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Resources, Actors and Policies:
Towards Sustainable Regional Development in the Highland-Lowland System of Mount Kenya

Pressure on the Land: The Search for Sustainable Use in a Highly Diverse Environment

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September 1998

Abstract

This paper presents for the highland-lowland system of Mt. Kenya and the Ewaso Ng'iro basin: (1) the current use of land resources and effects of the growing pressure on land resources, (2) the possibilities of improving land management and productivity, and (3) the challenges of trying to achieve sustainable use of land resources.

Land use and its dynamics are assessed and presented as a first step in identifying current land resource use and degradation. An overview of the main soil types and their characteristics shows potentials and limitations for land use.

Major impacts of land use and soil management on natural resources are presented for 3 major zones along the highland-lowland system. These are: (a) The effect of land use on the water recharge of the rivers on wet mountain slopes; (b) water conservation measures and their effect on productivity in the semi-humid to semi-arid lower mountain zone and the highland plateau and (c) the effect of overgrazing on water availability and productivity in the semi-arid to arid areas of the Laikipia plateau and the lower part of the basin.

African highland-lowland systems like the Ewaso Ng'iro basin pose a major challenge in terms of sustainable resource use: increasing pressure on limited natural resources. Reducing the potential conflict over resource use and the danger of resource degradation requires improved knowledge and practices in resource management. In order to optimize land management practices in a highland-lowland system that do not deprive the downstream users, good local and regional knowledge, a good database, and suitable management tools are needed. The scarcer the resources, the better the knowledge and the management of the resources and their optimum use must be adapted to the local situations.

1. Introduction

The study area of Mt. Kenya and the Upper Ewaso Ng'iro basin, and its potentials and limitations for the use of natural resources of the Upper Ewaso Ng'iro basin, have already been introduced in a separate paper within this special issue (Gichuki et al. 1998a). Aspects of sustainable use of water resources, which are the prime limiting resources in the Eastern African region, are further described in Gichuki et al. (1998b). The land resources, i.e. the soil and vegetation including the crops, grasses, and natural and planted forests, are resources of great importance to the rural populations living around Mt. Kenya.

There are three major regions in the highland-lowland system of the Ewaso Ng'iro basin, each of which presents major challenges in terms of sustainable use of the land resources:

a) On the humid to semi-humid mountain slopes, the main development is increasing pressure on the forest zone and intensified use of the land for crop production.
b) The semi-arid to semi-humid lower mountain zone and the highland plateau are undergoing a rapid change of land use, i.e. an expansion of irrigated and rainfed crop production, and increased pressure on commonly used grazing lands.
c) The semi-arid to arid areas of the Laikipia plateau and the lower part of the basin, which have been subjected to heavy grazing pressure and which show clear signs of vegetation degradation, such as no or very sparse grass cover and soil degradation by erosion.

This paper will discuss: (1) the current use of land resources and the effects of the growing pressure on the land resources, (2) the possibilities for improving land management and productivity, and (3) the challenges of achieving sustainable use of land resources in the highland-lowland system of the Ewaso Ng'iro basin.

All findings are derived from studies carried out within the Laikipia Research Programme and the Natural Resource Monitoring, Modelling and Management (NRM^3) project. Some of the findings are still preliminary and illustrate the need for long-term continuation of applied and development-oriented research.

2. Mapping land use and its dynamics

2.1 Land use/cover assessment

The first basic information needed to determine the potential of the land resource and identify processes of degradation is assessment of present and recent changes of vegetation cover and land use.

A classification system and methodology using satellite imagery and aerial photography has been developed with special reference to soil and water management. The main focus is assessment of soil cover by tree / shrub layer, cover by the herbaceous layer (grasses, herbs, forbs, crops), and land use and soil management. The classification was developed to meet the following requirements:

- The methodology (classification) should cover a wide range of land use and vegetation types, from the humid to the semi-arid tropics (and subtropics).
- The map should provide a basis for environmental monitoring and modelling, with special emphasis on the hydrological characteristics, where soil cover and topsoil management are extremely important.
- The categories should be clearly identifiable in the field without the need for detailed information from a specialist.
- The map should be compiled by using satellite imagery and aerial photographs with as little ground truthing as possible.
- The methodology should be scale independent, i.e. applicable at scales ranging from small catchments to entire basins, with varying degrees of generalization, depending on the mapping scale.
- The map and its categories should be as compatible as possible with existing classification systems for Africa (e.g. FAO 1997).

The classification system developed has a hierarchical structure with 7 main categories: Treeland (T), Grassland (G), Cropland (C), Water/Swamp (W), Urban (U), Rock (R), and Ice /Snow (I). Composites of the categories are used, depending on the mapping scale, in areas where there is a mixture of the different cover types within small areas. Figure 1 shows how the system considers canopy layer, a primary and a secondary land use type. Additionally, the cover conditions, e.g. of grassland, can be further described by adding qualifiers like (s) for sparse (for 2-20% ground cover) and (b) for bare (<2% cover), or by adding management information like soil and water conservation measures.

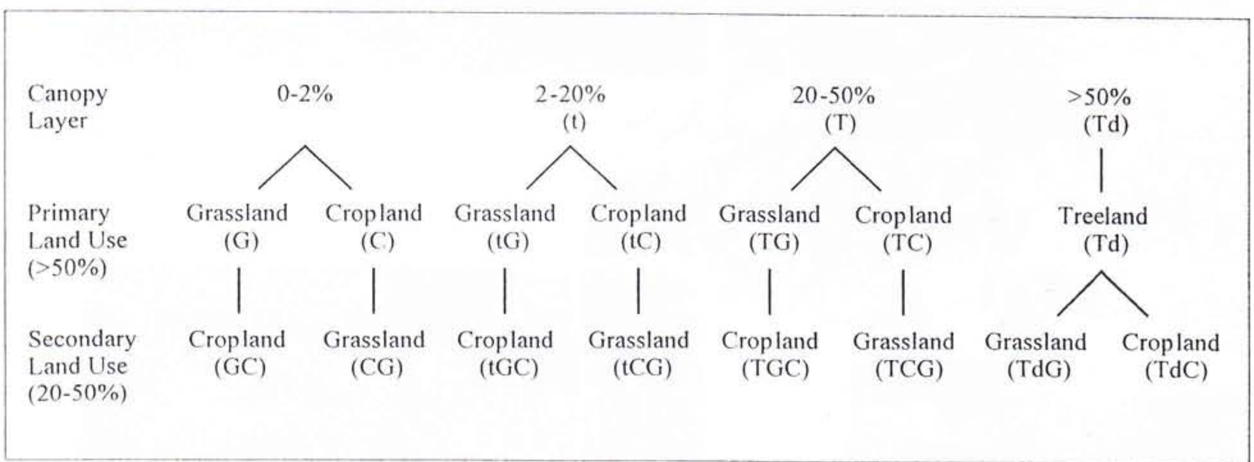
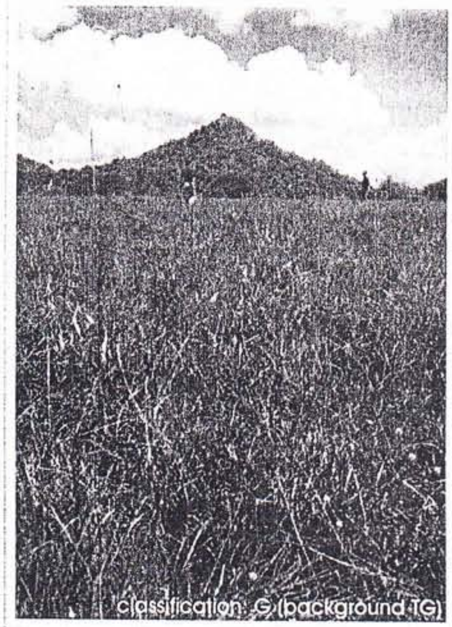


Figure 1: Classification system for treeland, grassland and cropland complexes (Roth 1997)

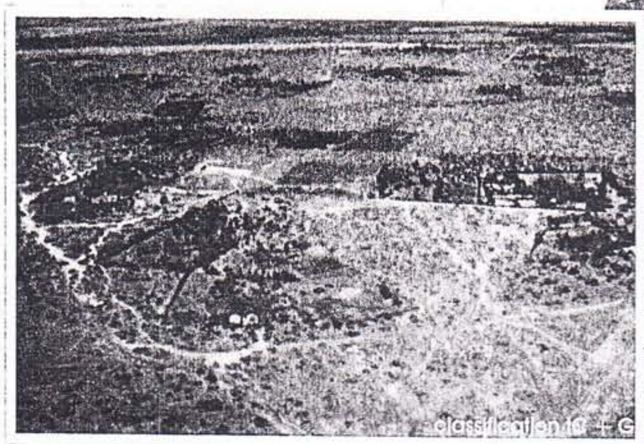
Figure 2: Land use / vegetation map (showing typical views: alpine region, forest, small-scale crop production with agroforestry and grazing land) (following page)



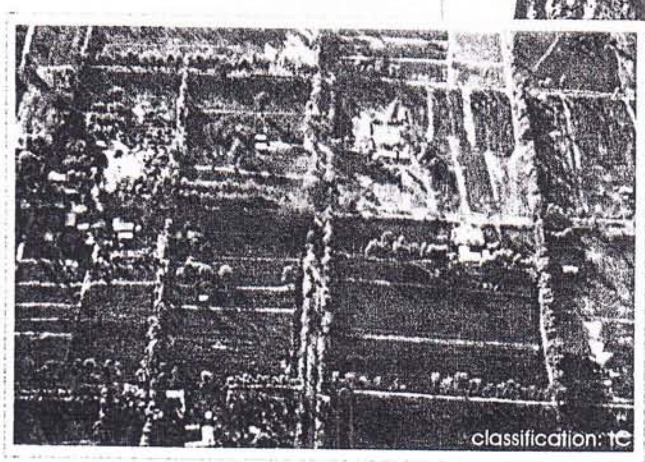
Semi-arid to arid zone:
good grass cover

Arid zone:
bad grass cov
gully erosion

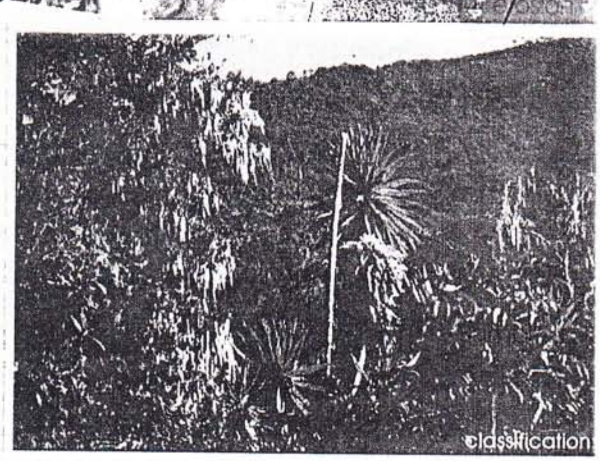
Ev
Samburu N



Semi-arid zone:
small-scale farming



Semi-humid zone:
small-scale agriculture



Mountain forest zone

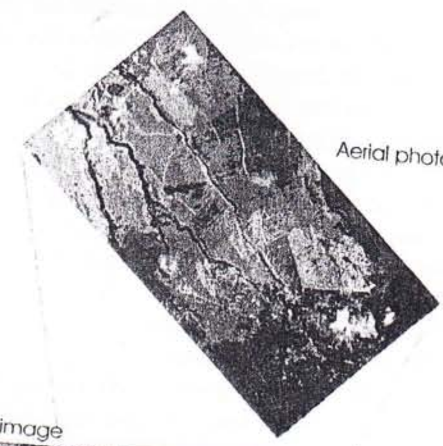
o Ng'iro:
nal park

Land Use / Vegetation Cover

Mt. Kenya, part of Ewaso Ng'iro Basin

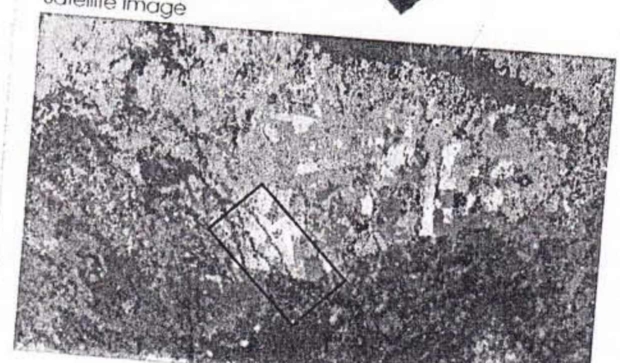
Concept / analysis: HP.Liniger, M. Thomas, S. Roth, G. Schwilch
GIS compilation / layout: G. Schwilch, S. Roth
Source: S. Roth 1997, M. Thomas 1993
Photos: HP. Liniger

Td:	> 50% dense trees
TPd:	> 50% dense planted trees
Go:	> 50% bamboo-grass
TG:	> 50% grassland with 20-50% trees
tG:	> 50% grassland with 2-20% trees
TGs:	> 50% sparse grassland with 20-50%trees
tGs:	> 50% sparse grassland with 2-20% trees
tGb:	> 50% bare grassland with 2-20% trees
G:	> 50% grassland
Gb:	> 50% bare grassland
Cveg:	> 50% cropland (green vegetation)
Cgrain:	> 50% cropland (grain)
Cfallow:	> 50% cropland (fallow)
tC:	> 50% cropland with 2-20% trees
tCG:	> 50% cropland with 20-50% grassland and 2-20% tree
R:	> 50% rock
tRG:	> 50% rock with 20-50% grassland and 2-20% trees
I / Cl:	ice or clouds
W:	water
U:	urban



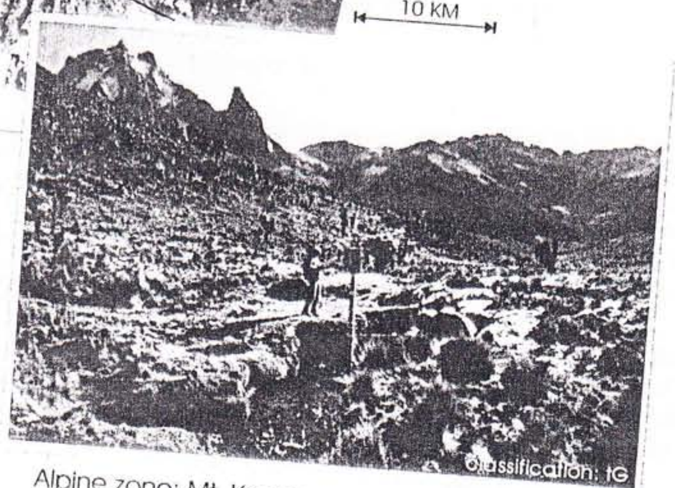
Aerial photo

Satellite image



classification: Cgrain

Mountain slope: large-scale farming



Alpine zone: Mt. Kenya

2.2 Major land uses

The resulting land use/cover map of the basin (see Figure 2) shows that:

In the mountain zones of Mt. Kenya (southeast of the map):

- Above the forest treeline around 3000 to 3500 m a.s.l., the alpine zone and moorland have natural vegetation and show little human impact.
- The upper mountain slopes still have largely intact natural forests.
- On the lower mountain slopes, natural vegetation has partly been changed to forest plantations, cropland, grazing land, or mixed systems of agroforestry.

In the plateau zone (west to northwest of Mt. Kenya):

- Cropland is expanding further into the semi-arid area (mixed farming with crop and livestock production)
- The grazing land under large-scale ranching has good grass cover (west of Mt. Kenya)
- The grazing areas under subdivision from large-scale to small-scale farming, especially the area under common management and in the communally managed areas inhabited by pastoralists (northwest of Mt. Kenya), are rather bare and have reduced herbaceous cover.
- The surface areas of the hills, scarps and dry valleys have higher vegetation cover.

In the lowland zone (north of Mt. Kenya):

- The riverine areas, mountains, hills and scarps have mostly natural vegetation with good cover conditions. Depending on stoniness and soil limitations, this cover is reduced and patchy.
- Outside these areas, the tree/bush cover is mostly natural savannah. However, the herbaceous layer is very bare, due to heavy grazing pressure.

2.3 Changes in land use

Current land use and recent changes in land use give indications of the potential of natural resources, as well as current and potential degradation. A comparison of 1984 and 1992 illustrates the dynamics in recent years in the semi-humid to semi-arid lower mountain zone of Mt. Kenya. The major changes are:

- Increase of cropland and agroforestry systems: Within 8 years, the treed cropland increased by a factor of 5 and the treed crop-grassland doubled. A major change is the introduction of agroforestry tree species, which are commonly planted by the small-scale farmers who immigrated from higher rainfall areas into the lower mountain zone of Mt. Kenya. In these areas of small-scale settlement the tree cover has increased. The most common tree is *Gevillea robusta* (Silky Oak), introduced from Australia at the beginning of this century, which is mainly used as a shade tree for coffee plantations. Today, *Grevillea* is the most commonly used and planted tree among small-scale farmers in the highlands of Kenya. The result is an increase of the tree cover in small-scale farming areas compared with previous use by large-scale farmers.
- A 25% decrease in grazing land, due to the increase in cropland: In the lower mountain zone of Mt. Kenya, land previously used largely for grazing was put under crop production in the recent decades. The vegetation cover of the soils below 3500 m a.s.l. is predominantly dense mountain forest mixed with bamboo and covers 80-100% of the ground. On the northern slopes of Mt. Kenya (Embori area), forest has been cleared for smallholder potato production up to 3000 m a.s.l. (Liniger 1995).
- A slight decrease in natural forests.

3. Soil resources and soil management challenges

Soils and their management have an influence on water storage and availability to plants, runoff, erosion, water loss by evaporation, and fertility. There is a high spatial variability of soil type and properties within the highland-lowland system, from Mt. Kenya to the lowlands of the Ewaso Ng'iro basin. Soil formation and characteristics depend on geology, landform/relief, climate, and human activities.

Figure 3 and Table 1 illustrate soil characteristics of the major soil types, giving a broad overview of the distribution and characteristics of the main soil types. The major soils are first separated on the basis of geology (volcanic and basement complex). Further differentiation is according to climate and land form/relief, starting from the cold wet mountains and steep slopes and moving to the warm, dry and flat lowlands.

Figure 4 shows the great variability of land use and soil types and how land use / vegetation and soils are connected in the lower mountain zone of Mt. Kenya and the highland plateau. In the semi-humid to semi-arid Kalalu area, cropland and mixed land are the main types of use on the ridges with deep fertile red soils, whereas natural vegetation and grazing are more concentrated on the shallower slopes of the valleys. However, land pressure has led to increased crop production on the steeper valley slopes, with risks of soil erosion and lower production. In the semi-arid Matanya area, the deep but vertic soils pose a special challenge with respect to rainfed crop production. Less rainfall and high evapotranspiration rates also increase the risk of crop failures. Therefore, the main land use is grazing and the main vegetation cover is still treed grassland.

Table 1: Soil characteristics of the major soil types

a) Major **soils on volcanic material** for the upper Ewaso Ng'iro Basin (including Aberdares and Mt. Kenya)

Landform / land description	Dominant soil type	Water storage	Nutrients / fertility	Erosion if no cover
M1: Mountain Alpine region: Aberdares, Mt. Kenya	Leptosol, Regosol	+	+	++
M2: Upper Slopes: Aberdares, Mt. Kenya	humic Andosol	+++	++	+++
M3: Lower Slopes: Aberdares and Mt. Kenya)	humic Acrisol	++++	+++	+++
	Nitosols, ferric Luvisol	++++	++++	++++
P: Plateaux - convex: (on elevations)	luvic Phaeozem	++++	++++	++
P: Plateaux - concave: (flat or in depressions)	verto-luvic Phaeozem, Vertisol	++++	++++	+
V: valley bottoms / depressions	Fluvisol and Gleysol	++++	++++	+
E: Eroded lands	Leptosol	+	+	++++

+: low, ++ medium, +++ high, ++++ very high;

b) Major **soil on basement material** for upper Ewaso Ng'iro Basin (including Aberdares and Mt. Kenya)

Landform / land description	Dominant soil type	Water storage	Nutrients/ fertility	Erosion if no cover
H: Hills	Cambisol	++	++	++
F: Footslopes:	chromic Luvisol, Lixisol	++++	+++	++++
P: Plateaux - convex: (on elevations)	Lixisol	+++	++	+++
P: Plateaux - concave: (flat or in depressions)	vertic Luvisol, Vertisol	++++	++++	+
V, B: Valley bottoms / depressions, Bottomlands	Fluvisol and Gleysol	++++	++++	+
E: Eroded lands	eroded Lixisol (leptic)	++	+	++++

+: low, ++ medium, +++ high, ++++ very high;

Short description of the soil types:

Leptosol:	Shallow soil, poorly developed
Humic Andosol	Ashy soil with high organic matter content; black topsoil; clay; loam
Humic Acrisoil	Well-developed soil, with high organic matter content (black topsoil); clay; accumulation of clay in subsoil
Ferric Luvisol / Lixisol	Well-developed soil with iron concretions; clay with clay accumulation in subsoil
Nitosol	Well-developed soil, deeply weathered, with clay accumulation is subsoil
Luvic Phaeozem	Well developed black soil with high organic matter content; clay
Vertisols	Black cracking clay soil
Fluvisol	Less-developed soil from river deposits
Gleysol	Well-developed soil, poorly drained, variable texture
Cambisol	Young soils, with some shiny materials, loam clay to clay

The great variability of land resources from the mountains to the lowlands and limited and highly variable water resources, combined with the high pressure of the growing populations around Mt. Kenya pose a major challenge: to optimize the use of natural resources on one hand, and on the other, to minimize the risk of degradation for the whole highland-lowland system.

For volcanic soils the main soil management challenges are as follows: The loose volcanic soil of Mt. Kenya and the Aberdare Mountains is mainly under forest cover. In areas where the forest has been cleared for cultivation, there is a threat of reduced water infiltration capacity and water storage capacity. This would lead to increased surface runoff and soil erosion and ultimately a decline in land productivity. A change of natural vegetation to cropland on these loose volcanic soils on the moderately to steep slopes of Mt. Kenya and the Aberdares would require conservation measures. An additional constraint is the acidity of these soils. The lower mountain slopes and upper plains have deep soils with high water retention capacity, good workability of the soils, and high fertility. These soils in the semi-humid to semi-arid environment are thus very suitable for rainfed crop production.

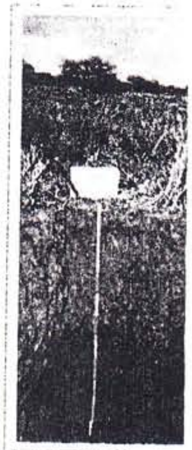
Figure 3. Generalized soil map and major soil types (following page)

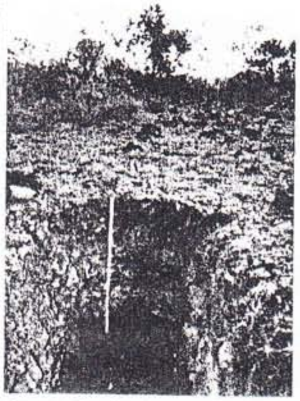
Mountains / Hills (steep slopes):
Leptosol, Cambisol

- semi-arid to semi-humid
- shallow, red sandy loam
- eroded or young soil with shiny materials
- low water storage capacity
- low fertility
- suitable for natural bush/tree vegetation and grass production

Footslopes:
Luvisol and Lixisol

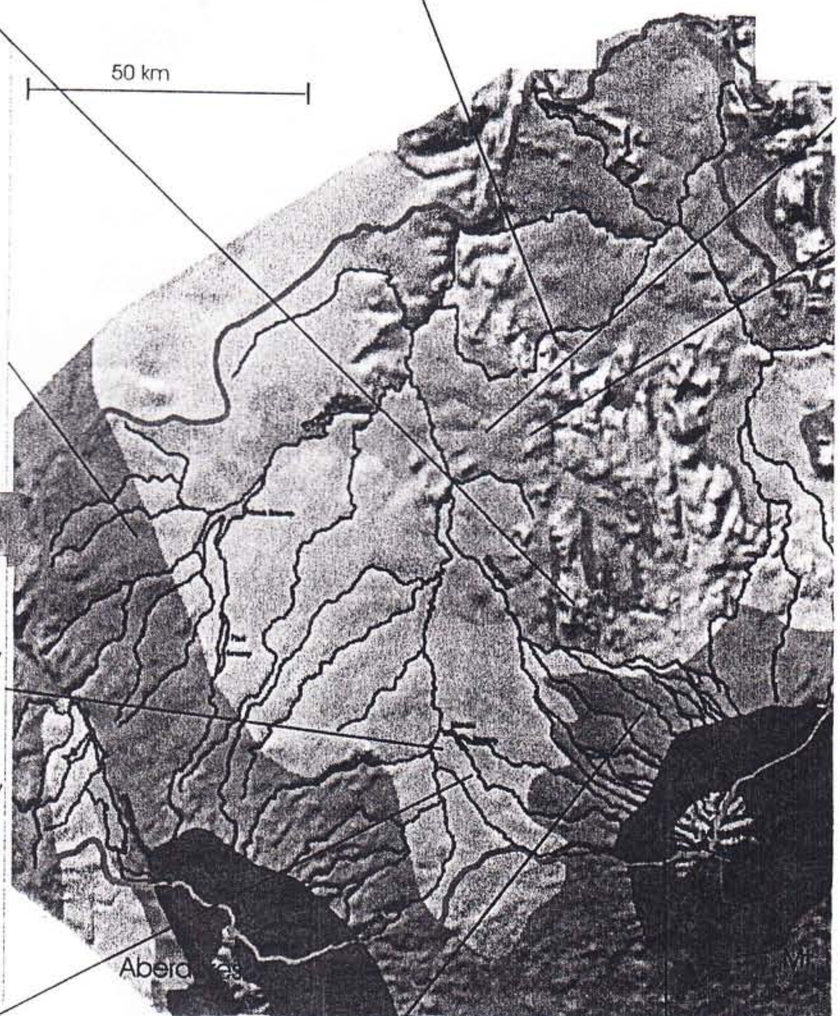
- semi-arid
- deep, accumulated reddish, sandy loams
- good water storage capacity
- medium fertility
- erodible (esp. for gully erosion) and prone to surface crusting when lacking vegetation cover
- suitable for natural tree/bush/grassland

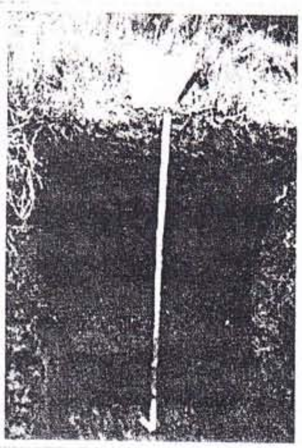




Sloping areas:
Leptosol

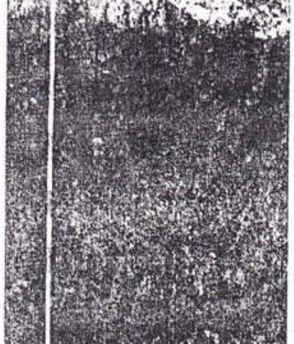
- various climates
- eroded
- very shallow
- very low water storage capacity
- not fertile
- barely suitable for trees/bushes and grasses





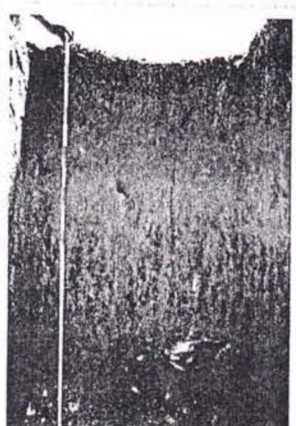
Plateau (flat or concave) depressions:
Vertic Luvisol/Phaeozem, Vertisol

- semi-arid
- deep, dark brown to black
- swelling/slightly cracking clay
- top horizon deep and self-mulched
- high water storage capacity
- marginally suitable for crops
- often combined with *Accacia drepanolobium* and grassland



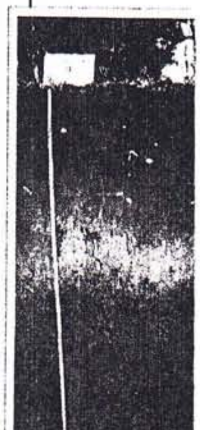
Plateau (convex) on elevations:
Luvic (to verto-luvic) Phaeozem

- semi-arid
- deep, brown grey clay
- profile not washed through by rain water
- high water storage capacity
- fertile
- marginal to unsuitable for rainfed crops
- good for grassland



Lower mountain slopes Mt. Kenya/Aberdares:
Luvisol/Acrisol

- semi-humid to semi-arid
- deep, clay
- clay concentration in B-Horizon (Profile washed through)
- high water storage capacity
- fertile
- erodible
- very suitable for cropland, grazing land and forest



Major Soils

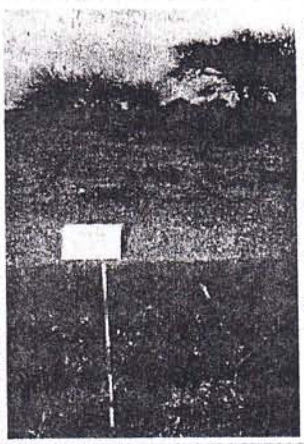
of the Upper Ewaso Ng'iro Basin

Concept / analysis: HP. Liniger
GIS compilation / layout: G. Schwilch
Data source: T. Kingl 1996, Kenya soil survey 1980, J. Mbuvi and G. Kironchi 1994
Photos: HP. Liniger, G. Kironchi

- Alpine region: Regosols, Leptosols (shallow)
- Upper mountain slopes: humic Andosols (medium deep to deep)
- Lower mountain slopes and ridges: Acrisols, Luvisols, Nitosols (deep or eroded)
- Plateau:
  - on elevations: luvic Phaeozems (deep)
  - in flat depressions: vertic soils (deep)
- Swamps: dark Gleysols
- Hills, mountains, scarps: red /brown Cambisols (shallow - med. deep)
- Footslopes of hills / mountains: red accumulated soil (very deep)
- Plateau, plains:
  - on ridges, elevations: Lixisols (medium deep or eroded)
  - in depressions: vertic soils (deep)
- Rivers
- Ewaso Ng'iro Basin boundary

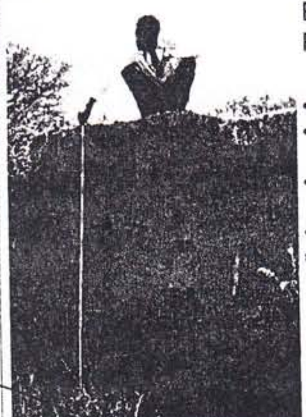
Plateau (convex) on elevations:
Lixisol

- semi-arid
- medium to deep, sandy loam
- medium to good water storage capacity
- medium to low fertility
- erodible when lacking cover
- ➤ suitable for grass/bush land



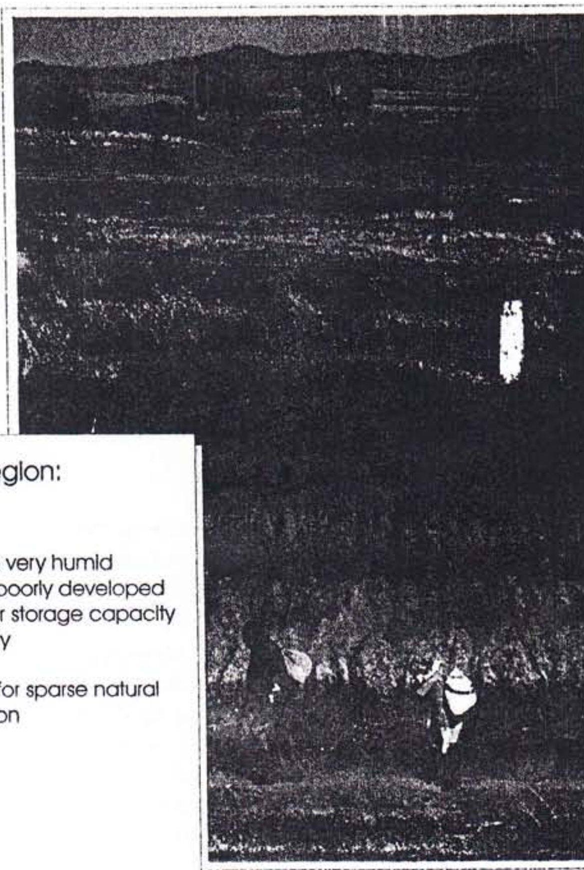
Gentle to moderate slopes with no cover:
leptic Lixisol

- semi-arid
- eroded
- shallow to medium deep, sandy loam
- low to medium water storage capacity
- low fertility
- ➤ poor vegetation cover, sparse grasses and bushes



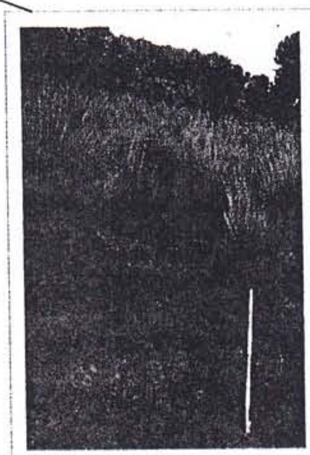
Bottomlands:
Fluvisol

- semi-arid to arid
- accumulated, deposited materials
- good water storage capacity
- fertile
- ➤ natural riverine vegetation



Upper mountain slopes:
Humic Andosol

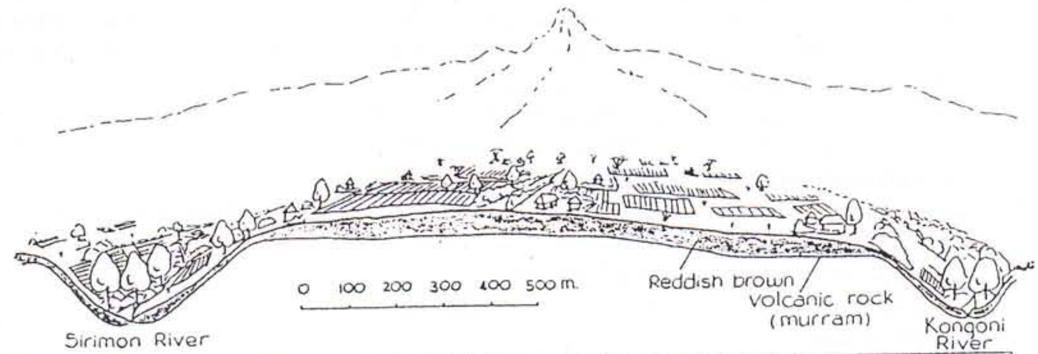
- humid
- deep, clay
- well-developed
- high organic matter (black topsoil)
- high water storage capacity
- medium fertility (acid)
- erodible
- ➤ suitable for natural vegetation (forest), limited crop production (potatoes)



Alpine region:
Regosol

- humid to very humid
- shallow, poorly developed
- low water storage capacity
- low fertility
- erodible
- ➤ suitable for sparse natural vegetation

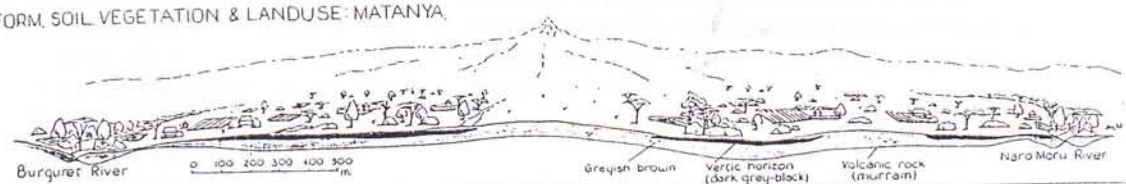
LANDFORM, SOIL VEGETATION & LANDUSE: KALALU



SLOPE %	15-20 ▷ ◁10-20		◁20-35	◁ 3-6 ◁0-2▷ 4-6 ▷	20-35▷	15▷	◁15-20
SOIL DEPTH	Medium		Shallow	Very deep	Shallow	Medium	
SOIL TYPE	Eutric Cambisol, Chromic Luvisol		Eutric Regosol	Ferric Luvisol	Eutric Regosol	Eutric Cambisol, Chromic Luvisol	
EROSION (E) DECOMPOSITION (D)	E/D	E	E	No erosion	E	E	D/E
VEGETATION & LANDUSE	Forest	Grazing, Crop	Woodland Grazing	Mainly crop land	Woodland, Grazing	Grazing, Crop	Forest

• Classification KENYA SOIL SURVEY DESAULES 1986.

LANDFORM, SOIL VEGETATION & LANDUSE: MATANYA



SLOPE %	◁▷ 0	◁5	◁ 1-3	2 ◁0-1▷ 3-4▷	1▷	◁1 ◁0-1▷	1-2▷ ◁-3▷0	◁4-5
SOIL DEPTH	very deep	shallow	moderate-very deep	very deep	very deep		moderate-very deep	
SOIL TYPE	± Gleyic Cambisol, Luvisol	Regosol	Vertic Luvisol ↔ Verto-luvic Phaeozem	Haplic-luvic Phaeozem	Verto-luvic Phaeozem ↔ Vertic Luvisol	Haplic-luvic Phaeozem	Vertic Luvisol	± Gleyic Cambisol, Luvisol
EROSION (E) DECOMPOSITION (D)	D/E	E	Sheet and gully erosion	No erosion	few gullies	no erosion	sheet gully erosion	D/E
VEGETATION & LANDUSE	Forest	Mainly open woodland (accacia drepanolobium) and crop land		Grass land	Dense-open woodland (accacia drepanolobium) and crop land			Forest

Classification KENYA SOIL SURVEY DESAULES 1986

Figure 4. Soils and land use in Kalalu (in the lower mountain zone of Mt. Kenya) and Matanya (on the volcanic plateau)

However, if soil cover is reduced, these red soils are highly susceptible to surface crusting and sealing. The vertic properties of the soils on the plateau also include high fertility and storage capacity but the workability is restricted due to stickiness when wet and hardness when dry. Furthermore, the rainfall is already critical for rainfed agriculture. These soils create a management challenge associated with tillage and accessibility of these areas during the rainy seasons.

For the soils of the **basement complex**, the following management challenges occur: The soils on the footslopes of the hills and scarps are extremely susceptible to gully erosion if runoff water builds up on the higher slopes. Surface sealing and crusting of the soil presents the greatest challenge to all the soils on gentle to steep slopes. When soil is not covered by vegetation or dead material, the surface becomes very hard, reducing water infiltration. The consequences are high runoff losses, erosion, low seed germination, or poor development of the seedling. There is a vicious degradation cycle that ends in very bare areas where rainfall cannot infiltrate, vegetation cover cannot be restored, and soils become eroded (Liniger and Thomas 1998).

4. Impact of land use and soil management

4.1 Rainfall, runoff and soil water

A comparison of rainfall, evaporation, and runoff water availability for the soils in the 3 zones (upper and lower mountain zone and semi-arid plateau) is presented in Figure 5.

In Karuri on the upper mountain slopes of Mt. Kenya (Figure 5 left), there are clear periods of water excess during the long rains (April - May) and the short rains (October - November). On grassland with good vegetation cover there is very little runoff, whereas between 20-45% of the rainfall was lost from the cropland in the heavy rainfall event during the long rains. Soil moisture showed little variation during the year and between the treatments. Basically, water supply was sufficient, except in the dry season of January to February.

In Kalalu on the lower mountain slopes of Mt. Kenya (Figure 5 middle), there were also periods of excess water, although fewer than on the upper mountain slopes . Runoff during heavy storms was very high, often around 40 - 60% on overgrazed areas. On cropland with good cover, e.g. mulch there was no runoff, whereas under local treatment with less cover, runoff can exceed 30 % of the storm. Soil moisture in this zone clearly shows the difference between the dry and wet seasons and the role of deep soil in storing water during the wet season and making it available during the dry season. Furthermore, the effect of the land use is very striking in this zone. Mulching conserves more water and makes it available for the crops (see below). There is also a marked difference between cropland and grazing land. Grazing land has less water available in the soil.

In the semi-arid plateau on the basement soils of Mukogodo (Figure 5 right), rainfall is about half of that in Kalalu and 40% of the amount in Karuri. In addition, the evaporation rates are almost double those on the slopes of Mt. Kenya. The result is a serious water deficit. This is made worse by the high runoff from soils that are not well covered. Bare soils, which are common in this area, generally lose between 40 and 80% of rainwater to surface runoff (see below). Soils with some cover have the capacity to store water and make it available for the plants. There is little variation in soil moisture during the year under bare soils. Soils with some perennial grasses have the ability to recover and produce biomass during the rainy season (as indicated by the change in the soil cover).

Comparing the 3 different zones, it can be said in summary that as rainfall declines towards the lowlands, the soils play a greater role in storing excess rainfall water during single events and make the water available to plants. The very deep soil at the lower mountain zone of Mt. Kenya has the greatest capacity to store water and to "stretch" the water supply. The soil on the dry plateau in many cases has a greater capacity to store more water than utilized, due to high evaporation loss and high runoff.

4.2 Influence of forest and crop production on water yield in the Mt. Kenya forest zone

Mountain forests and their deep soils play a role in collecting water and releasing it to the river flowing from Mt. Kenya and the Aberdares to the semi-arid and arid lowlands. Vegetation and land use types have a great influence on the water cycle, especially on steep, erodible mountain slopes.

A comparison of natural forests with forest plantations and cropland on Mt. Kenya showed that the soil under cypress plantation was the driest, as the water was used up much faster than under natural forest (Figure 6). Rainfall did not recharge the soil pro-

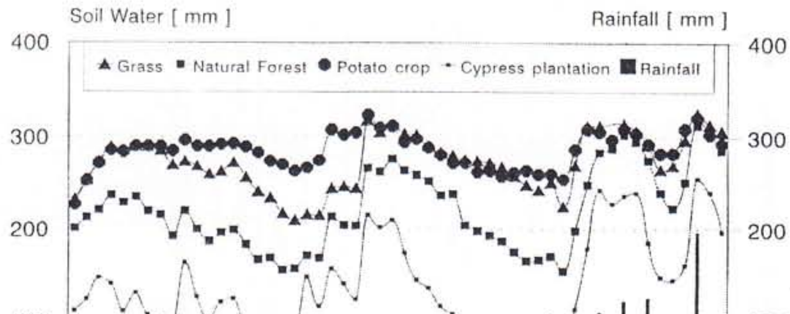


Figure 6. Soil water under different land use / vegetation systems in the lower forest belt of Mount Kenya (at 2400 m a.s.l.); November 1991 to May 1993 (Source: Njeru and Liniger 1994)

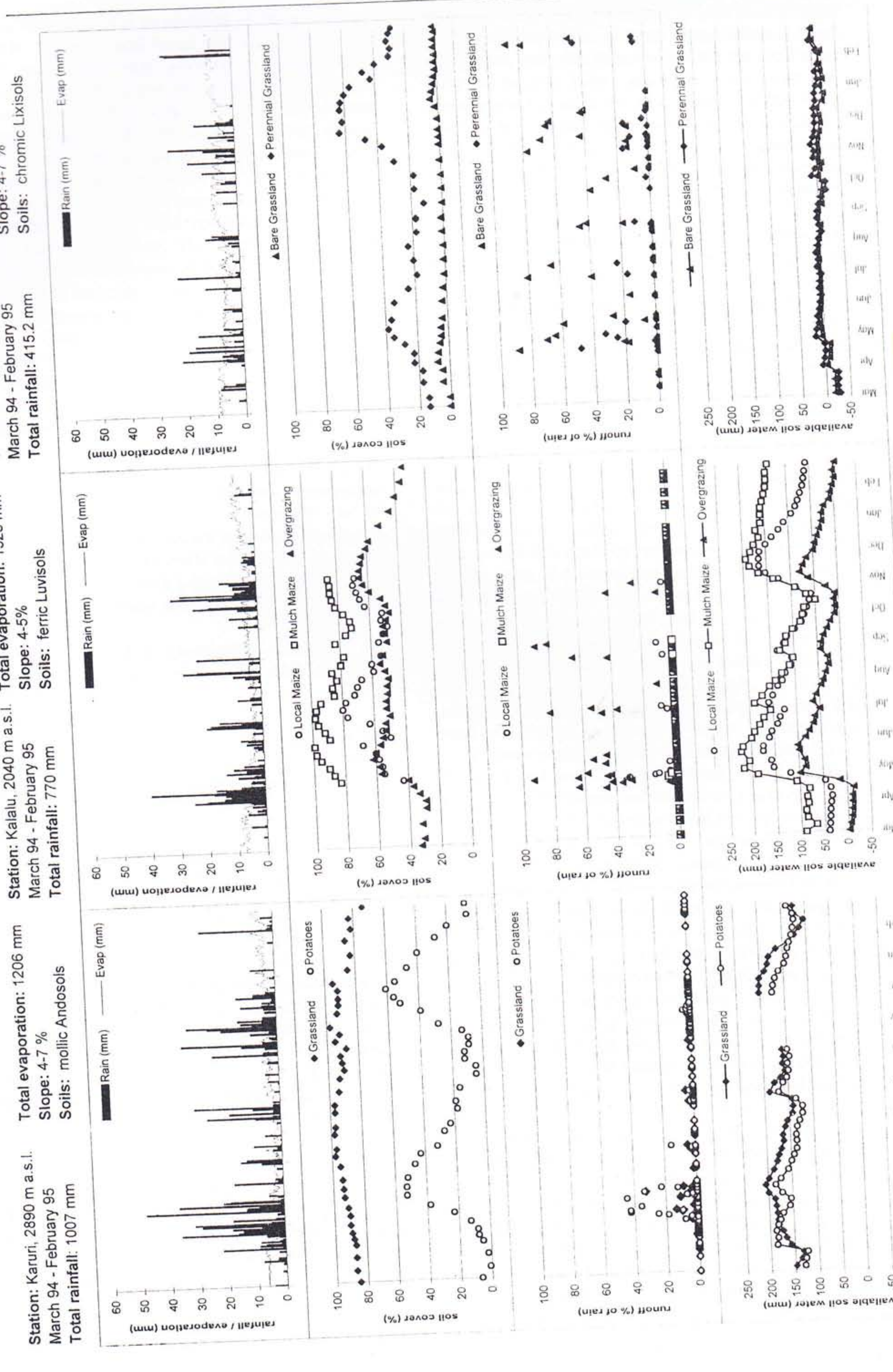


Figure 5. Overview of rainfall, soil cover, runoff and soil moisture in 3 major zones (Source NRM^3 database, Kironchi 1998)

file and thus there was no recharge of the groundwater table. Under natural forest, the soils were much wetter and there were periods of groundwater recharge. However, under crops (e.g. potatoes) the soils were even wetter, with the highest groundwater recharge. Although surface runoff occurred during heavy storms, cropland still provided the greatest contribution to groundwater and river flow. There are many questions about the long-term effects of land use on the water and land resources (Liniger and Weingartner forthcoming). The change from natural forest cover to other types of land use (often called deforestation) has often been associated with destruction and degradation of natural resources. This is based on observations and research findings which show that in the first years of land use change (e.g. from forests to agriculture), when the vegetation cover is removed and the topsoil disturbed, high runoff and soil erosion rates occur. However, after the first years of transition, the negative impacts are reduced as improved management practices take effect (Hamilton 1987). Soil cover, land management, and conservation practices are important for sustainable use of resources. Agricultural systems have been developed in mountains all over the world without destruction of natural resources and with a locally well-adapted sustainable system of water and land use.

4.3 Intensification of crop production and agroforestry in the lower mountain slopes and the adjacent plateau

This is the zone where cropland has been expanding over the last 3 decades. Since soils have been identified as very suitable for crop production and have a high storage capacity, and the climate is only marginally suitable for crop production, water has to be used in the most efficient way.

Figure 7 shows the results of a comparison between maize grain production under a local treatment and a conservation method using mulching with minimum tillage (with a cover of around 3 t/ha of maize residues). Results are presented for 12 years in the semi-arid to semi-humid lower mountain zone of Mt. Kenya (Kalalu) and the semi-arid highland plateau (Matanya) for the most commonly used maize varieties. Kalalu has higher seasonal rainfall partly because of the longer crop growing season, from March to September, while Matanya has two short crop growing seasons, from March to August and September to February. Kalalu generally has higher maize yields than Matanya due to differences in rainfall regimes, length of growing seasons, and variety differences. However, the seasonal variation is extremely high. During very high rainfall seasons, both treatments produce high yield, and during extremely low rainfall seasons both treatments fail. Apart from these extreme seasonal variations, mulching treatments generally produced higher yields than local treatments (no mulch) at both sites (Liniger 1991), with the effect of water conservation in "normal" years, and with differences when the local treatment led to crop failure and mulching at least produced a yield of around 1 t/ha or more. At the semi-arid site this was the case in one-third of the seasons. The main effect of the mulch treatment conservation method is to reduce direct evaporation loss from the soil surface, which is between 40 to 60% of seasonal rainfall.

Land use analysis showed the rapid increase of agroforestry systems in the lower mountain zone of Mt. Kenya and the highland plateau. Trees have been planted in and mainly around cropland. There are several uses for trees, including windbreaks, timber, shade, marking of plot boundaries, etc. Another use is to provide mulch material so that more crop residues can be fed to the animals. However, trees also need water and are likely to compete with crops. Another long-term experiment revealed the competition of trees with crops and the possibilities for improving tree management and thus reducing this competition. Figure 8 illustrates how *Grevillea* trees and locally used live fences compete with maize crops, and how this competition could be reduced by seasonally pruning the roots of the trees and the live fence. But there are additional labour costs involved in pruning the roots. These were measured and compared with the additional benefits of increased yields. In Figure 9, the results are presented over several seasons, showing that in the more suitable zone of Kalalu, the benefits are generally much higher than the costs. For the semi-arid zone, the workload is higher due to heavier soils (vertic properties) and the increased risk of crop failure. In the event of such failures, farmers' investments cannot be recovered. However, other socio-economic and cultural issues involved are important with regards to small-scale farmers' acceptance of new technologies and further development of their own water conservation methods (see Wiesmann 1998).

Given the high variability of the climate and the soils, it is very expensive to set up trials for crop and grass production at different sites. Furthermore, it is very difficult to extrapolate the results over the last 20-30 years. Long-term monitoring sites have been established for setting up and calibrating models that can be applied to identify the potentials of different management and plant varieties under different natural conditions. Figure 10 shows that seasonal rainfall is not sufficient information to predict crop yield because the distribution of the rainfall within the seasons is a major factor affecting yields. Models are currently being developed to help as planning and decision-making tools, to improve crop and grass production and to minimize the risks of failures and degradation of the environment (Njeru 1998). A major question is how far crop production can be pushed into the dry Laikipia plateau with different conservation technologies, and what risks are involved.

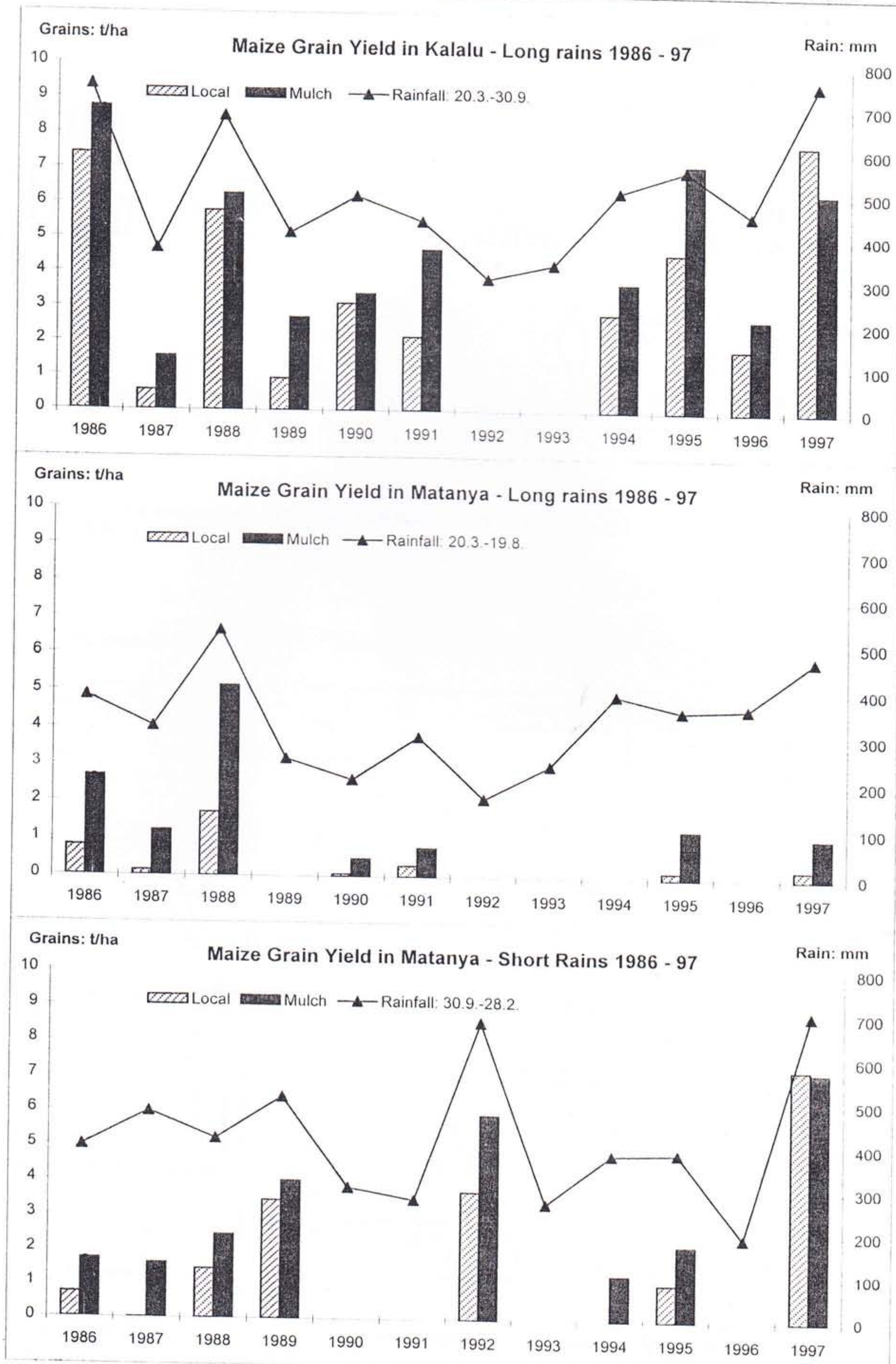


Figure 7. Maize yield variation over 12 years, with and without mulching in Kalalu and Matanya

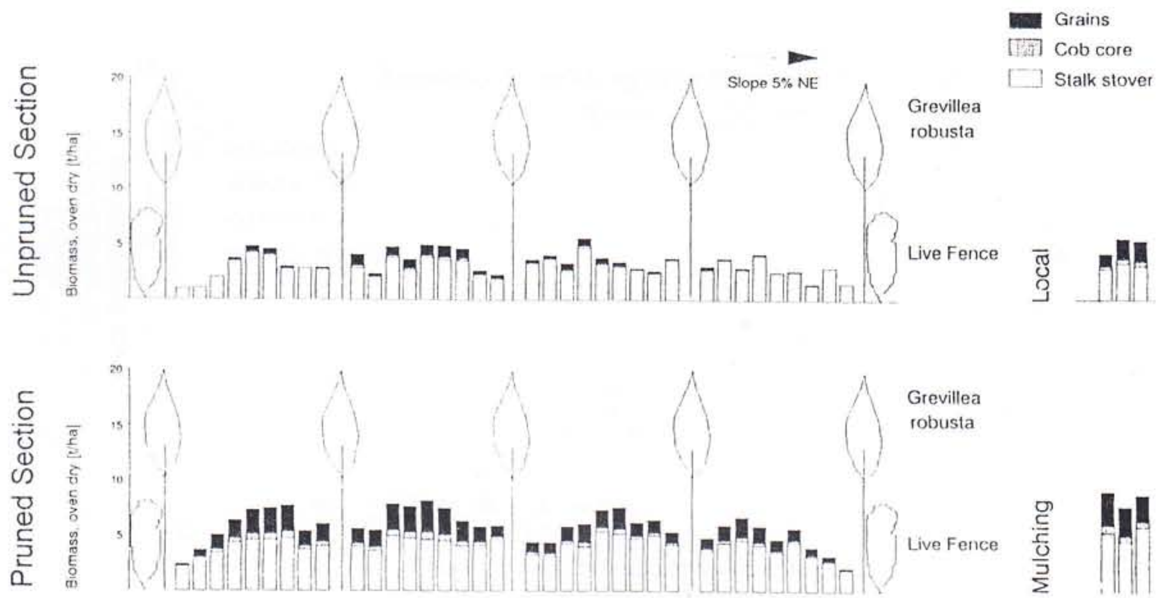


Figure 8. Agroforestry and competition with crops in Kalalu. Average for 1989 - 92
(Source: NRM[3] Database)

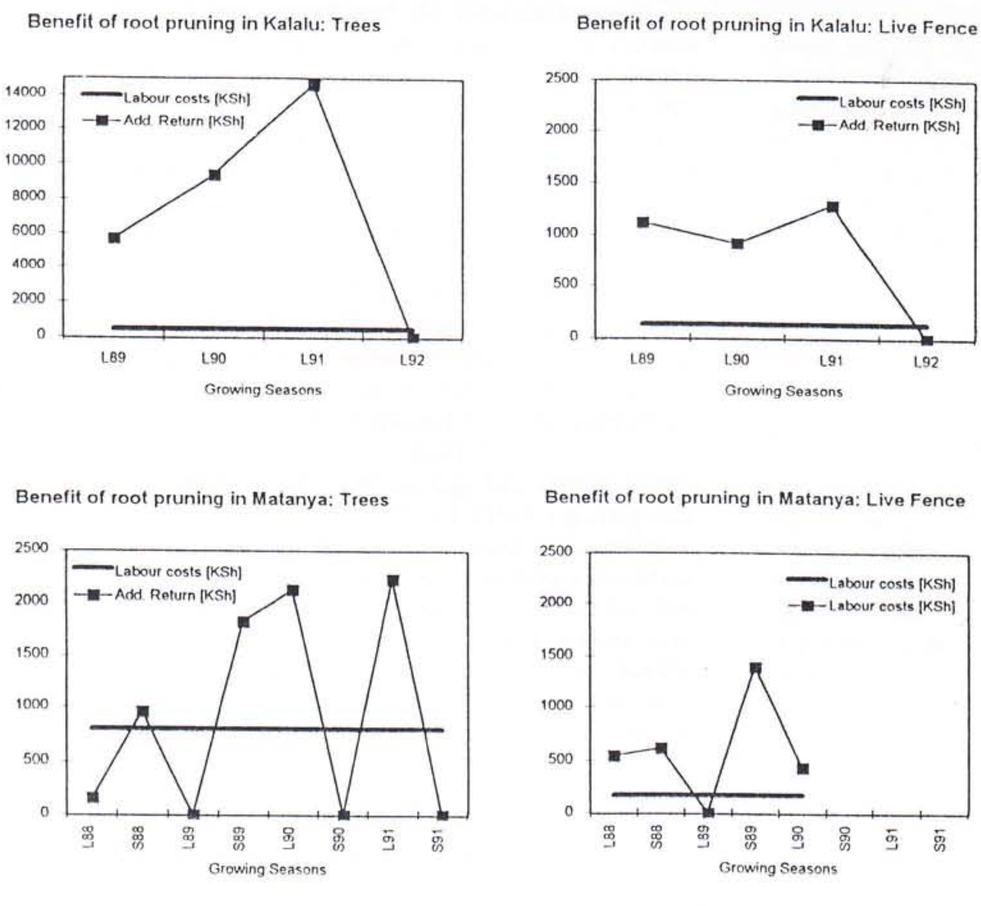


Figure 9. Cost and benefits of root pruning of agroforestry trees and live fences (in Kenya shillings) for different seasons (S: short rains, L: long rains)

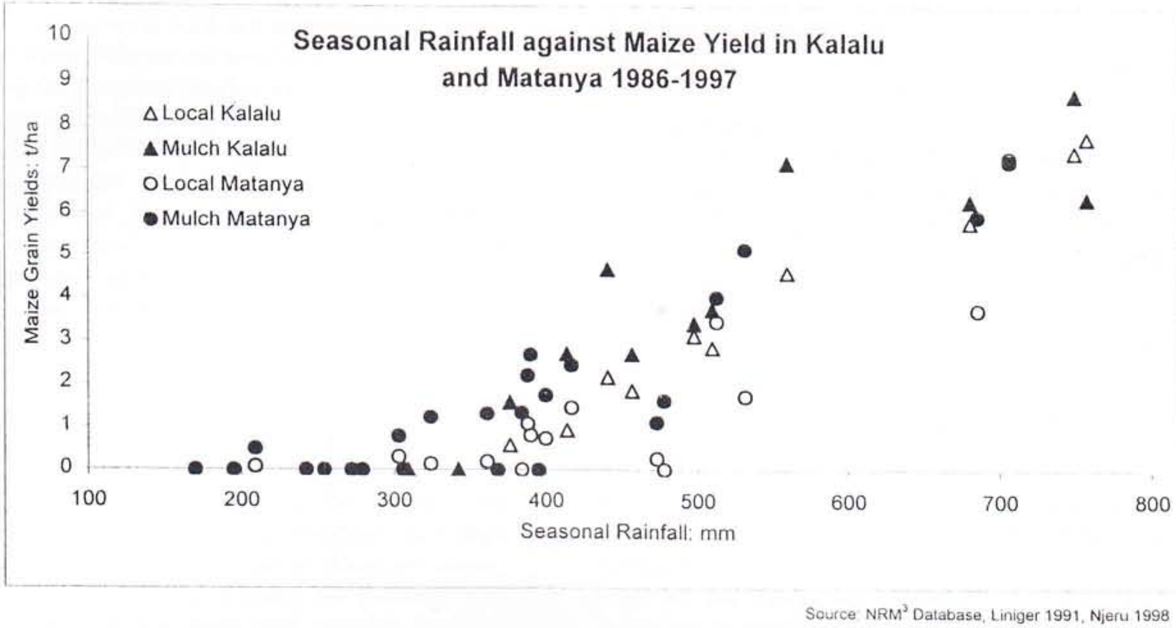


Figure 10. Correlation of seasonal rainfall and maize yield production

4.4 Importance of grass cover in the plateau and lowlands

As previously mentioned, the main challenge in the semi-arid plateau and the lowlands is to increase grassland productivity and to reduce degradation risks. Figure 8 in the paper by Gichuki et al. 1998b, shows the high amount of water being lost to the system during the heavy rains. Liniger and Thomas 1998 show how water loss through runoff and consequent erosion are related to the soil cover. There is a need to assure that a minimum soil cover of around 40% also remains during the dry season, and that the perennial grasses do not completely disappear due to extreme grazing pressure. Even though the area still has a good tree and shrub cover, the perennial grasses have disappeared over large areas, and the consequences for productivity and degradation are obvious.

Kinyua et al. (forthcoming) and Okello (1996) clearly demonstrate the effect of different grazing land conditions on productivity. If good grass cover is maintained, the annual production and the value of the fodder that is produced are several times higher than on an overgrazed area, where perennial grasses have almost disappeared. There is a need for GRASS: Ground Cover for the Restoration of Arid and Semi-arid Soils, as elaborated in Liniger and Thomas (1998).

5. Conclusions

Due to the high variability and scarcity of resources, there is a need to fine-tune any land (and water) use to the local biophysical as well as the socio-econonomic situation. No blanket or miracle solutions can be propagated.

However, the following considerations may be applied:

In all parts of the basin, vegetation and vegetation cover on the soil play a key role in the management of water, soil and vegetation. In and above the mountain forest zone, where the rainfall is higher than what is needed for vegetation, the main challenge is to store excessive water during the rainy seasons and release it with seasonal delays during the dry season to the lowlands. This entails keeping the surface of the soils under good cover and preserving maximum storage capacity. Below the forest zone, where there is a water deficit, the challenge is to conserve as much water as possible for vegetation and for human and animal use. Losses of water have to be minimized. This can be achieved by reducing surface runoff and loss by direct evaporation from the soil surface. For both aims it is paramount to have soil with a good cover and topsoil management that preserves good soil structure. Agroforestry, mulching, minimum tillage and other water conservation systems on cropland, and improved management on grazing land that offer higher productivity with less danger of resource degradation, provide opportunities for improved resource use and increased land productivity.

Maintaining or improving soil fertility, although not further elaborated in this paper, are other major aspects, since fertility is generally low on the basement complex and fertility mining is showing increasing constraints on the "naturally" fertile volcanic soils.

Sustainable soil management implies using the soil in a manner that does not compromise production capacity for future generations and does not lead to environmental problems downstream. African highland-lowland systems such as the Ewaso Ng'iro basin, pose a major challenge to sustainable resource use:

increasing pressure on limited natural resources in a very complex highland-lowland system with great resource variability as well as a wide variety of expectations among different resource users.

Reducing the potential conflict over resource use and the danger of resource degradation requires improved knowledge and practices in resource management. In order to optimize land management practices in a highland-lowland system that do not deprive downstream users, good local and regional knowledge, a good database, and suitable management tools are needed. The scarcer the resources, the better the knowledge and the management of the resources and their optimum use must be adapted to local situations. There are still plenty of opportunities to improve the use of land resources. The establishment of a Natural Resource Information System (NRIS) and applied research to improve local and regional resource use (see Gichuki et al. 1998a), and continued exchange and interaction between researchers, decision makers, planners and local resource users, are preconditions for sustainable development and meeting growing demands.

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