hudson 1986, Morgan 1986, FAO 1965). Thus only results are presented in table 7.4 and appendix 6. Waterway B was designed completly on the basis of longitudial measurments. Smaller field grass waterways which are shown on appendix 6, have not been drawn with their dimensions because the measurement of elevations has not been done in the field. Thus only probable dimensions of the field waterways are produced as table 7.4. shows.

Crossing of waterways

There are three methods for crossing a waterway; fords (see figure 7.3), culverts and bridges. Factors affecting the decision of the type depends mainly on construction and maintenance costs, stream size, expected roads use, etc.. Many waterway crossings in the field will probably not need paticular structures apart from a ford reinforced by stones like at grass waterway B and a culvert (alternatively ford) at field grass waterway b (location see appendix 6).

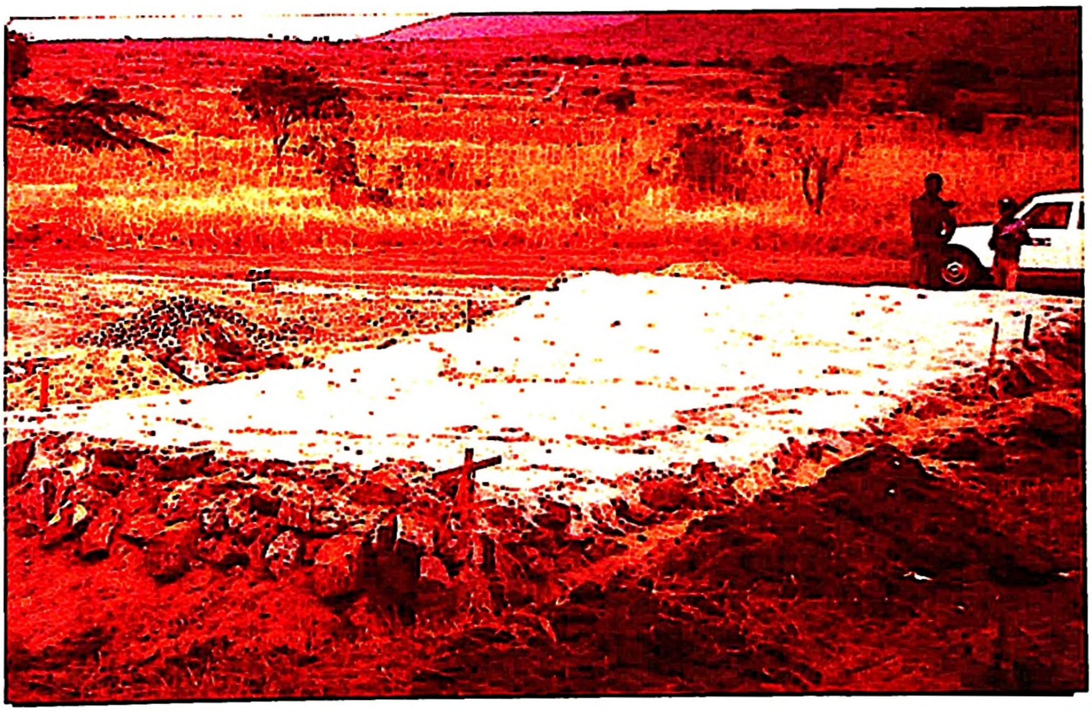

Figure 7.3 The ford constructed on grass waterway A

Table 7.4 Characteristics for the decision of waterways.
Grass waterway B

	No14+26m No13+26m	No13+26m No11	No11 No9	No9 No7+20m	No7+20m No4+6m	No4+6m 2+50m	No2+50m No 0
T_c	9.2	21	-	-	31.7	3.17	-
I	80	80	-	-	70	70	-
C	0.21	0.21	-	-	0.21	0.19	-
A	29	65	-	-	135	152	-
Q	1.38	3.04	3.04	3.04	5.51	5.63	5.63
V	1.05	1.35	1.5	1.5	1.5	1.48	1.7
S	0.7	0.7	2.0	2.0	1.2	0.75	1.2
d	0.53	0.78	0.41	0.41	0.61	0.85	0.71
D	0.68	0.93	0.56	0.56	0.76	1.00	0.86
t	3.69	4.34	7.33	7.33	9.06	6.73	6.98
T	4.18	4.74	8.56	8.56	10.12	7.30	7.68

Table 7.4 cont.
Field grass waterway

	a	b	c	d
T_c (min.)	9.2	31.7	5.6	7.3
I (mm/h)	100	70	113	113
C	0.21	0.21	0.21	0.21
A (ha)	23.2	82	6.3	17.4
Q (m^3/sec)	1.35	3.36	0.42	1.15
V (m/sec)	1.1	1.5	0.75	1.5
S (%)	1.75	1.3	0.2	1.3
d (m)	0.29	0.57	0.82	0.82
D (m)	0.44	0.72	0.97	0.97
t (m)	6.39	5.86	1.02	1.40
T (m)	7.88	6.59	1.10	1.51

Explanation of the signs refers to the figure 4.7

Because of the stream size of grass waterway B, a ford will be the best sturcture. The culvert crossing the field grass waterway b, may be an appropriate solution since the dimension of the waterway is not so large.

7.3.3 Layout of buffer strips

Narrow grass strips on the contour are placed in fields which have a potential soil loss higher than 60 t/ha/y. In this method grass strips of the same width, are established at regular vertical intervals (VI) on the contours (see figure 7.4). This is the simplest method and a short time is required for the establishment of the strip-lines. The disadvantage is that tillage operations between the strips (cultivated area) are made difficult due to the various widths of the cultivated area.

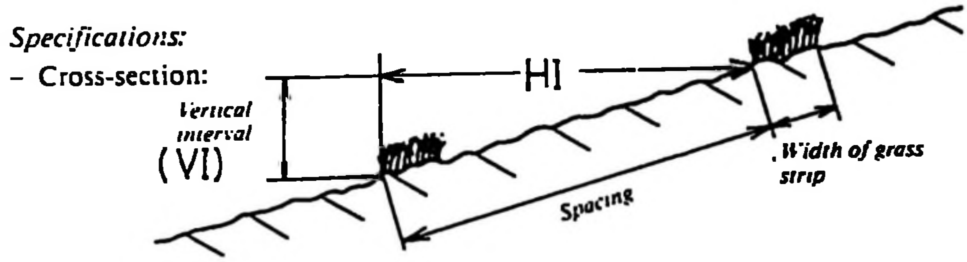

Figure 7.4 A side view of buffer strips.

From the piont of view of reducing soil erosion efficiently, wider grass and smaller spacing provided better filtering of the soil materials. However, closer spacing of grass strips makes tillage operations by machinery very difficult. The formula derived in Zimbabwe (see chapter 4.3) seems to be appropriate for tha design using of grass strips at Mazimbu. The results of calculations according to the formula is shown on appendix 6. However, the field planners are the decision makers, so they should try out buffer strips with different dimensions.

<u>Narrow grass buffer strips with a slight gradient</u> has been discussed earlier, buffer strips on the contours will probably not give a soil loss below the tolerance level in a field where the potential soil loss exceeds 60 t/ha/y. Thus in an area expecting a large amount of soil losses, the narrow grass buffer strips with a slight gradient should be used. These grass strips will be able to be replaced by terraces as permanent structure with time. However as many experts (Roose et al 1971, Thomas et al 1983, Wenner 1983) report, the zone of grass strips can be built up as small embankments due to sedimention. The small embankments will gradually function as small graded terraces. The establishment of graded grass strips usually requires a longer time, to settle the lines of strips, as compared to the establishment of strips on the contours. The specification of the

graded grass strips: vertical interval (VI) and horisontal interval (HI) the same as for strips on the contours.

<u>Buffer strip cropping based on the uniform width of the cultivated area</u> has been used extensively in areas which have to grow large amounts of hay in the USA. The tillage operations are simpler as compared with the above methods, since the cultivated areas are of a uniform width. However, during the first stage, establishment demands much more time and large proportions of culivated land is occupied by grass. This method therefore does not seem suitable in our case. For detailed information please refer elsewhere, for instance FAO (1965), Troeh et at (1980), Schwab et al (1981), etc..

<u>Grass establishment for the buffer strips</u>

The zone of grass strips is planted with permanent vegetation to reduce the velocity of runoff water and to catch any soil particles which have been eroded from the cultivated strips. The vegatation has to be perennial so that the first planting provides a permanent residence of grass strips. Grass in the buffer zone can be combined with several types of trees such as citrus, legumes, etc.. However, the buffer strips are recommended to be planted (or sown) pasture leys so that the grasses can be used for forage. If the vegetation will be sown and reaped by machines, only grasses can be sown.

The speed at which the sowing takes place is an important factor in cases where large areas of the fields are to be established with grass in a short period of time, e.g. durimg 'short rains'. The regular width of a sowing machine provides the optimum width of 2 m. The most important thing concerning the reaping of the grass is that the grass on the buffer zone should not be reaped or grazed for at least two years until a good buffer zone has been achieved.

The type of grasses which can be recommended, is strongly dependent on the accessibility. Thus several types of grass are mentioned below. Several types of grass can of course be sown as a mixture.

Bermuda grass, star grass (Cynodon dactylon)-----	good
Nandi setaria (Seraria anceps) ----------	good
Rhodes grass (Chlori gayana) ----------	good
Africn foxtail (Cenchrus ciliaris) ----------	fair
Elephant grass (Pennisetum purpureum) ----------	fair

(after Rensburg 1955,1958, Thomas et al 1983, Lwanga et al 1985)

8 CONCLUSIONS

The litterature examined in this thesis reveals that plants and plant residues are very effective as protection against soil erosion. Accelerated soil erosion becomes a problem many places where the natural vegetation is removed. Erosion is often more severe in tropical climates than in temperate climates. This is partly a result of higher erosivity in the tropics.

The visible erosion features in Mazimbu indicates that erosion on the farm is severe. Potential soil loss for maize under present management as estimated by USLE also gives evidence of severe erosion. The estimated potential soil loss varies from 24 to 110 ton/ha/year, and it is too high to be accepted. Due to the serious erosion, soil conservation has to be practiced. If not, soil erosion will continue or even increase, and it will probably be impossible to maintain production level per land unit.

Estimation of the factors in USLE revealed an expression for the influence from each factor on erosion in Mazimbu. The estimated soil and crop management factor (C) is very high, while the rainfall erosivity (R) and the topography factor (LS) are not extremely high. Soil erodibility (K) seems to be generally low. The estimated USLE values corespond well to values reported from similar conditions. Therefore, it is reasonable to conclude that the soil and crop management practiced at present are main reasons for the erosion at Mazimbu. Long slopes seem to result in erosion some places.

The validity of USLE outside the United States is discussed and tested by several resarchers. Various conditions such as soil properties and rainfall characteristics differ between the United States and other parts of the world. The results of the calculations of USLE factors are influenced by these variations. In the case of this study, the estimated values for the USLE factors and the potential soil loss for Mazimbu are compared to results from similar conditions. The values seem to be within an acceptable range. This have made USLE to a usable tool in soil conservation planning for Mazimbu.

The precise validity of the estimated USLE factors and potential soil loss can only be tested by field experiments. The suitability of the conservation plan has to be considered some years after it has been implemented

The following are the main ingredients in the soil conservation plan:

1) Inflow from the surroundings is prevented by a stormwater drain and a grassed waterway.
2) Runoff within the fields is reduced and controlled by grass-buffer strips and grassed waterways.
3) Crop management is improved with the introduction of cover crops in the rotations. Permanent grass is introduced in some fields with high erosion risk.
4) Soil management is improved as a chisel-cultivator substitutes the disk implements. This leaves plant residues for protection of the soil on the soil surface.

The soil conservation plan interferes with existing farm practices since grass and cover crops substitute maize, sorghum, sunflower and beans to some extent. This should result in a discussion of whether meat production (cattle and goats) can be increased. The conservation plan should be initiated immediately. It is important to evaluate the recommendations continually, to see whether modifications are necessary.

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APPENDIX 1

SOIL PROFILE DESCRIPTIONS

The pH-values that are given for each horizon refere to measurements in H2O and CaCl2, with H2O as the first value.

PROFILE NO.: 1.
Classification: Ferralic Cambisol
Date of examination: 18.07.1987
Author: Abel K. Kaaya & Marit Hauken
Location: Mazimbu ANC-farm, 500m above field 15, ca. 10m north east of electical line. 37°36'38''E. 6°46'53''S.
Altitude: 530 m
Physiography - surroundings: Undulating
- site: Convex slope, ca. 3%
Land-use / vegetation: Former sisal estate, now bush/ grassland
Parent material: Gneiss, weathered in situ
Drainage: Well drained
Moisture conditions: Dry
Evidence of erosion: Slight sheet erosion

Profile description

Ah 0-20cm
Dull brown (7,5 YR 5/6) dry, brown to dark brown (7.5YR 4/4) moist; sand ; weak to moderate very fine, fine and medium granular; non-sticky, nonplastic, very friable moist, soft dry; many very fine and fine, few medium and coarse pores; very frequent very fine, fine and medium roots, very few coarse roots; gradual, smooth boundary.
pH 6.0/4.7

Bu1 20-75cm
Strong brown (7.5YR 5/6) dry, yellowish red (5YR 4/8) moist; sandy loam; moderate fine and medium subangular blocky; slightly sticky, slightly plastic in the lowest part , friable moist, slightly hard dry; many very fine and fine, few medium and coarse pores; frequent very fine and fine roots, few coarse roots (20-39cm); decreasing root content 39-75cm; clear, wavy boundary.
pH 5.4/4.1

Bms1 75-110cm
Strong brown (7.5YR 5/6) dry, yellow red (5YR 4/8) moist; common, medium, prominent, sharp, red (2.5YR 4/8) mottles; sandy clay loam; strong fine and medium angular blocky; sticky, slightly plastic, firm moist, hard dry; weakly cemented; many very fine pores,few medium and fine pores; very few very fine and coarse roots; abrupt, smooth boundary.
pH 5.7/3.9

Bms2 110-130cm
Light brown (7.5Y/R 6/4) dry, dark brown (7.5YR 4/4) moist; many coarse, prominent, sharp, red (2.5YR 4/8) and yellowish red (5YR 5/8) mottles; sandy clay loam; very strong fine, medium and coarse angular blocky; sticky, plastic, firm moist, very hard dry; weakly cemented; many very fine, few medium and coarse pores; very few medium and fine roots; clear, wavy boundary.
pH 5.9/3.9

BC 130-210cm +
Dark brown (7.5YR 4/4) dry and moist (7.5YR 3/4); many coarse, prominent, sharp, yellowish red (5YR 5/8) mottles; sandy clay; very strong angular fine, medium and coarse blocky; sticky, plastic, very firm moist, extremely hard dry; patchy thin cutans, probably from illuvial clay; weakly cemented; few very fine and fine pores; few weathered fragments, mainly feldspars and mica gravel; very few very fine and fine roots.
pH 5.4/3.8

Classification.
Classification as Ferralic Cambisol is based mainly on texture, colour and chemical properties. The Bu1 and Bms2 horizons are considered a cambic B-horizon. ECEC/100g clay* in Bu1 vary from 11.7-15.3 m.e., which is low enough to give the soil ferralic properties.

*see section 5.4

Profile 1

PROFILE NO.: 3
Classification: Albic Luvisol (Truncated Luvisol,see remarks)
Date of examination: 18.07.1987
Author: Abel K. Kaaya & Marit Hauken
Location: Mazimbu ANC-farm, north-western corner of field 6.
37°37'9''E. 6°47'19''S.
Altitude: Ca. 515m
Physiography - surroundings: Undulating
- site: Almost flat, ca. 1,5% slope towards south east
Land-use / vegetation: Prior sisal estate,farmland since 1982 with rotation of maize, sorghum and sunflower
Parent material: Gneiss, weathering in situ
Drainage: Moderately well drained
Moisture conditions: Dry 0-132 cm, moist 132+
Evidence of erosion: Severe sheet erosion
Remarks: Textural and chemical differences between the upper 40cm and the lower horizons indicate that the topsoil could be deposits over an eroded soil, hence the profile could be a truncated Luvisol.

Profile description

Ap1 0-19cm
Yellowish brown (10YR 5/4) dry, dark yellowish brown (10YR 3/4) Nmoist; sand; weak to moderate fine, medium and coarse granular; slightly sticky, nonplastic, friable moist, slightly hard dry; many very fine and fine pores, few medium pores; very frequent very fine and fine roots; abrupt, smooth boundary.
pH 5.4/4.4

Ap2 19-32cm
Brown (10YR 5/3) dry, dark brown (10YR 3/3) moist; many, medium, distinct,diffuse, strong brown (7.5YR 5/6) mottles; sand; moderate medium and coarse granular; slightly sticky, nonplastic, very friable moist, slightly hard dry; many very fine and fine pores; few fine roots; abrupt, smooth boundary.
pH 5.1/4.4

E 32-40cm
Pale brown (10YR 6/3) dry, yellowish brown (10YR 5/4) moist; many, medium, prominent, clear, strong brown (7.5YR 5/8) mottles; sand; moderate medium, coarse and very coarse subangular blocky; slightly sticky, nonplastic, very friable moist, hard dry; common very fine pores, few fine pores; very few very fine roots; abrupt smooth boundary; there exist a horizontal parting below the horizon. This could be due to cultivation or to erosion and sedimentation.
pH 6.3/5.3

Bt 40-85cm
Dark yellowish brown (10YR 4/4) dry, dark brown (10YR 3/3) moist; many medium, prominent, clear, reddish yellow (7.5YR 6/8) mottles; sandy clay loam; very strong, coarse and very coarse angular blocky; sticky, slightly plastic. friable moist, extremely hard dry; some black, sticky and plastic linings formed from clay and organic matter movement; many very fine pores; few vertical and horizontal cracks, 1-3mm wide, probably due to tillage/ compaction; very few very fine roots; gradual smooth boundary.
pH 7.7/6.1

Bm1 85-129 cm
Strong brown (7.5YR 5/6) dry, dark brown (7.5YR 4/6) moist; many medium, coarse, distinct, clear, yellowish red (5YR 5/8) mottles; sandy loam; strong, medium, coarse and very coarse angular blocky; slightly sticky, slightly plastic, firm moist, extremely hard dry; few animal burrows (5-10cm) with clay lining; common very fine pores; few fragments of slightly weathered feldspar gravel; clear wavy boundary.
pH 9.5/7.9

Bm2 129-193cm +
Strong brown (7.5YR 5/8) moist, and slightly darker (7.5YR 4/6) below 147cm; sandy loam; strong medium, coarse and very coarse subangular blocky; slightly sticky, nonplastic, firm moist; few animal burrows (5-10cm) with clay lining; few very fine and fine pores; at around 147cm there is a grayish layer, mainly formed from quartz.
pH 9.5/8.0

Classification.
The E-horizon qualifies as an albic E due to colour and very low clay content. The B is considered an argillic horizon mainly because of clay content, which decreases more than 20 % from its maximum within 125 cm from the surface. Base saturation (NH4OAc) in the B-layer is > 50% These characteristics lead to the classification as an Albic Luvisol.

Alternatively, the upper 40cm are considered as sediments over an eroded soil, and the soil can only be classified as a Luvisol that has been eroded, hence truncated Luvisol.

Profile 3

PROFILE NO.: 4
Classification: Ferralic Cambisol
Date of examination: 19.07.1987
Author: Abel K. Kaaya & Marit Hauken
Location: Mazimbu ANC- farm. Southern courner of field 5.
6°47'26''S, 37°37'13''E.
Altitude: ca. 510m.
Physiography - surroundings: Undulating
- site: Convex slope, ca 7% towards north
Land-use / vegetation: As profile 3.
Parent material: Gneiss, weathering in situ
Drainage: Well to somewhat exessively drained
Moisture conditions: Dry at examination
Evidence of erosion: Severe sheet erosion / moderate rill-erosion
Remarks: Very thin Ap-layer indicates that this is an eroded soil.

Profile description

Ap 0-9cm
Dark reddish brown (5YR 3/6) dry and moist (5YR 2/3); sandy loam; weak medium, coarse and very coarse granular; slightly sticky, slightly plastic, very friable moist, soft dry; common very fine pores, few fine and medium pores; very frequent fine and very fine roots; abrupt, smooth boundary.
pH 5.6/4.7

Bs1 9-30cm
Red (2.5YR 4/8) dry, dark red (2.5YR 3/6) moist; sandy clay; strong medium and coarse angular blocky; sticky, plastic, friable moist, hard dry; few animal burrows (2-5cm) partly filled with decomposed roots; many very fine pores few fine, medium and coarse pores; frequent very fine and fine roots; clear, smooth boundary.
pH 5.2/4.7

Bs2 30-46cm
Same colour and texture as B1; moderate fine and medium subangular blocky; slightly sticky, slightly plastic, friable moist, slightly hard dry; animal burrows as in B1; pores as in B1; frequent very fine roots, very few fine roots; abrupt smooth boundary;
pH 4.8/4.2

BC 46-60cm
Same colour as B1 and B2. The layer consist mainly of quartz gravel, most <0.5cm, some 1-2cm diam, few fragments of feldspar and hornblende (?) gravel. The particles are rounded through weathering; common very fine and medium pores; common fine roots; clear wavy boundary.
pH 4.9/4.4

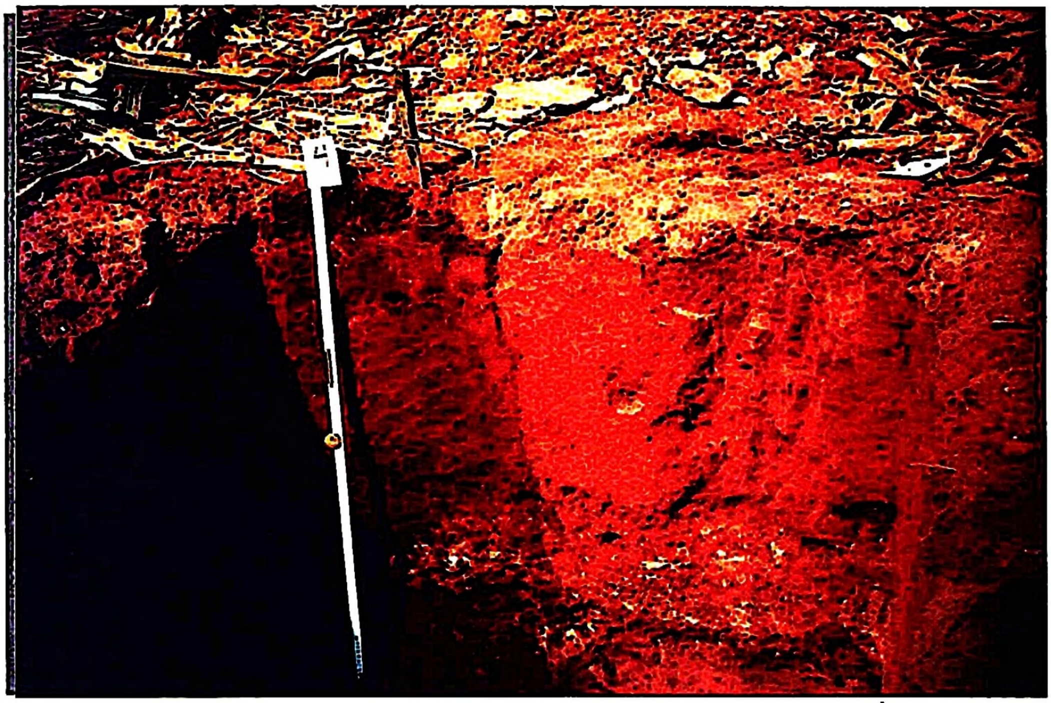
CR 60-94cm+
Wavy layers of intensely weathered gneiss, easy to dig /break; few very fine roots.

Classification

The B-horizon is considered a cambic B. ECEC/100g clay in the Bs1 is 17.6m.e., which gives the soil ferralic properties. Cambic B with ferralic properties lead to the classification as a Ferralic Cambisol.

The difference in colour between the two profiles that are classified as Ferralic Cambisols could be due to variations in parent material.

Profile 4



PROFILE NO.: 5
Classification: Chromic Cambisol
Date of examination: 19.07.1987
Author: Abel K. Kaaya & Marit Hauken
Location: Mazimbu ANC-farm. South-Eastern corner of field 7.
6°47'50''S, 37°37'28''E.
Altitude: 500 m.
Physiography - surroundings: Undulating
- site: Almost flat; 1% slope towards south.
Land-use / vegetation: Farmland since 1982. Rotation with sun flower/ sorghum / maize. 1987: Sunflower.
Parent material: Colluvial/alluvial material from the Luagala/ Uluguru mountains
Drainage: Well drained
Moisture conditions: Dry soil while examined
Evidence of erosion: No signs of erosion. This field was culti vated late and the surface has been exposed to little rain after cultivation.

Profile description

Ap 0-27cm
Dark brown (7.5YR 4/4) dry, dark reddish brown (5YR 3/6) moist;- sand; strong very fine to coarse angular blocky; non-sticky, nonplastic, friable moist, hard dry; common very fine pores, very few fine pores; frequent very fine roots; clear wavy boundary.
pH 6.8/6.0

Bu1 27-61cm
Strong brown (7.5YR 4/6) dry, dark reddish brown (5YR 3/6) moist; sand; strong very fine to coarse angular blocky; non-sticky, nonplastic, friable moist, hard dry; many very fine pores, very few fine pores; a ca 3cm layer of gravel, mainly quartz (<1cm) at the bottom of the horizon, not continous; few very fine roots; some roots in cracks; gradual smooth boundary.
pH 6.1/5.1

Bt1 61-115cm
Strong brown (7.5YR 4/6) dry, dark reddish brown (5YR 3/6) moist;sandy loam; very strong fine, medium and coarse angular blocky; slightly sticky, slightly plastic, friable moist, extremely hard dry; common very fine pores, few fine pores; few fragments of weathered quartz and feldspar gravel; no roots except in cracks; clear, smooth boundary.
pH 6.1/5.3

Bt2 115-152cm
Yellowish red (5YR 4/8) dry, dark reddish brown (5YR 3/4) moist; sandy loam; structure and consistence similar to Bt1; common very fine pores, few fine pores; no roots; clear, smooth boundary.
pH 6.7/6.1
BC 152-172cm +
Layer with stones, mainly quartz, gneiss and feldspars >1-2cm, some rounded through weathering and water transport.

Classification
Classification as Chromic Cambisol is based mainly on texture and colour. The Bt1-horizon qualifies as a cambic B, and the strong brown/reddish brown colour gives the horizon chromic properties.

Profile 5

PROFILE NO.: 7
Classification: Albic Arenosol
Date of examination: 3.08.1987
Author: Marit Hauken
Location: Mazimbu ANC-farm. North-Eastern side of field 12.
6°46'13''S, 37°37'37''E.
Altitude: ca 515m.
Physiography - surroundings: Undulating
- site: Plateau, almost flat;
Land-use / vegetation: Farmland since 1982. Rotation with sunflower / sorghum / maize. 1987: Maize
Parent material: Gneiss, weathering in situ
Drainage: Somewhat excessively drained
Moisture conditions: Dry soil while examined
Evidence of erosion: Sheet, 1-2
Remarks:- Black pieces of coal indicate burning earlier.
- No salt or alkali at site, but signs of saline groundwater/soil ca. 250m south west of profile, ca 10m lower in altitude.
-The profile is 1m deep. A soil auger was used to collect soil samples down to the bedrock. Auger samples showed little difference from Bu1.

Profile description

Ap 0-15cm
Brown (7.5YR 5/4) dry, dark brown (7.5YR 3/4) moist; sand; structureless/very weak very fine and fine subangular blocky; non-sticky, nonplastic, loose moist, slightly hard dry; many very fine pores; very frequent very fine roots, very few fine roots; abrupt, smooth boundary.
pH 5.4/4.4

AB 15-57cm
Same as above except for roots; frequent very fine roots; gradual, smooth boundary.
pH 5.3/4.4

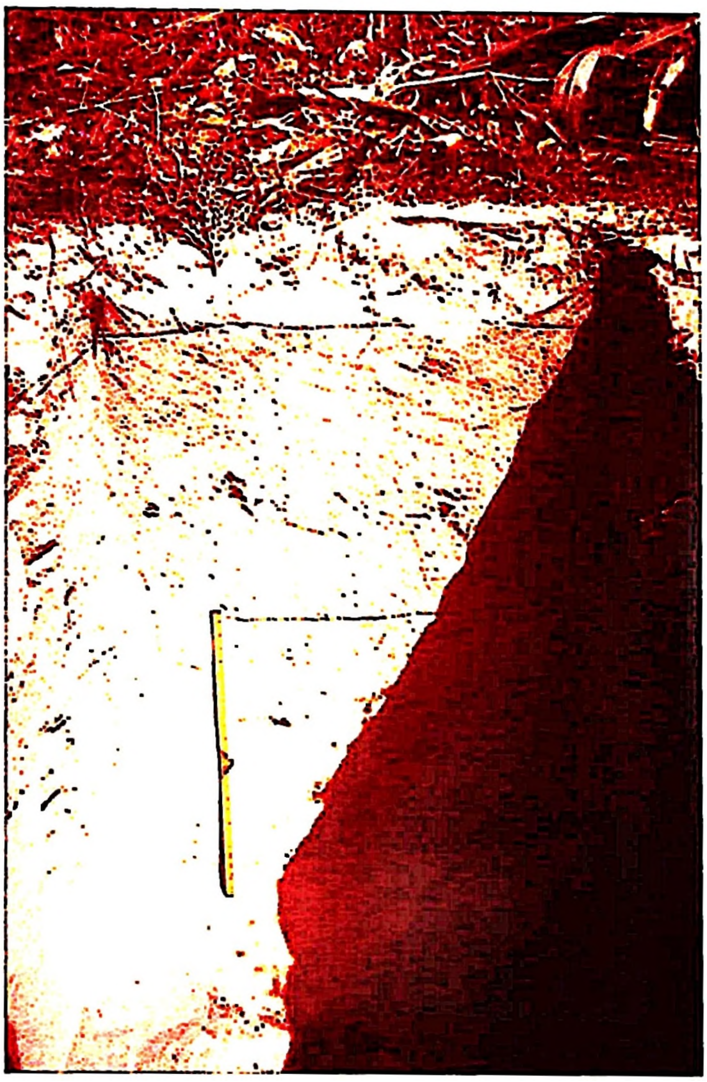
Bu1 57-100cm
Reddish yellow (7.5YR 6/6) dry, yellowish red (5YR 4/8) moist, few spots (1x3 - 7x25cm) with same colour as Ap; sand; structureless, single grain; non-sticky, nonplastic, friable moist, soft dry; many very fine pores; frequent very fine roots;
pH 5.0/4.4

Bu2 100-170cm
This section was not dug out, but samples taken with an auger showed properties similar to Bu1. Before 170cm the colour was lighter; pink (7.5YR 7/4) dry and strong brown (7.5YR 5/6) moist.

R 170cm +
Probably foliated and banded gneiss, as this was observed on bare spots in the surroundings.

Classification
Classification as an Albic Arenosol is based on texture and colour.

Profile 7



	Horizon	Depth (cm)	Particle size distribution 2- 0.1mm	0.1- 0.06mm	0.06- 0.002mm	<0.002mm	Texture	Organic matter Ign.loss %	O.M. %	pH H_2O	pH $CaCl_2$
Profile 1											
	Ah	0-20	83	6	5	7	sand	1.26	0.3	6.0	4.7
	Bul	20-39	68	8	7	16	sandy loam	1.90	0.0	5.4	4.1
	-"-	39-75	63	7	7	23	sandy clay loam	2.34	0.3	5.4	4.0
	Bms1	75-110	65	6	7	22	sandy clay loam	2.60	0.6	5.7	3.9
	Bms2	110-130	58	7	7	28	sandy clay loam	2.98	0.5	5.9	3.9
	BC	130-210	40	5	5	49	sandy clay	5.18	1.7	5.4	3.8
Profile 3											
	Ap1	0-19	80	8	7	5	sand	1.22	0.2	5.4	4.4
	Ap2	19-32	74	11	8	6	sand	1.15	0.2	5.1	4.4
	E	32-40	82	10	6	2	sand	0.64	0.0	6.3	5.3
	Bt	40-85	60	7	8	25	sandy clay loam	2.73	0.2	7.7	6.1
	Bm1	85-129	66	8	8	18	sandy loam	1.83	0.0	9.5	7.9
	Bm2	129-147	63	7	9	20	sandy loam	1.86	0.0	9.6	8.0
	-"-	147-193+	72	5	4	19	sandy loam	1.64	0.0	9.5	8.0
Profile 4											
	Ap	0-9	66	11	9	14	sandy loam	3.48	2.5	5.6	4.7
	Bs1	9-30	43	7	6	44	sandy clay	5.82	2.3	5.2	4.7
	Bs2	30-46	46	8	8	38	sandy clay	4.70	2.2	4.8	4.2
	BC	46-60	50	24	6	20	sandy clay loam	3.38	1.4	4.9	4.4
Profile 5											
	Ap	0-27	82	10	9	0	sand	1.62	1.6	6.8	6.0
	Bul	27-61	74	10	10	5	sand	1.55	0.6	6.1	5.1
	Bt1	61-115	68	6	7	19	sandy loam	2.53	0.5	6.1	5.3
	Bt2	115-152	59	9	11	21	sandy loam	-	-	6.7	6.1
Profile 7											
	Ap	0-15	81	8	7	4	sand	1.01	0.0	5.5	4.4
	AB	15-57	77	9	8	5	sand	0.92	0.0	5.3	4.4
	Bul	57-100	78	10	7	5	sand	0.71	0.0	5.0	4.4