LUCID's Land Use Change Analysis as an Approach
for Investigating Biodiversity Loss and Land Degradation Project

Technical Report of Soil Survey and Sampling: Loitokitok Division, Kajiado District

LUCID Working Paper Series Number: 10

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A. INTRODUCTION

The purpose of this study was to examine soil characteristics along the agro-ecological gradient of the northeastern slopes of Mt. Kilimanjaro in Kajiado District, Kenya. The results of the soil analyses will be compared to results from a plant and land use survey, and land use change analyses conducted in the same areas (published in other LUCID working papers). By comparing the results of the various types of information, the LUCID project will determine the relationship between soil characteristics, vegetation, land use and land use change, and change in biodiversity.

For this study of soil characteristics, the author conducted a survey of soil erosion indicators and land use histories, and collected soil samples for fertility tests in plots along two transects in Kajiado District. The survey included characterization of soil erosion indicators in different land use types and in different agro-ecological zones (AEZ) along the ecological gradient from the highland forest on the Tanzanian border to the semi-arid rangelands in the lowlands. Since the study is focussing on human-induced land use changes, the transects were located to include swamps now under cultivation but not the Amboseli National Park. The location of the transects and the AEZ's are illustrated in Figure 1.

B. SITE CHARACTERISTICS

The Amboseli – Loitokitok transects are in the Loitokitok Division of Kajiado District. They lie on the slopes of Mt. Kilimanjaro. Besides differences in ecological conditions, land use and agricultural systems are structured differently across the zones. The District shows the typical agro-ecological profile of the leeward side of Mt. Kilimanjaro from the cold, wet upper zones to hot, dry zones of Amboseli.

Kajiado district had a total population of 500,000 in 1999 of which 145,000 people lived in Loitokitok Division. Population density has increased from 12 per km^2 in 1969 to 24 per km^2 in 1999 (MOARD, 2001). In Loitokitok Division, it increased from 7 to 15 per km^2 in 1979 and 1999 respectively (GOK 1999). Figure 2 shows the trend of population and population density for Loitokitok Division.

The District has an area of about 2.1 million hectares of which 0. 6 million hectares are in Loitokitok Division. About 168,000 hectares is arable of which 13% has potential for crop production. About 3% of the cultivated land, including 1% under irrigation, is in Loitokitok Division. The remainder of the land is suitable for grazing. There has been change in land use from pastoralism to agriculture and mixed agro-pastoralism following the sub-division of group ranches into private land holdings (Herlocker 1999). This is as exemplified in Figure 3, which illustrates declining livestock numbers from 1996 to 2001. Crops grown include maize, beans, tomatoes and onions. The uncultivated land is being used either for pasture for beef production or for wildlife conservation. Individually owned farms are large (up to 50 ha), but the cultivated portions within farms are variable. The district economy rests upon a combination of livestock production (44.1%), agricultural production (29.4%), and off-farm income sources (26.4%) as detailed by Katampoi et al (1990).

Figure 1: Agro-ecological zonation and the Amboseli-Loitokitok transects.

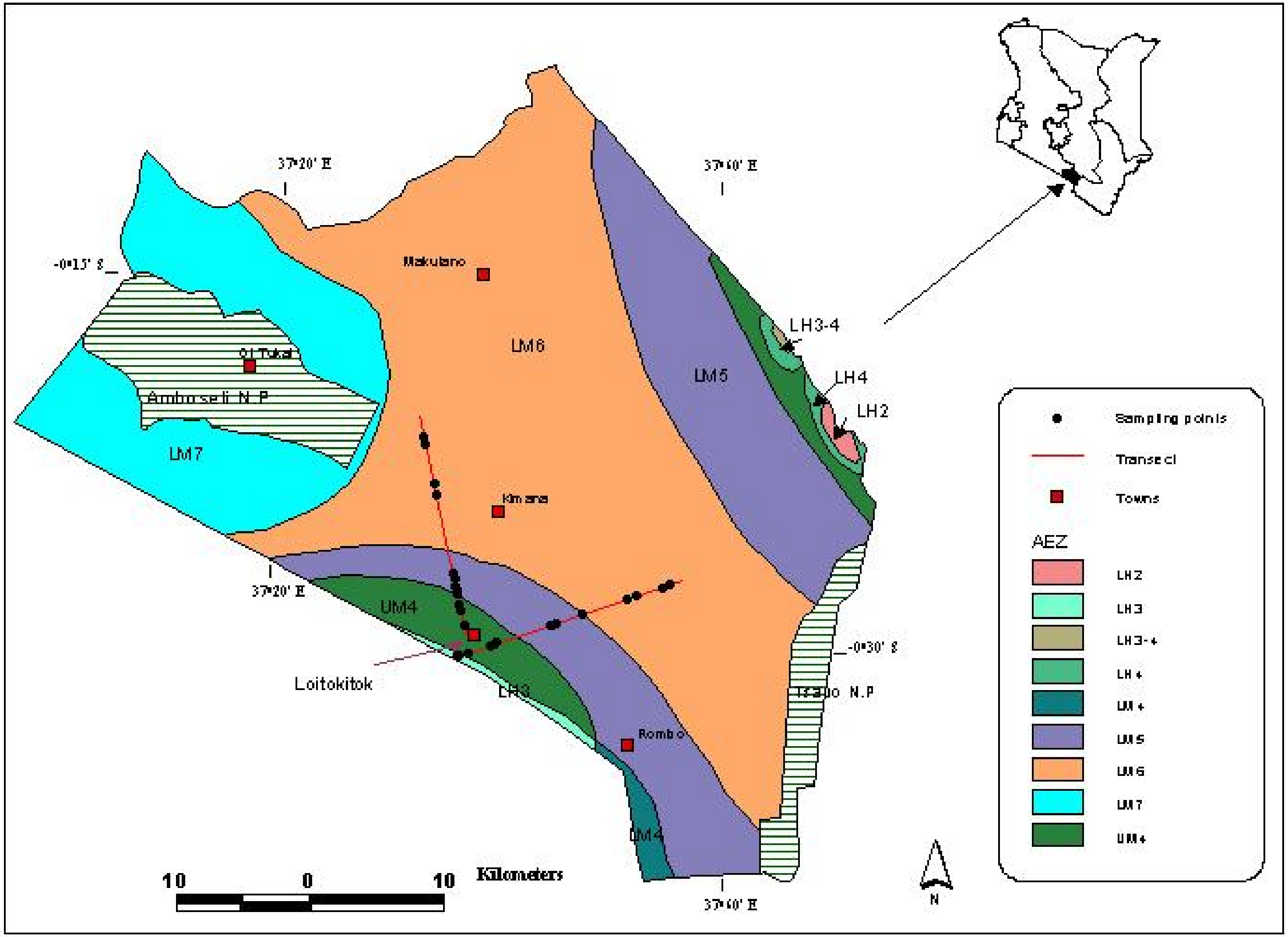
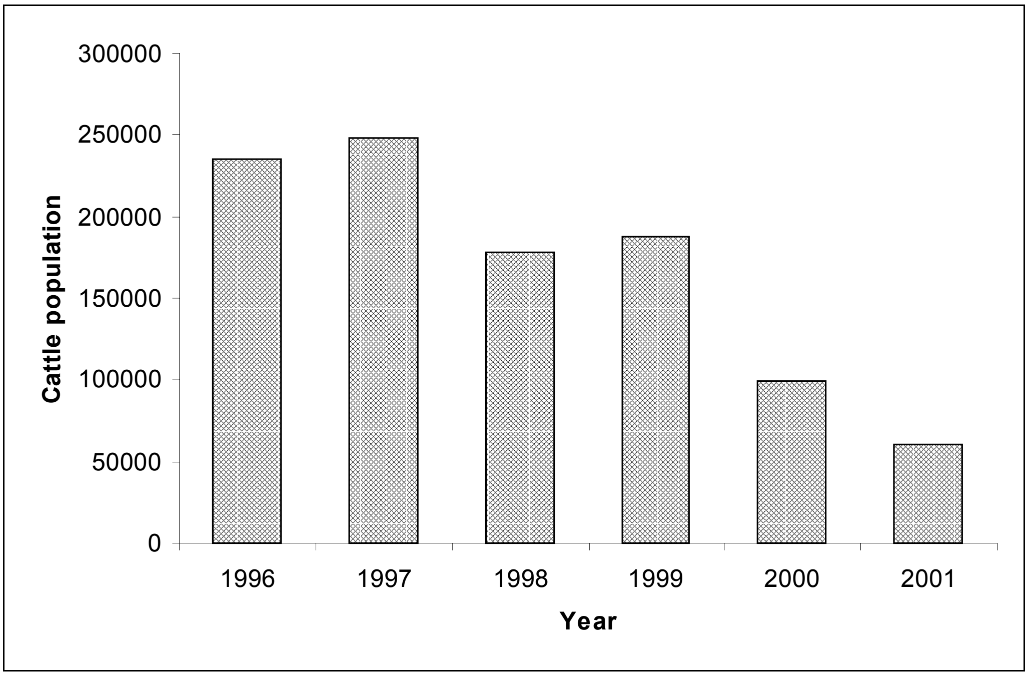


Figure 2. Population and population density for Loitokitok Division, Kajiado district, Kenya. Data source: GoK 1999.

Figure 3. Cattle population for Loitokitok Division, Kajiado District. Source: District Agricultural Officer (DAO), Annual Reports 1996-2001.



The climate is dry in most of the study area. Most of the area is located in agro-ecological zones LM5 and LM6 with a small part in zones LH3 and UM4. Average annual rainfall is between 475 and 750 mm. The rainfall distribution is bimodal with the long rains (March – May) being the most important and relatively reliable. The probability that rainfall is less than 2/3 of potential evaporation during the rainy seasons varies between 60 and 80% in most of the area (Braun and de Weg 1977). Mt. Kilimanjaro's foothills are bordered by irregular undulating volcanic uplands. The rest of the area consists of gently undulating plains and undulating uplands.

Bedrock and landform determine the distribution of soils. Moderately deep, firm clay soils have developed in the uplands with Basement System rocks rich in ferromagnesian minerals (Ferral - chromic Luvisols). On the plains, undifferentiated Basement System rocks have very deep, friable to firm, sandy clays. The Mt. Kilimanjaro volcanics show a complex of very shallow and rocky Lithosols, well drained, red, friable, clays of various depths (Chromic Luvisols) and imperfectly drained, dark coloured, firm, saline-sodic clays. On the lacustrine plains of the Amboseli basin, saline-sodic clay soils of varying depth and drainage condition have developed. The river alluvial plains have deep, well-drained, dark brown, sandy clay loan to clay soils or stratified soils and imperfectly drained, cracking clay soils (Luvisols to Vertisols). All these soils are partly calcareous, saline and sodic (Van Wijngaarden and Van Engelen 1985).

C. MATERIALS AND METHODS

C.1. Sampling strategy and soil sample collection

Sampling was stratified according to AEZ and land use class. Within each of the AEZ along the transects, the location of at least four points were randomly selected by computer (the points identified along the transect on Figure 1). Each of these points served as a midpoint for a kilometre long sub-transect that was perpendicular to the main transect. Twenty-three sub-transects were thus located, along which quadrants were chosen representing different land use classes. If a land use class was quite prominent in the AEZ but not sufficiently represented in a sub-transect, supplemental sampling was conducted. The one-kilometre length provided a distance long enough to include all major land use types and variability in soil units and landscape forms.

Each land use class was represented in the sub-transects with at least three quadrants. In the quadrants, vegetation species were surveyed and soil samples were collected. Composite samples from 0-20 (top soil) and 20-30 cm (subsoil) were collected. A total of 72 (36 top and 36 sub) soil samples were collected but due to budget constraints only the topsoil samples have been analysed. Since soil properties and laboratory measurements have inherent variation, it is necessary to sample at least in triplicate. It was therefore decided to collect soil from three locations in each quadrant and pool them for the analyses. Standard sample sizes were used for the individual samples. The choice of analyses followed the objectives of the study concerning soil erosion and productivity (soil nutrient amounts and related assessments) and their variability within the zones. Other information to be collected included the following:

1. Soil erosion indicators and their qualitative or quantitative assessments (see Appendix 1).
2. Information on land use history using a standard questionnaire.

Given the above, we developed a form and questionnaire that makes use of existing information, requires a minimum of resources, and results in a quantitative description of the variability of soil across AEZ and land uses.

C.2. Laboratory Analysis
The International Centre for Research in Agroforestry (ICRAF) analysed the soil samples as outlined by Okalebo et al (1993) and Heanes (1984). All samples entering the ICRAF laboratory received the following treatments:

- Air drying, breaking up of aggregates by careful pounding with pestle and mortar, sieving through 2mm sieve. Only soil that passes the sieve is analysed.
- pH: 2.5.1 solution: soil ratio: dionised water;
- EA, Ca,: 10:1 solution: soil ratio, 1MKCL extraction, analysis by NaOH titration (EA) or AAS (Ca, Mg);
- K and P: 10:1 soil: solution ratio, 0.5M $NaHCO_3$ + EDTA, pH 8.5 (modified Olsen) analysis by flame photometer (K) or colorimetrically by molybdenum method (P).
- Total organic carbon was determined by an improved chromic acid digestion.

D. **RESULTS AND DISCUSSION**
Each of the quadrants in Amboseli/Loitokitok were surveyed and sampled following the methodology described above. A total of 72 soil samples were collected. The results of only the topsoil samples are presented.

D.1. Land use
Traditionally, the rangelands of Kajiado District supported a pastoral subsistence economy and wildlife. This is due to low, erratic rainfall and short growing seasons. Unlike other areas in the District, the Loitokitok Division has higher agricultural potential with additional rain falling on the slopes of Mt. Kilimanjaro. The mountain slopes had been used as a dry season grazing area for Maasai communities before group ranches were developed. Due to the increasing population especially around Loitokitok town, agricultural activities have grown. Rainfed agriculture dominates but irrigated agriculture has also developed around the many swamps. In the lower midland zones, grazing by beef cattle and wildlife is dominant. Amboseli National Park provides a home for diverse wildlife species.

Land use varies within and between AEZ's as detailed in Table 1. The study transects ran from the Mt. Kilimanjaro forest to swamps in the semi-arid rangelands. Altitude decreases from the upper midland zones to the lower midland zones. This is associated with variations in other factors including population density, rainfall amount and intensity, and finally soil type. This pattern contributes immensely to variations in land use.

D.2. Soil fertility
Soil fertility decline (also described as soil productivity decline) is deterioration of chemical, physical and biological soil properties (FAO, 2001). The main contributing processes, besides soil erosion are: decline in organic and biological activity; degradation of soil structure; loss of other important soil chemical and physical qualities such as N, P, K and organic carbon; reduction in availability of macro-nutrients; and an increase in toxicity due to acidification or salinisation. In the study area, there is gradual decline of soil fertility nutrients P, K and organic carbon from the upper midland zones to lower midland zones as illustrated in Figures 3 and 4.

It has also been shown that soils in Sub-Saharan Africa have inherently low fertility and do not usually receive adequate nutrient replenishment in the form of mineral or organic fertilizer (Dudal 2002). Soil fertility in agronomic terms varies with land use and AEZ. The soil fertility data concerning phosphorus, soil organic carbon and potassium range from moderate to adequate throughout the main transect as seen in Table 1 and Figure 2 (ranges as defined by Mehlich et al 1964). Table 1 includes the average soil nutrient status by land use in each AEZ, the number of sample points (n), and the mean and standard deviation. Figures 2 and 3 show the average percent threshold level of each nutrient by land use class and by AEZ.

Table 1: Land use, pH, phosphorus (P), potassium (K), soil organic carbon (SOC), and erosion class by AEZ along the Amboseli-Loitokitok transect.

(a) Zone UM4

Land use	pH	P (Olsen) ppm	K (%)	SOC (%)	Mean Erosion class
Maize (n=8)	6.60	40.23	1.24	1.98	E1-E3
std dev	0.34	28.11	0.30	0.77	
Pasture (n=1)	7.3	38.9	1.53	4.08	E0
Fallow (n=1)	6.4	19.75	1.21	1.48	E0
Bushland (n=1)	6.2	25.3	1.38	2.04	E1
Irrigated (n=1)	6.6	15.6	1.4	1.48	E0
Woodlot (n=1)	6.6	13.6	1.34	3.39	E1
Mountain forest (n=1)	6.5	26.8	1.27	3.06	E0
Other grains (n=1)	6.4	11.9	0.86	1.55	E0
Grand mean	**6.58**	**24.01**	**1.28**	**2.38**	

Erosion indicators summary: *Slight sheet to moderate erosion. Evident yellowing of leaves in crop fields. Signs of nitrogen deficiency.*

(b) Zone LH3

Land use	pH	P (Olsen) ppm	K (%)	SOC (%)	Mean Erosion class
Coffee (n=2)	6.75	33.3	1.18	1.725	E0
std dev	0.21	7.78	0.03	0.25	
Pasture (n=1)	6.3	3.4	0.78	1.47	E1
Maize (n=2)	6.7	41.05	1.51	2.725	E1
std dev	0.14	24.96	0.10	1.01	
Other grains (n=1)	6.4	42	0.91	1.87	E2
Fallow (n=1)	6.5	3.6	0.94	1.47	E2
Grand mean	**5.47**	**24.72**	**0.90**	**1.71**	

Erosion indicators summary: *Variable rate of erosion. No erosion to severe sheet erosion. Exposed roots or rocks.*

(c) Zone LM5

Land use	pH	P (Olsen) ppm	K (%)	SOC (%)	Mean Erosion class
Maize (n=4)	6.48	27.68	1.49	1.36	E0-E2
std dev	0.41	12.25	0.19	0.70	
Fallow (n=1)	6.4	22.5	1.33	0.39	
Bushland (n=3)	6.43	57.33	1.51	0.87	E0-E3
std dev	0.35	64.35	0.58	0.49	
Grand mean	**6.44**	**35.84**	**1.44**	**0.87**	

Erosion indicators summary: *Moderate to severe sheet wash, rills to gully development in some areas. Some evidence of nitrogen deficiency.*

(d) Zone LM6

Land use	pH	P (Olsen) ppm	K (%)	SOC (%)	Mean Erosion class
Maize (n=2)	8.60	13.35	0.99	1.25	E0
std dev	0.42	6.43	0.28	0.12	
Irrigation (n=3)	7.39	13.44	0.86	1.08	E0
std dev	3.08	5.14	0.29	0.44	
Bushland (n=6)	6.75	37.55	1.12	1.07	E0-E3
std dev	0.26	20.18	0.48	0.57	
Woodland (n=1)	8	48.8	2.98	3.29	E0
Pasture (n=2)	8.10	37.30	1.40	1.10	E1
std dev	0.00	19.52	0.13	0.40	
Grand mean	**7.77**	**30.09**	**1.47**	**1.56**	

Erosion indicators summary: *Erosion range from, no evidence of erosion. Occasional severe sheet erosion. There is evidence of soil nutrient deficiencies observed from crops.*

Figure 4: Percent threshold level of phosphorus, potassium and soil organic carbon (SOC) for the various land uses by AEZ.

Figure 4a. Zone LH3

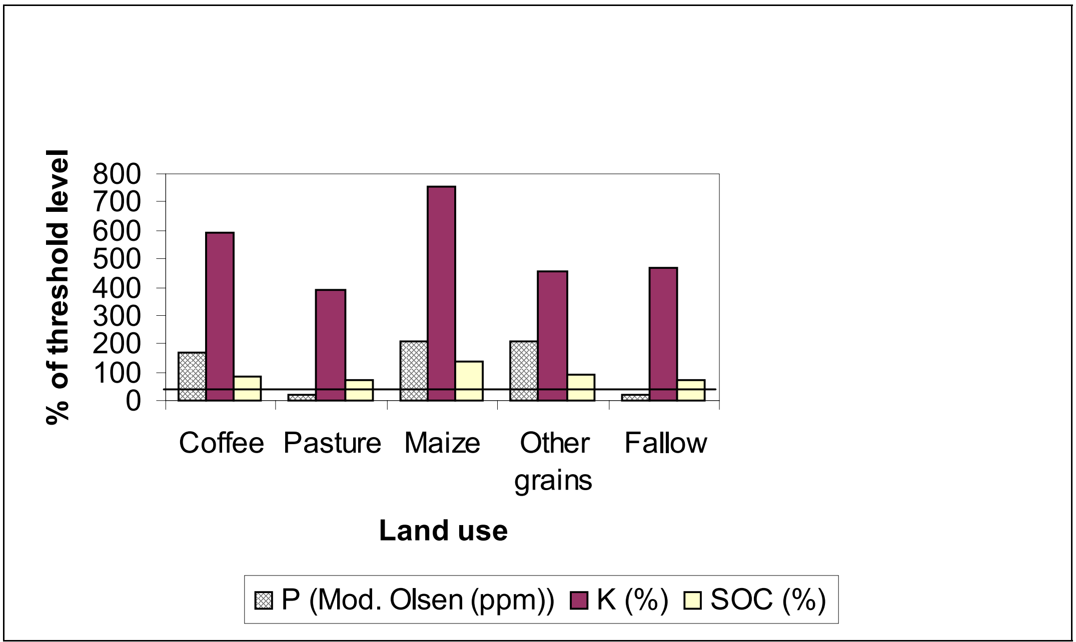


Figure 4b. Zone UM4.

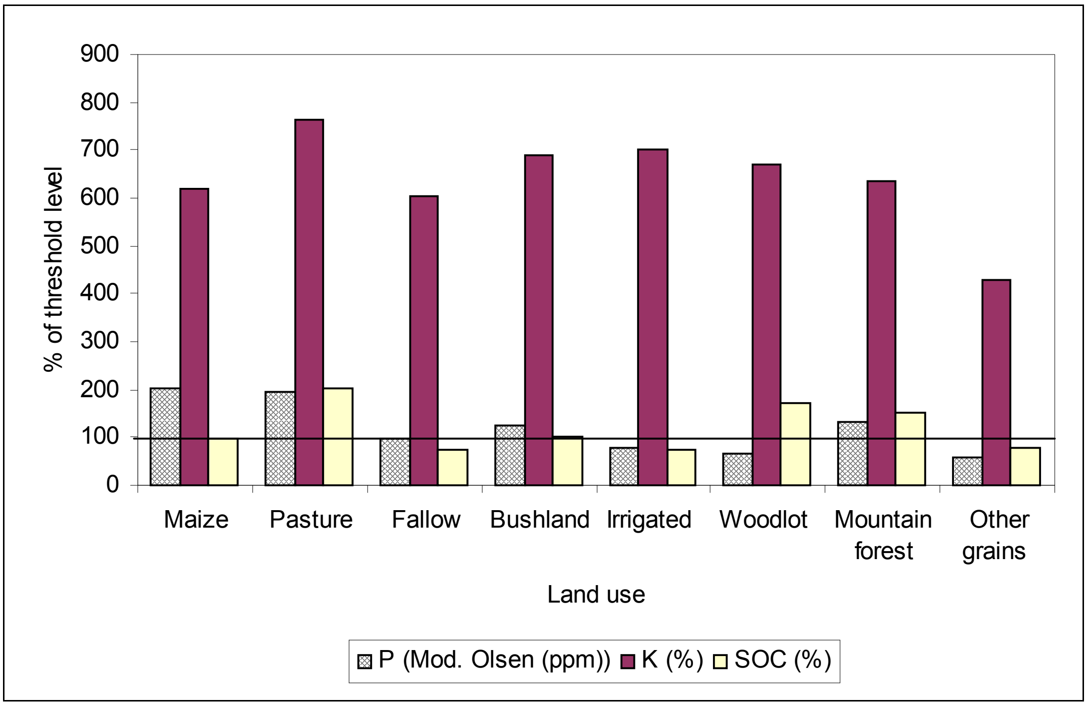


Figure 4c. Zone LM5.

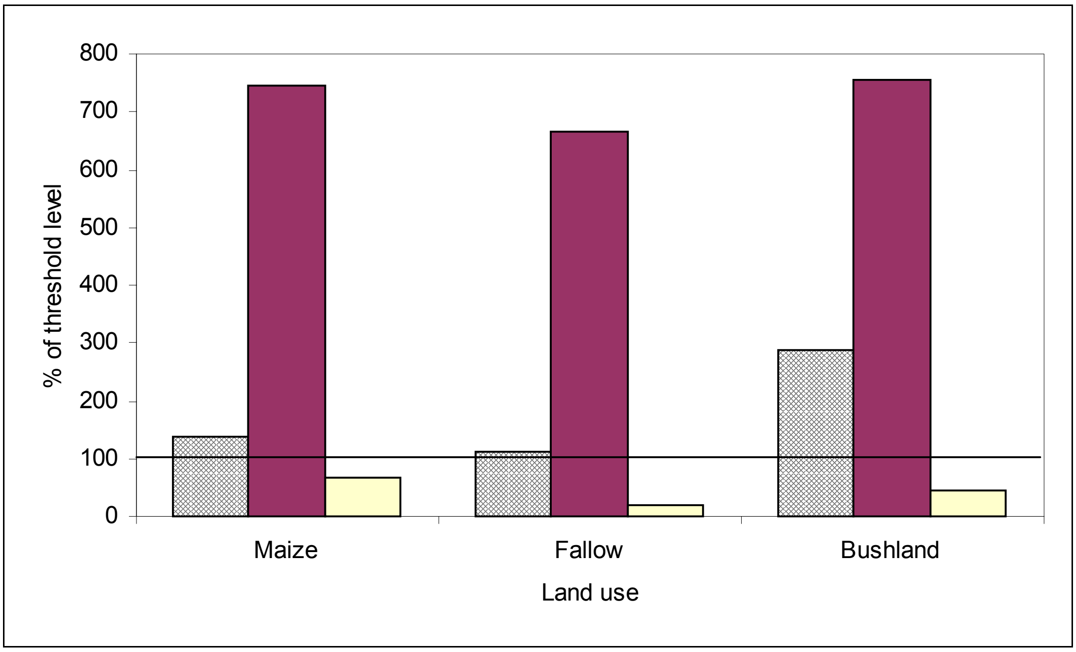
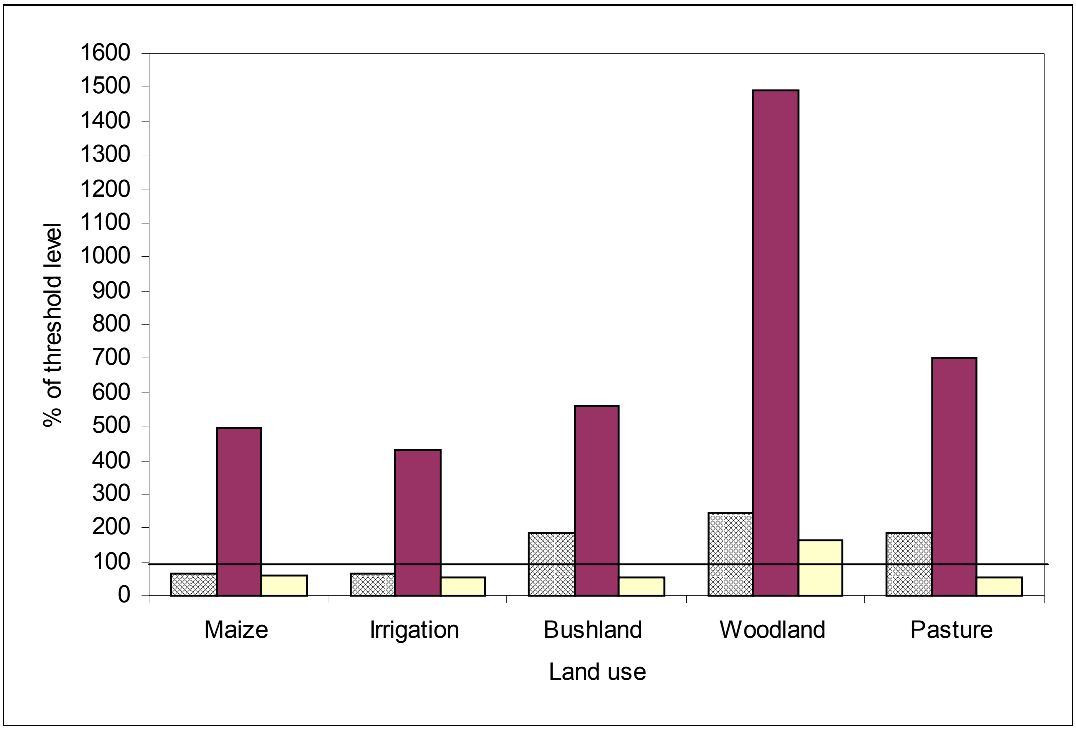


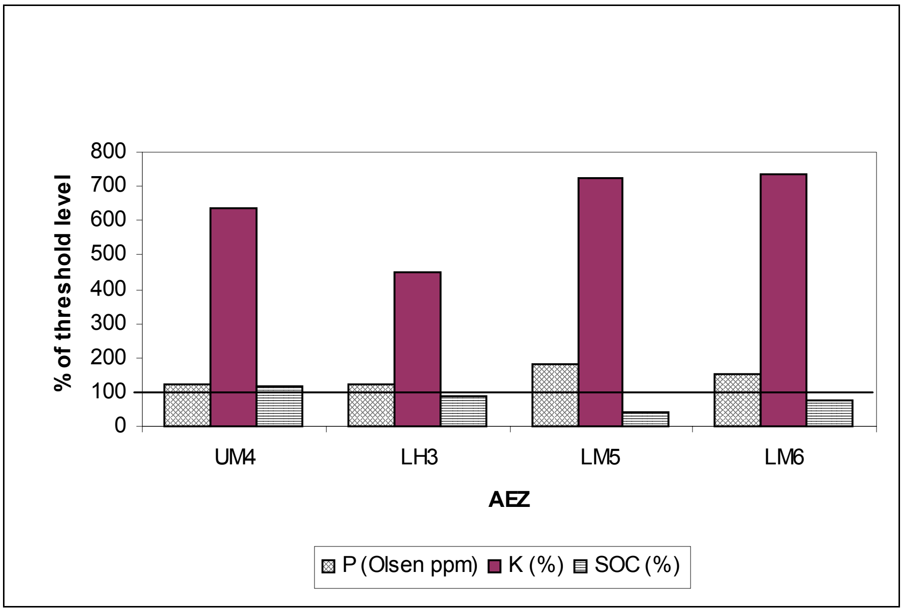
Figure 4d. Zone LM6 .



This is calculated by dividing laboratory-measured values by specific nutrient critical value multiplied by 100. Specific critical nutrient values were determined by Mehlich et al (1964) and modified by Legger (1980). Appendix 1shows classes and nutrient critical value defined for available nitrogen, phosphorus, potassium and organic carbon (SOC).

In most cases across all AEZ, nutrient levels are generally adequate. Within AEZ's, however, there occur nutrient variations between land uses. Soil organic carbon (SOC) and phosphorus (P) are generally low in cultivated areas, e.g. maize, coffee, and in crops in irrigated areas. (Figure 2a to 2d). This is due to continuous cultivation and a high mineralisation rate of soil organic carbon prompted by high temperatures and adequate moisture. The low P and SOC levels are due to continuous nutrient mining through crop products without sufficient replenishment in the form of fertilizers or farmyard manure. High soil nutrient levels are due to the presence of many weatherable primary minerals, which occurred during volcanic ash enrichment of chemically poor soils or during rock formation. The soils have inherent high K reserves as observed by Legger and van der Pouw (1980). K levels are adequate in agronomic terms from the upper to lower zones. Potassium (K) soil stock in the semi-arid areas range from 18000 t/ha compared to the phosphorus and nitrogen stock of 50-3600 Kg/ha respectively (Gachimbi et al 2000). However, the stock is threatened by nutrient mining through continuous cultivation and erosion.

Figure 5. Percent threshold level of phosphorus, potassium and soil organic carbon (SOC) for various land uses by AEZ along the Amboseli-Loitokitok transects



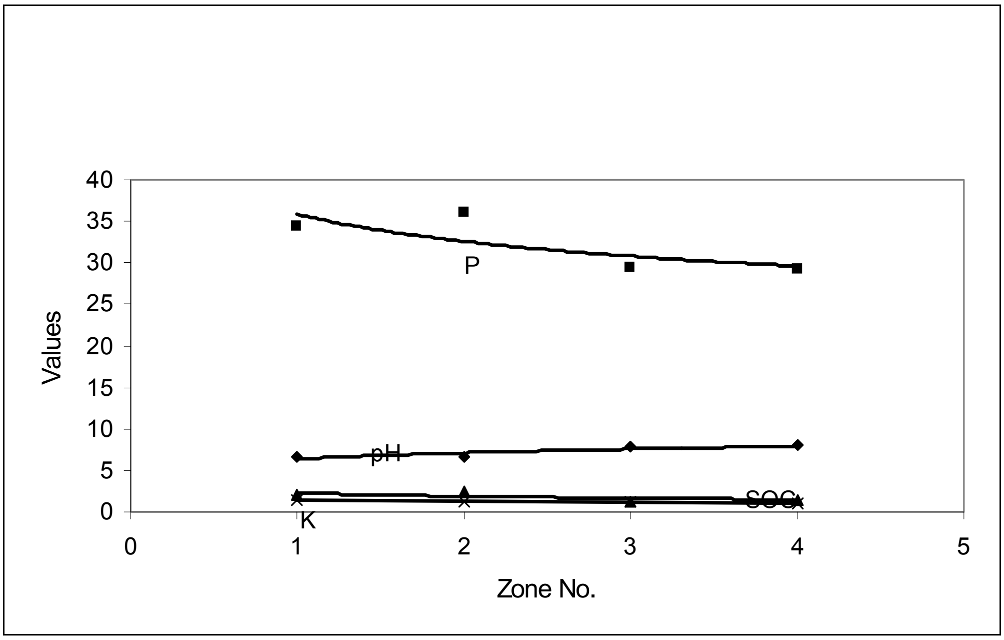
Soil pH ranges from slightly acidic to moderately alkaline in the lower zones (Figure 4) (ranges as defined by Legger (1978)). This range makes most crop nutrients available to the plants when required. This was also evident by visual observation in the field.

The P-status map shows adequate to low values (agronomic terms) for the soils in the upper to lower zones (UM3 to LM6). The soils in the plains show a characteristic wide range in available P, viz. from moderate to high. This reflects that strongly weathered soils of the non-dissected erosional plains and the weakly weathered soils of the plains, both on gneisses, have a low P-status. The same low levels of available P were recorded in some of the strongly weathered soils in lower zones.

The K-status shows a clear pattern. Adequate levels of available K are recorded in all AEZ (UM4 to LM6) (Figures 2 and 3).

The distribution of soil and its nutrient status is largely determined by parent material and physiography. Lower highland/ upper midland zones have moderately deep to very deep soils while the plains have shallow soils (as detailed in Table 1). Most volcanic soils from Mt. Kilimanjaro are deep and well drained. However, imperfectly drained soils were found along the plains and bottomlands where alluvial deposits are common.

Figure 6: Variation of pH, phosphorus (Olsen), potassium and soil organic carbon (SOC) with land use and AEZ in Amboseli- Loitokitok transect.



D.3. Erosion status across different land uses and AEZ

Methods of assessing erosion hazard are based on predicted soil losses as estimated by modelling climate, soil erodibility, slope, and vegetation factors (FAO, 1983). In this study, we are interested in actual erosion levels, and our assessment was based on observations of several erosion indicators. Results are presented in Table 1.

Classes for identifying the severity of observed erosion have been established by the FAO (1984), and are listed in Table 2. This classification scheme was adopted to assess the level of erosion in each sampled land unit along the sub-transects (see Appendix 1). The observed moderate to severe erosion is associated with a change in land use from pasture to cropping with a minimum of installation of soil and water conservation measures. This situation will clearly call for a combination of changed land use, special management practices, or major land improvements.

Observations of the occurrence and stage of gullies were used to assess the severity of erosion. If no gullies are present, the assessment was based on landform characteristics affecting runoff concentration. Areas subject to maximum velocity runoff are most susceptible to gullying, for example where pediment slopes occur below bare rocky inselbergs as found in LM5. The zone has prominent rill erosion and observable crop deficiencies (Tables 1c and d).

Table 3 and Figure 5 reflect that slight to moderate sheet wash, to severe sheetwash was found, and that gully sizes were generally small due to the use of trashlines and abundant plant cover. Otherwise, more sheet wash was found in the lower midland zones due to its soil properties. Soil in these areas is prone to erosion due to being sandy clay to loamy sand.

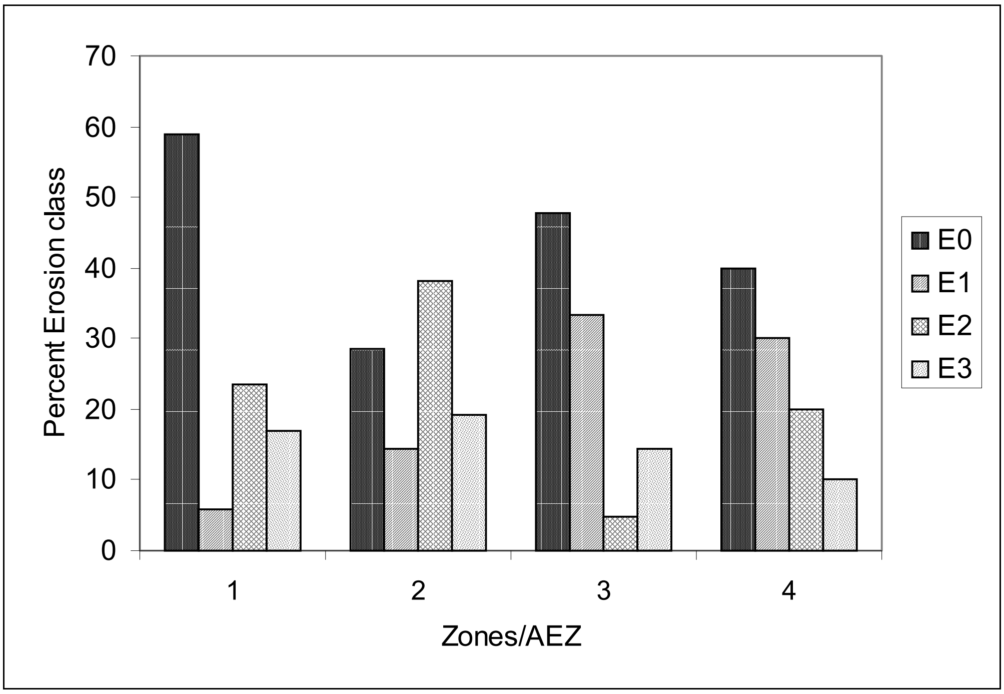
Table 2: Example of classes for assessment of observed erosion

Class	
EO	No visible evidence of erosion or very slight sheet wash.
E1	Slight- moderate sheetwash. Shallow rills affecting less than 10% of plot.
E2	Moderate- severe sheetwash. Rills affecting 10-25% of plot.
E3	Moderate- severe sheetwash. Gullies or rills affecting 25-50% of plot.

Table 3: Percent erosion classes within different land uses and AEZ in Amboseli – Loitokitok transect.

Zone No.	**AEZ**	**EO**	**E1**	**E2**	**E3**
1	LM6	58.8	5.9	23.5	17
2	LM5	28.6	14.3	38.1	19.1
3	UM4	47.8	33.3	4.8	14.3
4	LH3	40	30	20	10

Figure 7: Percent Erosion classes within different land uses and AEZ in Loitokitok-Amboseli transect.



E. CONCLUSION

All soils across the AEZ have inherently good soil fertility. They do not, however, receive adequate nutrient replenishment to compensate for continuous nutrient mining. This replenishment could come in the form of organic manures, inorganic fertilizers or biomass transfer through agro-forestry or short fallow. These practices, including short fallow, would be possible in the area because of ample land available and the ability of farmers to combine livestock raising with cropping.

With population continuing to rise and increasing frequency of drought, there is need to reverse nutrient mining (Smaling 1987). Improving soil fertility could trigger rural and national economic development, achieve long-term food security and improve farmers' standards of living, while mitigating environmental degradation and rural migration. This could be done through participatory introduction of integrated nutrient management technologies (Gachimbi et al 2002, Onduru et al 2001) to solve soil fertility decline within specific land uses in the arid and semi-arid areas**.**

In Mt. Kilimanjaro forest, the great production and cycling of foliage results in much biological activity, humus formation, and hence high levels of soil organic matter, potassium, nitrogen and other plant nutrients. There is also low soil erosion or near zero erosion. In contrast, on the land being used for annual or other crops, leaf production is much less, the biomass is largely removed, and the soil is tilled several times each year. The result is that the soil is much drier and subject to high erosion rates especially at the onset of the rainy seasons when the ground is bare. Once the topsoil has been eroded, sheet or gully erosion and soil layers of poorer quality are exposed. It is then essential to rehabilitate or restore the soil to bring it to good productive capacity for the next crop or pasture. Failing this, a spiral of degradation is set in motion consisting of reduced vegetation cover and biomass production, and reduced soil and water retention. Thus, the quality of the remaining soil should be of greater concern than the quality and quantity of that which has been lost.

Consequently, variable levels of plant nutrients and soil erosion are due to different levels of conservation management practices implemented by individual farmers. Farmers need to create favourable conditions for soil life and should manage organic matter to create a fertile soil in which healthy plants can develop. Farmers generally suffer from decreasing soil fertility. The restoration of soil organic matter is essential for the stabilization of plant production.

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APPENDICES

Appendix 1. Classes of fertility for single elements N, P, K and % C

Class	Available P (ppm)	Available Ca (me/100 g)	Available K (%)	Available N (%)	Percent C (%)
Very high		20	≥3	≥10	≥4
High	≥80	≥15	1-2	2-10	2-4
Moderate	20-80	2-15	0.2-1	2	1-2
Low	≤20	≤2	≤0.1-0.2	≤2	≤1
Critical value used	20	10	0.2	2	2

Appendix 2. pH scale (in 1:1 soil water ratio)

PH	*Rating*
Low 4.5	Extremely acid
4.5-4.9	Strongly acid
5.0-5.9	Moderately acid or Medium acidity
6.0-6.4	Slightly acid
6.5-6.9	Near neutral
7.0-7.4	Slightly alkaline
7.5-8.4	Moderately alkaline
8.5-8.9	Strongly alkaline
Above 9.0	Extremely alkaline

(Source: Legger 1978)

Appendix 3. Soil fertility and erosion indicators questionnaire

Transect No. ____________________

Date Sampled: __________________ **Site. ___________**

GPS points: **x______________** **Altitude_________**

y_____________

AEZ: **Indicator**	**Notes or presence**	
Soil and Water Erosion: **Classes of observed erosion indicators** <u>**Class**</u> **EO**: No visible evidence of erosion or very slight sheetwash. **EL**: Slight - moderate sheetwash. **E2:** Moderate - severe sheetwash, rills **E3:** Moderate - severe sheetwash, gullies. **Visual Indicators** • Soil loss • Sedimentation • Accumulation • Rills • Gullies • Pedestals • Armour layer • Accumulations of soil around clumps of vegetation or upslope of trees, fences or other barriers • Deposits of soil on gentle slopes • Exposed roots or parent material • Muddy water/mudflows during and shortly after storms • Sedimentation in streams and reservoirs • Dust storms/clouds • Sandy layer on soil surface • Parallel furrows in clay soil or ripples in sandy soil • Bare or barren spots • Nutrient deficiency/toxicity symptoms evident on plants • Decreased yields • Poor response to fertilizers • Increased sealing, crusting and run-off; reduced soil water		

Farm Soil Fertility Assessment Indicator:	High Moderate	Low
Visible changes in farmers' practices in the project area compared to outside farmers' practices in: • Soil fertility management (e.g., management of organic material, use of rock phosphate on acid soils, improved fertilization practices, application method, type, timing, balanced fertilization) • Crop choice (increased planting of perennial crops) and crop yields. • Land management practice (e.g., planting along contour lines, establishing soil erosion measurements). **Soil Texture Estimation:** • Soil Texture **Plant Leaf - Soil Fertility Calibration:** • Soil Colour • Yellowness of whole leaves and plant height • Growth and Colour • Yellowness of leaf edges and plant height **Qualitative Ranking** • Soil organic matter • Availability of N • Availability of P • Availability of K • Soil organic matter • Availability of N • Availability of P • Availability of K **Crop Yield Assessment Soil Fertility:** • Crop yield • Field Productivity		