odi

Working Paper

53

ENVIRONMENTAL CHANGE AND DRYLAND MANAGEMENT IN MACHAKOS DISTRICT, KENYA 1939-90

ENVIRONMENTAL PROFILE

edited by Michael Mortimore

A. Rainfall	S.K. Mutiso Michael Mortimore Mary Tiffen
B. Soil Erosion	D.B. Thomas
C. Soil Fertility	J.P. Mbuvi
D. Natural Vegetation	Kassim O. Farah

Results of ODI research presented in preliminary form for discussion and critical comment

ODI Working Papers available at December 1991

24: Industrialisation in Sub-Saharan Africa: Country case study: Cameroon
Igor Karmiloff, 1988, £3.00, ISBN 0 85003 112 5
25: Industrialisation in Sub-Saharan Africa: Country case study: Zimbabwe
Roger Riddell, 1988, £3.00, ISBN 0 85003 113 3
26: Industrialisation in Sub-Saharan Africa: Country case study: Zambia
Igor Karmiloff, 1988, £3.00, ISBN 0 85003 114 1
27: European Community Trade Barriers to Tropical Agricultural Products
Michael Davenport, 1988, £4.00, ISBN 0 85003 117 6
28: Trade and Financing Strategies for the New NICS: the Peru Case Study
Jurgen Schuldt L., 1988, £3.00, ISBN 0 85003 118 4
29: The Control of Money Supply in Developing Countries: China, 1949-1988
Anita Santorum, 1989, £3.00, ISBN 0 85003 122 2
30: Monetary Policy Effectiveness in Côte d'Ivoire
Christopher E Lane, 1990, £3.00, ISBN 0 85003 125 7
31: Economic Development and the Adaptive Economy
Tony Killick, 1990, £3.50, ISBN 0 85003 126 5
32: Principles of policy for the Adaptive Economy
Tony Killick, 1990, £3.50, ISBN 0 85003 127 3
33: Exchange Rates and Structural Adjustment
Tony Killick, 1990, £3.50, ISBN 0 85003 128 1
34: Markets and Governments in Agricultural and Industrial Adjustment
Tony Killick, 1990, £3.50, ISBN 0 85003 129 X
35: Financial Sector Policies in the Adaptive Economy
Tony Killick, 1990, £3.50, ISBN 0 85003 131 1
37: Judging Success: Evaluating NGO Income-Generating Projects
Roger Riddell, 1990, £3.50, ISBN 0 85003 133 8
38: ACP Export Diversification: Non-Traditional Exports from Zimbabwe
Roger Riddell, 1990, £3.50, ISBN 0 85003 134 6
39: Monetary Policy in Kenya, 1967-88
Tony Killick and F M Mwega, 1990, £3.50, ISBN 0 85003 135 4
40: ACP Export Diversification: Jamaica, Kenya and Ethiopia
Christopher Stevens, 1990, £3.50, ISBN 0 85003 136 2
41: ACP Export Diversification: The Case of Mauritius
Matthew McQueen, 1990, £3.50, ISBN 0 85003 137 0
42: An Econometric Study of Selected Monetary Policy Issues in Kenya
F. M. Mwega, 1990, £3.50, ISBN 0 85003 142 7
43: Differences in Econometric Performance between Franc Zone and other sub-Saharan African Countries
Christopher E. Lane and Sheila Page, 1991, £3.50, ISBN 085003 148 6
44:Monetary Policy Effectiveness in Indonesia, 1974-1900
Christopher E. Lane, David C. Cole and Betty F. Slade, 1991, £3.50, ISBN 0 85003 150 8
45:Monetary Control in Ghana: 1957-1988
Nii Kwaku Sowa, 1991, £3.50, ISBN 0 85003 152 4

(continued on inside back cover)

WORKING PAPER 53

ENVIRONMENTAL CHANGE AND DRYLAND MANAGEMENT IN MACHAKOS DISTRICT, KENYA 1930-90

ENVIRONMENTAL PROFILE

edited by Michael Mortimore

A.	Rainfall	S.K. Mutiso Michael Mortimore Mary Tiffen
B.	Soil Erosion	D.B. Thomas
C.	Soil Fertility	J.P. Mbuvi
D.	Natural Vegetation	Kassim O. Farah

December 1991

ISBN 0-85003-163-X

OVERSEAS DEVELOPMENT INSTITUTE
Regent's College
Inner Circle, Regent's Park
LONDON NW1 4NS

UNIVERSITY OF NAIROBI
P O Box 30197
Nairobi
Kenya

MINISTRY OF RECLAMATION AND DEVELOPMENT
OF ARID, SEMI-ARID AREAS AND WASTELANDS
Nairobi, Kenya

Preface and Acknowledgements

ODI Working Papers present in preliminary form work resulting from research undertaken under the auspices of the Institute.

This Working Paper is part of a study which aims to relate long term environmental change, population growth and technological change, and to identify the policies and institutions which are conducive to sustainable development. The first stage, published in these Working Papers, is to measure and assess as precisely as the evidence allows the changes that have occurred in the study area, the semi-arid Machakos District, Kenya, over a period of six decades. Degradation of its natural resources was evoking justifiable concern in the 1930s and 1940s. By several measures it is now in a more sustainable state, despite a five-fold increase in population. A long-term perspective is essential, since temporary factors, such as a run of poor rainfall years, can confuse analysis of change if only a few years are considered. The study is developing a methodology for incorporating historical, physical, social and economic data in an integrated assessment. The final report will include a synthesis and interpretation of the physical and social development path in Machakos, a consideration as to how far the lessons are relevant to other semi-arid environments, and recommendations on policies for sustainable economic growth.

The project is directed at ODI by Mary Tiffen, in association with Michael Mortimore, research associate, in co-operation with a team of scientists at the University of Nairobi, and with the assistance of the Ministry of Reclamation and Development of Arid, Semi-Arid Areas and Wastelands in Kenya. We are grateful to Professor Philip Mbithi, Vice-Chancellor of the University of Nairobi, for his support and advice. We also thank the Overseas Development Administration, the Rockefeller Foundation and the Environment Department of the World Bank for their financial support. Views expressed are those of the authors and do not necessarily reflect the views of ODI or supporting institutions. Comments are welcome, and should be sent directly to the authors or project leaders.

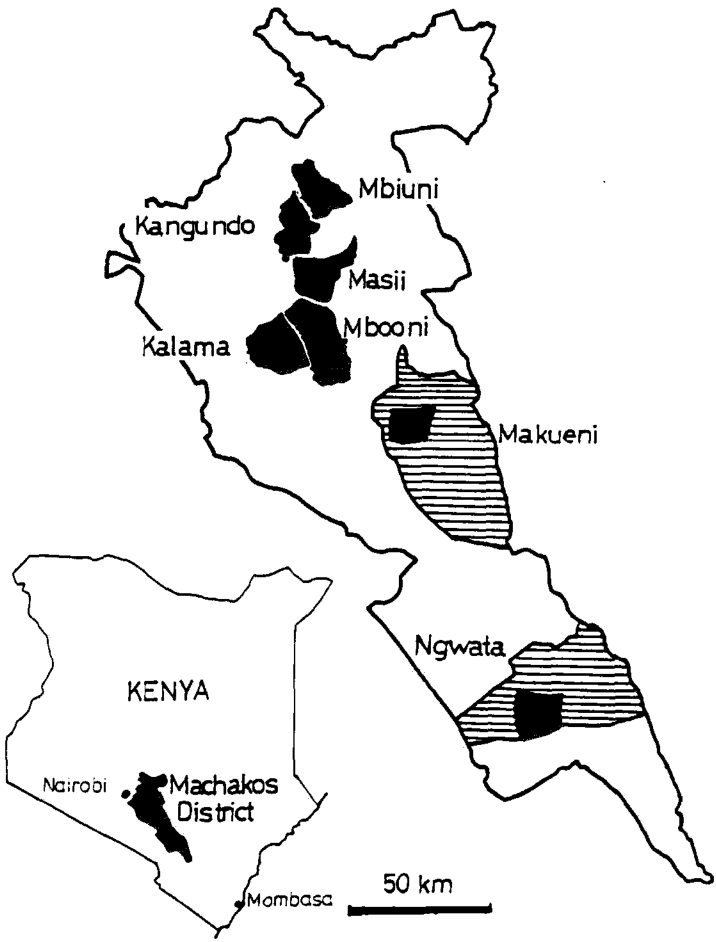
Other titles in this series (in which more are planned) are:

Machakos District: Production Profile
Machakos District: Conservation Profile
Machakos District: Technological Change
Machakos District: Land Use Profile
Machakos District: Population Profile
Machakos District: Institutional Profile

Michael Mortimore is the Editor of this paper, Environmental Profile, and has contributed to the chapters. The University of Nairobi authors are:

A.	Rainfall	Dr S.K. Mutiso, Department of Geography.
B.	Soil Erosion	Prof D.B. Thomas, Department of Agricultural Engineering.
C.	Soil Fertility	Dr J.P. Mbuvi, Department of Soil Science.
D.	Natural Vegetation	Dr Kassim O. Farah, Department of Range Science.

Preface Figure: **Machakos District, Kenya, showing study locations**
(In Makueni and Ngwata Locations, field studies were mostly within the areas shown black.)



CONTENTS

INTRODUCTION 1
Michael Mortimore

A. RAINFALL 3
S.K. Mutiso, Michael Mortimore and Mary Tiffen

1. Regional and Local Rainfall Controls 3
2. Rainfall Patterns 4
3. Rainfall Trends 5
4. Rainfall Cycles 13
5. Rainfall Variability 13
6. A Chronology of Droughts 16
7. Conclusion 23

B. SOIL EROSION 24
D. B. Thomas

1. Introduction: Forms and Processes of Erosion 24
2. An Historical Profile of Erosion 25
   2.1 Origins 25
   2.2 Baseline assessments 27
   2.3 Erosion in Kalama 1948-74 30
   2.4 Erosion in 1981-85 32
3. Measuring the Rate of Erosion 35
4. Erosion on Crop Land 36
5. Erosion on Grazing Land 38
6. Other Types of Erosion 40
7. Conclusions 41
8. Appendix 42

C. SOIL FERTILITY **44**
J.P. Mbuvi

1. Introduction 44
2. The Longitudinal Study 44
   - 2.1 Baseline materials 44
   - 2.2 Results 45
   - 2.3 A profile of soils on grazing land 47
3. The Spatial Analogue Study 47
   - 3.1 Sampling 47
   - 3.2 Results 48
   - 3.3 A profile of cultivated soils 49
4. Conclusion 50

D. NATURAL VEGETATION **51**
Kassim O. Farah

1. Introduction 51
2 Baseline Descriptions 52
3 Study Sites 53
4 Methods 54
5 Results 56
6 Grazing Management and Land Degradation 60
7 Northern Machakos 62

REFERENCES **67**

INTRODUCTION

Michael Mortimore

The objective of this paper is to construct profiles of environmental change in Machakos District during the period 1930-90. Such profiles are the necessary basis for an evaluation of dryland management during the period. The possibilities are severely constrained by the data that are available and by the little attention that has been given in earlier studies to the measurement of longitudinal change. Therefore it has been necessary to distil an assortment of data sets and use a variety of methodologies. Four profiles are presented, for rainfall (Section A), soil erosion (Section B), soil fertility (Section C), and natural vegetation (Section D).

Environmental change can be represented in the form of trends (positive or negative) or as variability (random or cyclical). All of these possibilities are found in the Machakos record. Environmental change results from the operation of exogenous and endogenous factors. Critical among the first group is the rainfall, over which neither people nor government have exercised any control. On the other hand, the management of primary resources, which is the result of interacting decisions by individuals, households, communities and government, exercises a powerful endogenous influence on the nature and rate of environmental change. The direction in which management has influenced environmental change in the past must be understood if policy interventions are to be assessed for the future.

In Section A (Rainfall) the records for five stations are examined in conjunction with earlier published studies. It is shown that there is no evidence of a long-term trend in the rainfall, but clear evidence of inter-annual and within-season variability. This variability, which is the principal characteristic of the rainfall from a management perspective, is superimposed on cycles of 9-11 years (for the long rains) and 16-22 years (for the short rains). A chronology of droughts is constructed, using a rainfall (or drought) index, which provides a basic reference for the Machakos study as a whole.

In Section B (Soil Erosion), a history of erosion is reconstructed from the data, descriptions, and studies available. This history shows a major turn-around from the 1930s and 1940s to the 1970s, and provides context for recent estimates of the rates of erosion. It is shown that erosion is no longer associated in general with cultivation, but predominantly with grazing land, where there are recent signs of improved conservation.

Section C (Soil Fertility) infers change in the chemical and physical properties of cultivated soils from selective sampling in the field, and laboratory analyses. The results from a longitudinal comparison of sites over a period of 13 years are found to be inconclusive, but a spatial analogue method shows very low fertility levels, on sites with a long history of cultivation without inputs, compared with uncultivated sites.

Section D (Natural Vegetation) traces the impact of grazing management on natural woodland (settled during the 1950s and 1960s) using standard ecological survey and air photo interpretation techniques. There is no evidence of irreversible land degradation, though bush encroachment threatens to reduce the value of the grazing for cattle. A study of two selected sites with a longer history of grazing indicates that at these, woodland communities are being managed sustainably for grazing and other purposes.

The profile of rainfall indicates that this critical variable is neither better nor worse today than in the past; low and erratic rainfall remains the overwhelming constraint on dryland management. The profile of soil erosion suggests a significant amelioration during the period, which is attributable to changes in management. The profile of soil fertility shows that the transition to permanent cultivation in terraced fields was sustained only with fertility improvement, and where inputs are lacking, productivity falls very low. The profile of natural vegetational change shows that grazing at relatively high stocking levels is compatible with conservationary objectives, given the transformation of grazing management that has occurred on individual holdings.

A. RAINFALL

S.K. Mutiso, Michael Mortimore and Mary Tiffen

1. REGIONAL AND LOCAL RAINFALL CONTROLS

The rainfall in Machakos District, like other areas of eastern Kenya, is characterised by small total amounts, strongly seasonal distribution, and high temporal and spatial variation from year to year and from season to season.

The dominant controls over the climate of East Africa are:

(a) the regional circulation pattern and the intertropical convergence zone (ITCZ);

(b) latitude, which affects the timing of rainfall minima and maxima, as the thermal equator follows the sun's zenith;

(c) topography and aspect, which influence the intensity of the ITCZ and the amount of rainfall; and

(d) inland lakes, for instance, Lake Victoria, which provides local sources of moisture.

The easterly trade winds and the ITCZ are the major rain-producing agents in East Africa. Since the ITCZ is a zone of pronounced air turbulence, its passage brings seasonal rains and is responsible for the saying that 'rainfall follows the sun'. It lies about 5°S. during the northern winter and about 15°N. during the southern winter, with a mean annual position of 5°N.

The NE trades blow from December to February, with a maximum development in January; and the SE trades blow from May to September, with a maximum in July. Usually, there is a strong association of the ITCZ with rainfall and of the trade winds with dry conditions. The movements of the ITCZ result in the seasonal nature of the East African rainfall regime, characterized by two distinct wet seasons in eastern Kenya, namely the Short Rains (October-December - *Nthwa*), and Long Rains (March-May - *Uua*), with a comparatively dry period between them.

However, not all regional rainfall behaviour can be explained in terms of the ITCZ. The drought of 1984, for example, has been analysed by Anyamba and Ogallo (1990). Wind data from 29 upper air stations in Africa showed that cyclonic activity in the Indian Ocean during April inhibited rain formation over East Africa in the long rains of that year.

The local rainfall controls in Machakos District can be subdivided into two categories, namely 'free' and 'forced' convective systems (Mutiso, 1988). In the first category, an airmass is overheated (the lapse rate steepening) in the stagnant air of topographic hollows (e.g., the Athi floodplains). It becomes lighter, and rises in convection currents, until it is sufficiently cooled below its dew point to form dark-based towering cumulo-nimbus cloud and ultimately rainfall or hailstones.

In forced convection, the rain bearing air-mass is forced to rise by a mountain or range of hills, as the central hill masses. The resultant rainfall is relief or orographic rainfall. The south-facing slopes of the central hill masses are therefore wetter than the north-facing leeward sides, which are shadow areas.

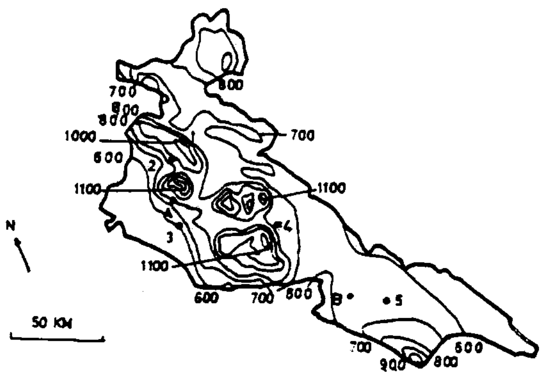
The final form of local control is when winds emanate from the differential heating of hill slopes and valley bottoms. During the day, the air on the slopes is heated faster than the air vertically above the valley floor. The lighter air rises and when it reaches dew point at the top of a mountain or hill range, rain-bearing clouds form. These dark-based clouds are common in the central hill masses of Machakos District.

2. RAINFALL PATTERNS

Average annual rainfall is shown in Figure A.1. Only about a third of the District receives the minimum of 750 mm considered necessary under a bimodal regime for most forms of crop production (Nieuwolt, 1978). This includes the ecologically favoured central hill masses.

Figure A.1: **Mean annual rainfall in Machakos District (after Parry et al. 1988:143)**

A: Machakos District Office
B: Makindu
1: Kabaa Catholic Mission
2: Kangundo
3: Katumani Research Station
4: Kampi ya Mawe Research Station
5: Kibwezi



The mean annual values conceal extreme events, and do not take into account run-off losses, evapotranspiration and the distribution of rainfall during the growing season. Detailed models are necessary for predicting soil moisture and thereby agricultural potential in a given area. The use of climatic data on a daily, decadal, monthly or seasonal basis, for drought prediction and crop planning in semi-arid Kenya, has been attempted with varying success by Stewart and Hash (1982); Stewart and Wang'ati (1980); Kashasha (1982), Mutiso, (1988); NES (1985); Musingi (1990); Palutikof (1986) and Parry et al. (1988).

It can be fairly concluded that, notwithstanding some progress towards linking the performance of individual crops (e.g., Katumani maize) with moisture models, no model is in prospect that can provide a reliable indicator of agricultural output in farming systems as a whole, in areas of diverse conditions of soil and slope. Therefore, total seasonal rainfall is used to investigate rainfall trends over time, and drought frequencies, under the semi-arid, bi-modal regime of Machakos District.

3. RAINFALL TRENDS

Parry et al. (1988:154-63) carried out an investigation of secular rainfall trends in Machakos and two neighbouring districts (Kirinyaga and Embu). Four station series were used: for Embu, Kerugoya, Machakos Town and Makindu. Eleven-year running means were plotted to smooth the series. They found (Table A.1) that Machakos and Makindu had statistically significant negative trends for the long rains; for the short rains, Machakos had a statistically significant positive trend while Makindu had a negative trend that is not significant (at 5% probability). However, taking all four stations together:

> *There does not appear to be a widespread general trend in the smoothed series. In every case, the range of annual rainfall is much greater than the difference between one average mean and the next. Thus, there is no evidence on the time scale of the next decade or so of significant changes in the climatic parameters.* (p.155).

Table A.1: Linear least-squares regression of seasonal rainfall: 11-year moving averages for 4 stations (after Parry et al., 1988:157)

Season	*Correlation (r) with year*			
	Kerugoya	*Embu*	*Machakos*	*Makindu*
Long rains (Mar-May)	-0.20	0.24	-0.48*	-0.38*
Short rains (Oct-Dec)	0.53*	0.40*	0.33*	-0.22
Periods	1936-85	1914-85	1897-1985	1907-85

* Significant at 5% probability.

In order to test this conclusion at a larger number of stations within the District, the rainfall series for the years 1957-88 were plotted for five additional stations (shown 1-5 on Figure A.1). These range from AEZ 3 (Kangundo and Kabaa, with 8-900 mm annual rainfall) to AEZ 4 (Katumani and Kampi ya Mawe, with about 700 mm and Kibwezi, with 650mm). Regressions of seasonal rainfall on year produced a range of values, but no evidence of a generalised, significant, trend (Table A.2).

Table A.2: Linear least-squares regression of seasonal rainfall

Season	*Correlation (r) with year*				
	Kabaa	*Kangundo*	*Katumani*	*Kampi ya Mawe*	*Kibwezi*
Long rains (Mar-May)	0.41*	0.39*	0.32	-0.09	0.25
Short rains (Oct-Dec)	0.04	-0.04	-0.29	-0.31	0.67*
Period	1957-88	1957-88	1957-88	1962-88	1957-88

* Significant at 5% probability.

In Sahelian Africa a significant reduction in mean annual rainfall occurred after 1970, amounting to over 30% in some areas (Mortimore, 1989). To test this possibility in Machakos District, mean seasonal rainfall during the periods 1957-71 (15 years) and 1972-90 (19 years) is shown in Table A.3 for the five stations. The differences are randomly variable and not significant.

Table A.3: Mean seasonal rainfall up to and after 1971 for 5 stations

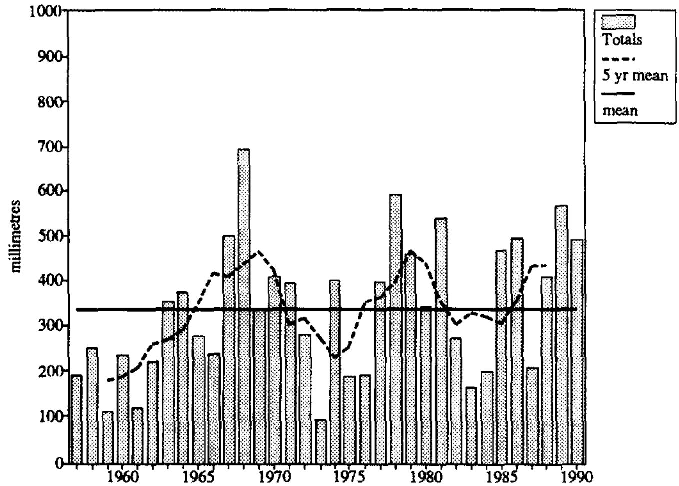
	Long rains			*Short rains*		
	1957-71	*1972-90*	*% change*	*1957-71*	*1972-90*	*% change*
Kabaa	312.86	354.39	13.3	341.77	357.77	4.7
Kangundo	362.94	365.60	0.7	321.26	316.31	-1.5
Katumani	304.39	307.41	1.0	308.83	263.72	-14.4
Kampi ya Mawe	318.83*	290.48	-8.9	301.89	349.53	15.8
Kibwezi	263.90	238.61	-9.6	428.45	398.56	-7.0

* Period 1962-71.

The conclusions of Parry et al., therefore, are confirmed with respect to long-term trends in Machakos District.

Figure A.2: **Rainfall at Kabaa, 1957-90**

Long rains



Short rains

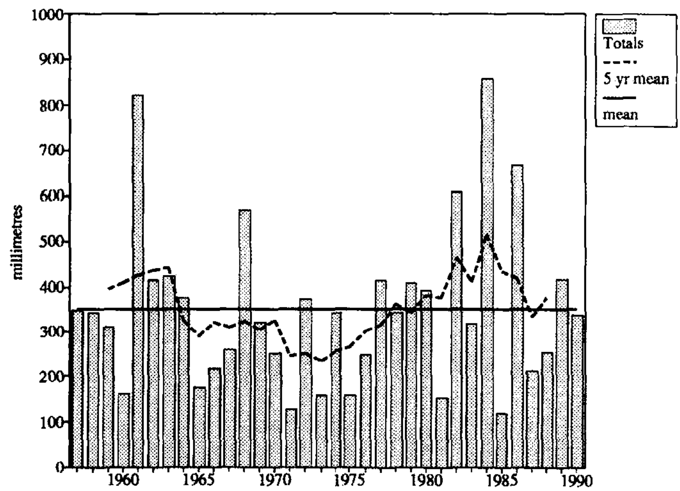
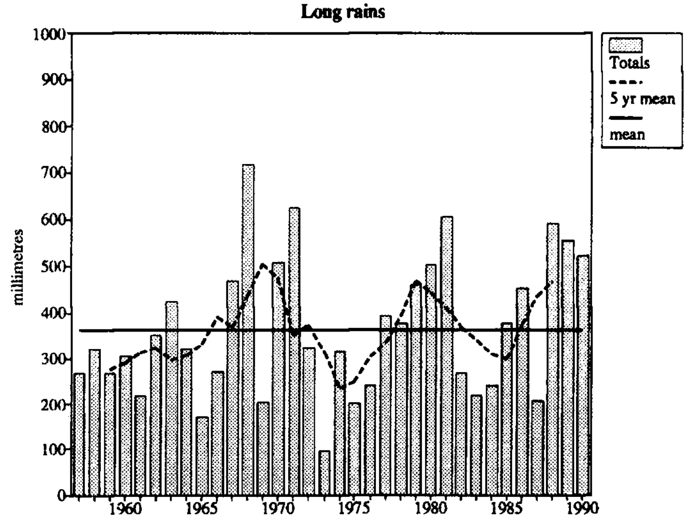


Figure A.3: **Rainfall at Kangundo, 1957-90**



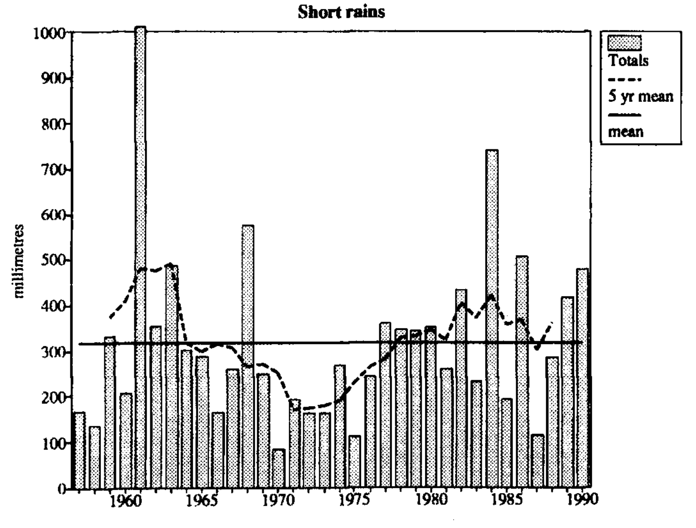
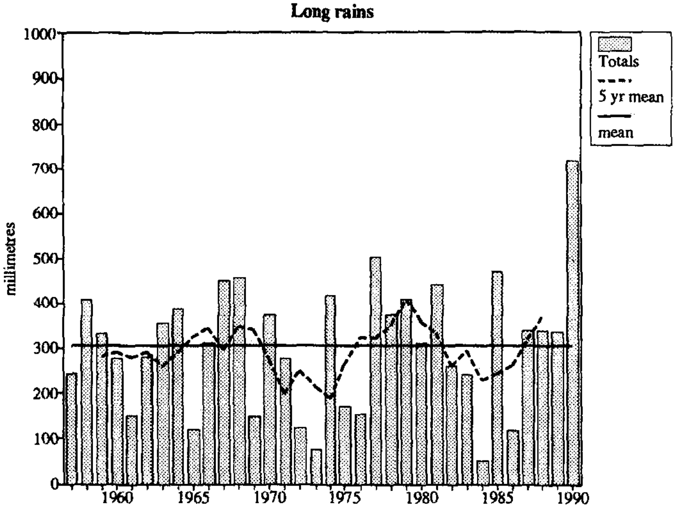


Figure A.4: **Rainfall at Katumani, 1957-90**



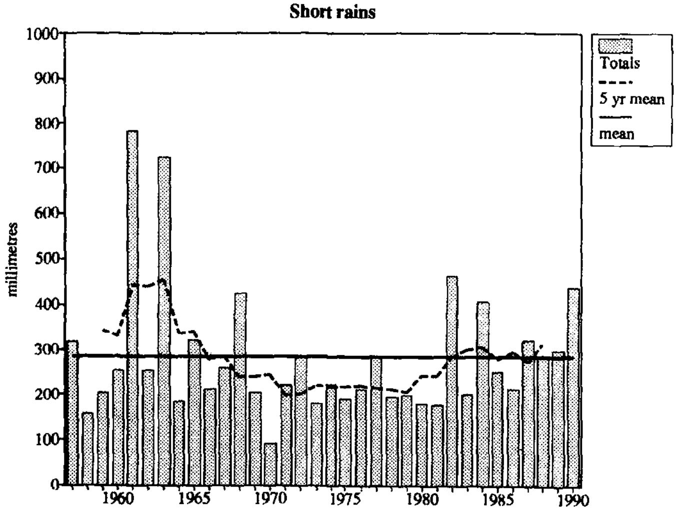
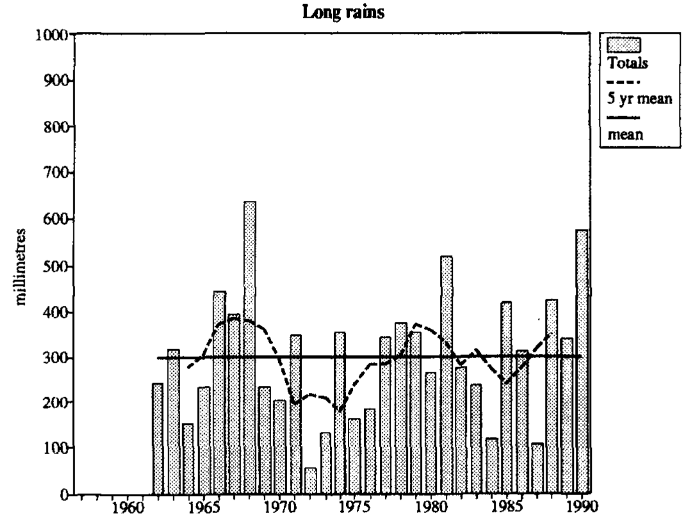


Figure A.5: **Rainfall at Kampi ya Mawe, 1962-90**



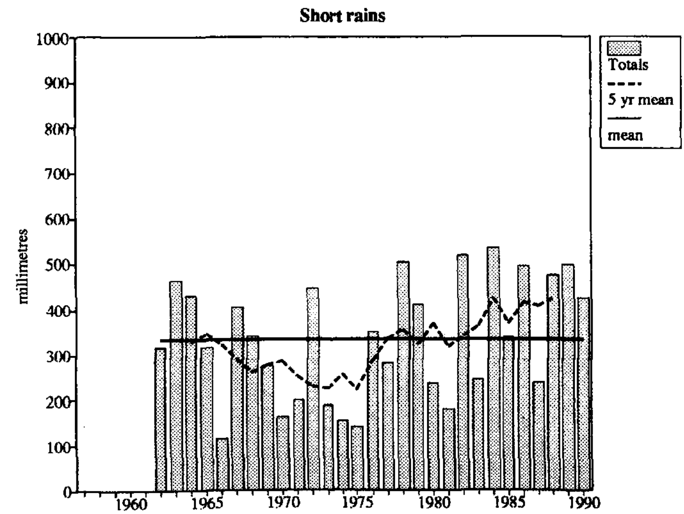
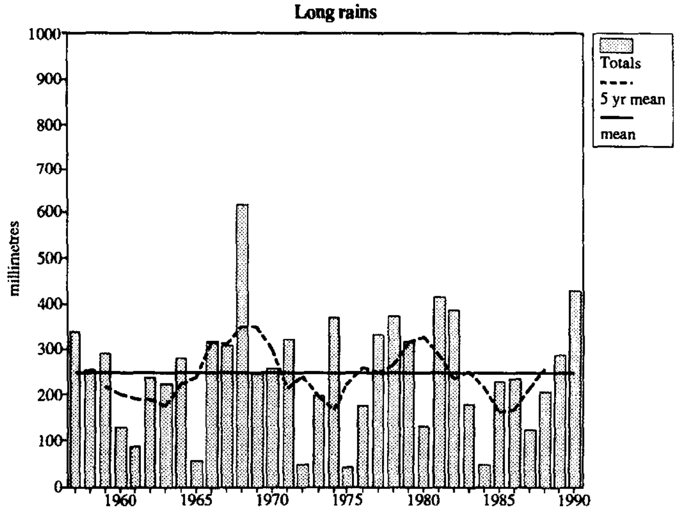


Figure A.6: **Rainfall at Kibwezi, 1957-90**



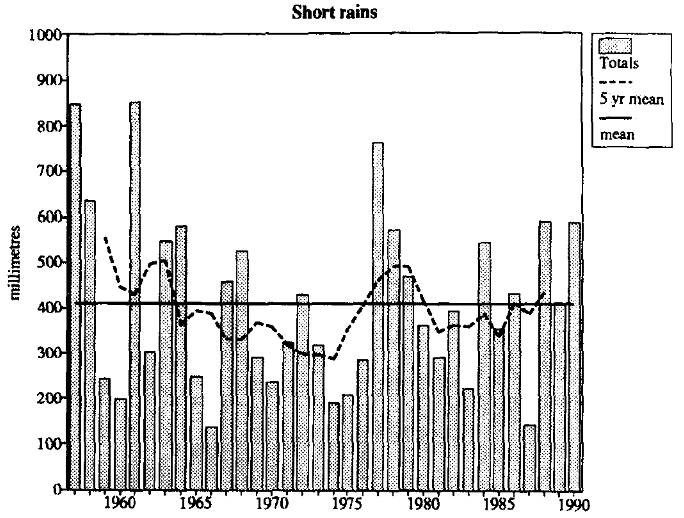
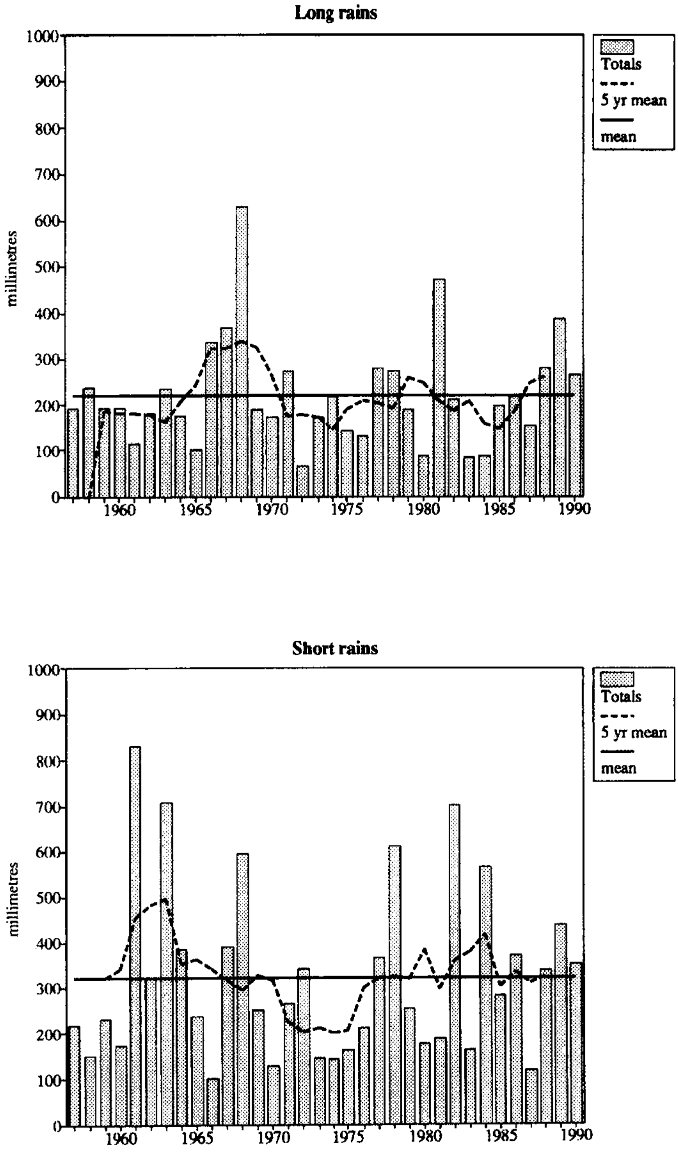


Figure A.7: Rainfall at Makindu, 1957-90



4. RAINFALL CYCLES

Parry et al found little conclusive evidence for cycles in the rainfall pattern.

Seasonal rainfall during the period 1957-90 for the five stations analysed in the present study, and also for Makindu (one of the stations used by Parry et al.) is plotted in Figures A.2-A.7. Total seasonal rainfall for each year, the long term mean for the period, and the five-year running mean are shown. Without having recourse to statistical analysis, the running means display unmistakeable evidence of a 9-11 year cycle in the long rains at all six stations, with two completed cycles having peaks in 1967-68 and 1977-79, and troughs in 1973 and 1982-85. In the short rains the six station series conform to a longer cycle of 16-22 years, declining from a peak in 1962-63 to a trough in 1970-74, and rising again to a peak in 1984 (1988 at one station).[1]

The use of an 11-year running mean (as opposed to five years) and a flatter graphical scale disguised these patterns in Parry et al.'s analysis. However, the differences between the running means and the values for individual seasons, shown in our plots, confirms their conclusion that such cycles have little predictive value for agricultural practice.

5. RAINFALL VARIABILITY

Variability, and not long-term change, is the important characteristic of the rainfall. Inter-annual variability (the difference between seasonal rainfall in successive years) was analysed by Parry et al. The inter-annual variability statistic for Makindu showed the highest values and largest fluctuations. For the long rains, some periods (late 1930s to early 1940s; 1950s to 1960s) had low inter-annual variability. Other periods (1920s; late 1940s; early 1970s) had high variability. Variability has recently decreased at Machakos but increased at the other three stations. For the short rains, all four stations showed recent increases in inter-annual variability. The 1920s to 1930s and the 1970s had low variability; the late 1950s to mid-1960s had high variability.

The statistical properties of recorded rainfall are the best guide to expectations. The seasonal and agricultural year (October to September) probabilities for Machakos and Makindu are summarised in Table A.4 (after Parry et al., 1988:156). Rainfall reliability in each of the two seasons - the long rains and the short rains - has been mapped for Machakos District by Jaetzold and Schmidt (1983). These maps are reproduced in Figures A.8 and A.9. The majority of crops are single-season annuals. But it should be noted that some long season crops, notably pigeon pea, are planted in the short rains and harvested after the long rains. The agricultural year, therefore, extends from October to May of the following calendar year. What is clear is that only a small proportion of the District can expect more than 250 mm in

---

[1] At the time of writing, data for the period before 1957 are not available for our five stations. It is hoped to test these cycles for the earlier period in due course.

Figure A.8: **Rainfall reliability of 60% during the long rains, including the months March - September (after Jaetzold and Schmidt, 1983)**

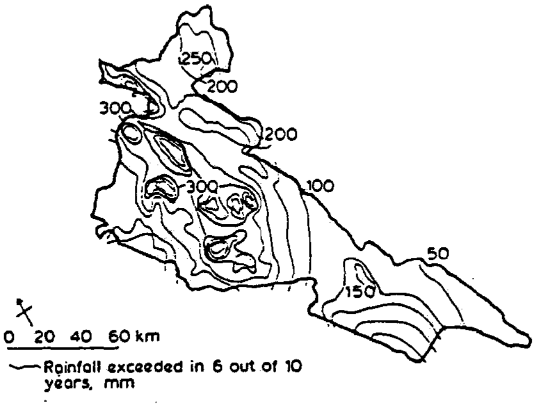


Figure A.9: **Rainfall reliability of 60% during the short rains, including the months October - February (after Jaetzold and Schmidt, 1983)**

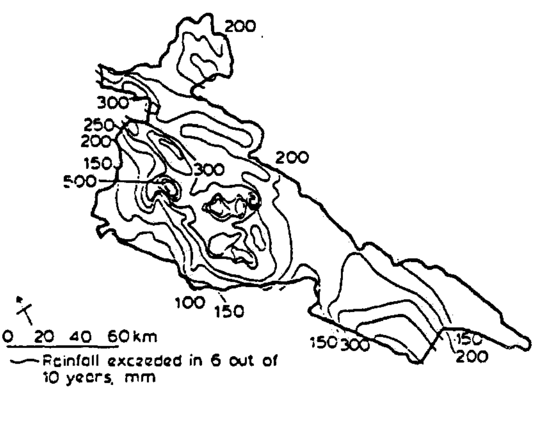


Table A.4: Seasonal and agricultural year rainfall probabilities (Parry et al, 1988:156), in mm.

Season	*Machakos*	*Makindu*
Mar-May (long) rains		
No of years	30	30
Best	872.0	510.7
10% probability	590.1	327.5
Median	396.5	175.2
90% probability	211.3	94.6
98% probability	133.0	23.6
Oct-Dec (short) rains		
Best	1577.0	816.6
10% probability	670.5	603.0
Median	344.0	260.5
90% probability	240.0	148.9
98% probability	198.0	102.7
Oct-Sept (agricultural year)		
Best	2261.0	1113.0
10% probability	1377.3	1016.3
Median	904.7	552.5
90% probability	645.0	330.5
98% probability	581.0	208.9

Probabilities are cumulative probabilities of exceeding the stated total.

either season in six or more years out of ten. This is the barest minimum for producing a crop of maize even assuming a satisfactory distribution within the season. The seasonal and annual figures do not take into account the distribution of rainfall during the growing season, evapotranspiration, and losses to runoff and percolation.

A more direct linkage between agricultural drought and food production may be attempted by means of crop or livestock production models which relate rainfall to output on the basis of experimental results. Parry et al. used such a model for the hybrid Katumani composite B maize, comparing the yields estimated with the model and the agroclimatic index, r/Eo (r=rainfall, Eo=potential evaporation), and using the values for 1974-77 and 1984. (These ten seasons were selected to represent a range of rainfall conditions.) A clear relation was demonstrated, estimated yields increasing with the r/Eo ratio. However, on seven farms estimated yields exceeded the observed yields in five seasons (in 1981-83) by factors ranging from about 4.5 to 10. We may also note that farmers grew local and crossed varieties of maize in addition to Katumani B. It is clear that the maize model used by Parry et al. offers, at best, an approximate indicator of food production in drought conditions, as recorded in the rainfall profile.

A similar attempt was made by Parry et al. to relate precipitation to livestock production. This is more difficult, given a larger number of variables and two stages in the food chain. Rainfall was related to total annual production of Napier grass forage and its conversion by stock to milk, at Katumani and Makindu, assuming certain farm sizes, forage areas and stocking rates. Notwithstanding its theoretical value, the assumptions of the model (and lack of on-farm trials) do not recommend its use as an indicator of actual livestock production in the District during droughts recorded in the past.

Therefore it is concluded that agricultural drought is still difficult to define in terms that accurately predict (or describe) crop or livestock production, especially in relation to farming systems in the semi-arid areas.

6. A CHRONOLOGY OF DROUGHTS

Given the difficulty of linking precipitation directly with agricultural performance, it has to be assumed that farming systems are adapted to local average rainfall conditions, and that the impact of a drought (or a flood) on those systems can be approximated as the deviation of seasonal rainfall from normal. Such a procedure necessarily blurs the distinction between meteorological and agricultural drought.

Following Parry et al. (1988), the drought index (DI) is defined as :

$$DI = \frac{P - \bar{X}}{S}$$

where
P = seasonal precipitation
$\bar{X}$ = the long-term average for that season
S = the seasonal standard deviation from P.

The DI is normalised with a mean of 0 and standard deviation of 1. However, given a skewed distribution in the short rains and at the driest station (Makindu), the DI is considered to overemphasise slightly the drought situation for the short rains, and for the drier areas. This qualification needs to be borne in mind.

Seasonal drought probabilities, using three arbitrarily defined classes of severity (light, moderate, and severe), are shown in Table A.5 for Machakos and Makindu (using Parry et al.'s series) and for our five stations. The table shows that except at two stations, a severe drought can be expected one year in four or five, both in the long and the short rains. There is little evidence to support the popular view that the short rains are more reliable.

The rainfall indices for each season and year at all seven stations are computed and averaged to produce a combined series from 1894 to 1988 (Figure A.10: the series for Machakos and Makindu were provided by T. E. Downing, Atmospheric Impact Research Group). Rainfall above the average is shown, as well as that below. It can be seen that variability is itself subject to change in the medium term (as pointed out by Parry et al - see above page 13). These changes do not appear to be related to the number of stations in the series (one only - Machakos - until 1903, two until 1956; six until 1962; and seven until 1988). It should be noted that this procedure uses averages for periods that are not identical.

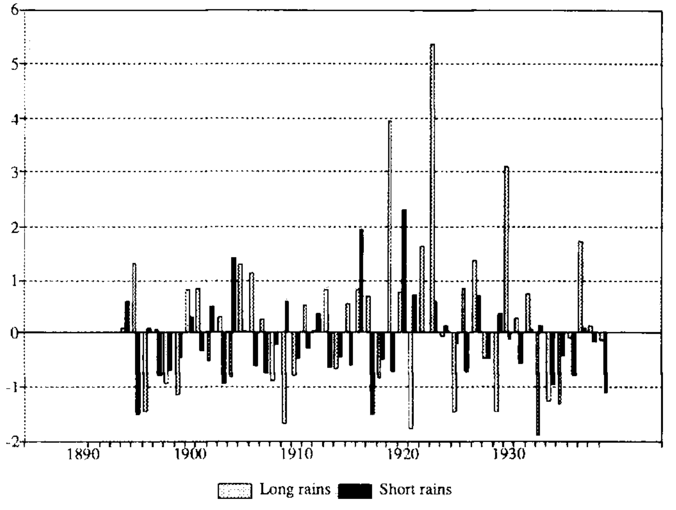
Table A.5: Seasonal drought probabilities using a drought index[1] (percentage of years)

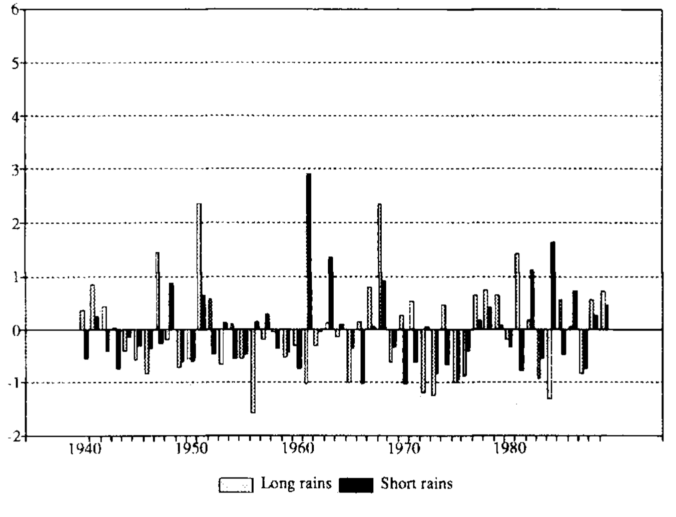
Season	*Machakos*	*Makindu*	*Kabaa*	*Kangundo*	*Katumani*	*Kampi ya Mawe*	*Kibwezi*	*Average[2]*
No of years	*90*	*80*	*34*	*34*	*34*	*29*	*34*	*86*
<u>Long rains (Mar-May)</u>								
Light drought or worse	43	51	47	50	38	45	38	44
Moderate drought or worse	39	40	38	38	26	28	29	40
Severe drought	24	23	26	24	26	24	24	29
<u>Short rains (Oct-Dec)</u>								
Light drought or worse	60	58	44	50	59	41	50	57
Moderate drought or worse	30	41	38	32	38	34	38	35
Severe drought	7	21	21	24	6	24	26	10

1 Light drought: DI ≤ −0.2; Moderate drought: DI ≤ −0.5; Severe drought: DI ≤ −0.8

2 Using a single series of drought indices constructed from available station series (see Figure A.10).

Figure A.10: **Rainfall (drought) index for Machakos District 1894-1988**





The droughts, especially when occurring in runs of two or more seasons, created food and fodder crises long remembered in the District. However, other factors combined with droughts to produce food shortages. Table A.6 reconstructs a chronology of drought in the District. It also collects, from several published sources, contemporary reports of the impact, causes and government responses to food and fodder shortages, from 1940 onwards.

Several observations arise from Table A.6.

1. Droughts occur characteristically in runs rather than singly. Of 90 light, moderate and severe seasonal droughts in our series, 70 occurred in runs of two or more seasons, and only 20 occurred singly. The longest runs of consecutive drought seasons were in 1897-99, 1949-50 and 1974-76 (all including four moderate or severe droughts). If single non-drought seasons are disregarded, the early 1970s were the worst period on record, with 10 moderate or severe droughts out of 16 seasons between 1969 and 1976. The years 1931-36 had six moderate or severe droughts in 12 seasons.

2. The 1940s were the last time that human mortality resulting from food shortage was reported on a significant scale in Kenya.

3. Livestock mortality continued to occur on a significant scale in the District up till the drought of 1983-4.

4. A rather poor correlation between measures of drought intensity and records of food shortages is to be expected in view of the following considerations:

    (a) records of food shortages are inadequate, especially of the earlier ones;

    (b) total seasonal rainfall does not necessarily provide a guide to crop or fodder production, as emphasised above;

    (c) the effects of drought (or flood, in at least one year) may have been compounded by other factors, such as war requisitions, maize marketing, or pests. In view of the complexity of such food crises, Table A.6 tells a surprisingly clear story.

Table A.6: **A chronology of droughts[1] and drought[2] cycles in Machakos**

Year	*Drought index* *LR*	*SR*	*Impact*[3]	*Causes understood of food/fodder crisis*	*Intervention by Government and others*
1895	-	-1.51(S)	'Yoa ya ngali'(= the	Drought, smallpox,	None
1896	-1.47(S)		carriage or Uganda Rail-	war, railway construction	
1897		-0.78(M)	way famine).		
1898	-0.94(S)	-0.69(M)	'Muvunga'(= sacks)		
1899	-1.14(S)	-0.44(L)	Human deaths (est.) up to 50-75% of population.		
1903		-0.93(S)	no		
1904	-0.81(S)		record		None
1907		-0.74(M)	'A minor famine'	Drought	
1908	-0.89(S)		(Lindblom)		
1909	-1.68(S)				
1910	-0.80(S)	-0.49(L)			
1913		-0.63(M)	Food	Drought (coincided	None
1914	-0.67(M)	-0.44(M)	shortages	with Sahelian famine)	
1917		-1.51(S)	No		
1918	-0.84(S)	-0.50(M)	record		
1928	-0.49(L)	-0.47(L)	'Kakuti'	Drought, locust, Quelea	Appeal for famine relief
1929	-1.47(S)		'Yua ya nzalukangye' (looking everywhere to find food); food shortage, denudation of grassland; cattle deaths	birds	dismissed by the Governor

(continued / ...)

Table A.6 *(continued)*: **A chronology of droughts[1] and drought cycles[2] in Machakos**

Year	*Drought index* *LR*	*SR*	*Impact[3]*	*Causes*	*Intervention*
1933	-1.90(S)		Food shortages,	Drought, locust	Maize and pigeon peas
1934	-1.26(L)	-0.96(S)	cattle deaths.		distributed; cattle tax
1935	-1.32(S)	-0.43(L)	Reports of intensified		suspended
1936		-0.78(M)	erosion		
1939		1.11(S)	Food	Drought, conscription	Compulsory destocking;
			shortage	(Italian/Somali war)	Maize imports; (crop exports
					banned)
1943		-0.73(M)			Maize imports
1944	-0.40(L)		25% foods needs produced	Drought, locusts,	Food relief
1945	-1.58(S)	-0.30(L)	Human mortality	smallpox,	Famine relief,
1946	-0.83(S)	-0.37(L)	(low)	military demands	intensified soil conservation
1949	-0.70(M)	-0.61(M)	'Makonge' (= sisal -		
1950	-0.56(M)	-0.60(M)	sold to buy food)		Famine relief, soil
			Food shortage	Drought	conservation, resettlement
1954		0.55(M)	Reduced	Drought	Conservation, resettlement,
1955	-0.55(M)	-0.49(L)	exports by 20-25%		dam building
1956	-1.57(S)		increased labour migration		
1960		-0.74(M)	'Ya mafuriko, na ndeke'		
1961	-1.03(S)	(+2.91)	(floods and aeroplanes)		
			Food shortage, cattle deaths,	Drought followed by floods	£10 million spent on
			(70%-80% among Maasai)		food aid; air drops

(continued / ...)

Table A.6 *(continued)*: **A chronology of droughts[1] and drought cycles[2] in Machakos**

Year	*Drought index LR*	*SR*	*Impact[3]*	*Causes*	*Intervention*
1965	-1.00(S)	-0.36(L)	Food and fodder shortages	Drought	Large food imports, cattle movements
1969	-0.61(M)	-0.34(M)	no record		
1971		-0.62(M)			
1972	-1.21(S)		Food and fodder shortages	Drought	Government food aid,
1973	-1.24(S)	-0.82(S)	cattle deaths		drought-resistant crops,
1974		-0.67(M)	(up to 80% among Maasai)		stock improvement
1975	-1.00(S)	-0.96(S)			schemes
1976	-0.88(S)	-0.41(L)			
1980		-0.47(L)	Food shortage	Drought, depletion of maize	NGO food for work
1981		-0.80(S)		stocks by early exports	programmes
1983	-0.92(S)	-0.54(M)	'Nikw'a ngwete' (I am dying	Drought, high prices	MIDP and other terracing
1984	-1.31(S)		with cash in my hands)		programmes, International
			Food shortage, cattle deaths		aid, yellow maize imports
1987	-0.82(M)	-0.75(M)			

Sources: Parry et al. (1987:130); Mutiso (1988); Owako (1969); Lindblom (1920: 24-5); Thomas (1974: 13); Peberdy (1958:10); Silberfein (1989).

Notes: L = light drought (DI = ≤—0.2); M = moderate drought (DI = ≤—0.5); S = severe drought (DI = ≤—0.8)

1. In selecting years for entry into this table, a drought is defined as two or more successive seasons having moderate or severe droughts. Single seasons are excluded on the ground that under a bimodal rainfall regime, it takes two meteorological droughts to create a food and fodder shortage. However, this principle may not be infallible. In 1925, a DI of −1.46 in the long rains generated widespread migration from lowland areas (Silberfein, 1987:83).
2. The duration of a drought cycle (shown by horizontal lines) is defined as including successive years in which one or both seasons had a light, moderate or severe drought, provided that not more than one non-drought season separated two drought seasons in the sequence.
3. The impact of a drought in the short rains is usually felt in the following calendar year.

7. CONCLUSION

An examination of selected data on rainfall shows that there is insufficient evidence of a generalised trend to support a firm hypothesis linking climatic with environmental change. Variability, rather than long-term change, was the most important characteristic of rainfall behaviour in Machakos District during the period 1957-90. Agricultural drought is still difficult to define in terms that accurately describe (or predict) crop and livestock production. Using a normalised index, a chronology of droughts has been constructed for the District from 1895 to 1990 (Table A.6). Droughts are categorised as mild, moderate or severe. Drought events have contributed to food shortages and fodder crises in combination with other factors. Droughts characteristically occur in runs of two or more seasons, and this amplifies their social, economic and environmental consequences. Interventions to ameliorate these consequences have not always been adequate or appropriate. Drought frequencies and magnitudes require continuous monitoring in relation to food supply and demand and the needs of the livestock sector.

B. SOIL EROSION

D.B. Thomas

1. INTRODUCTION: FORMS AND PROCESSES OF EROSION

Soil erosion by water is the most conspicuous form of land degradation in Machakos District. Erosion by wind occurs to a minor extent, but the damage caused is insignificant.

The main forms of water erosion are sheet, rill or gully erosion although a growing understanding of the processes of soil detachment and transport has shown that this classification is oversimplified. The importance of raindrop impact in detaching soil particles is now recognised, and what has been thought of as sheet erosion has been shown to include the concentration of runoff in fine rills. The first stage in the erosion process is inter-rill erosion, where soil is detached by raindrop splash and transported very slowly in overland flow. Rill erosion is the second stage, whereby runoff is concentrated, velocity is greater and detachment is mainly by scouring. Sheet erosion is the combined effect of inter-rill and rill erosion. It is conspicuous on grazing land, where it is associated with extensive areas of denuded ground. On cropland it is less noticeable, as cultivation obliterates the signs between one season and the next.

Gully erosion is an advanced form of rill erosion. Intermittent water flow, draining small catchments, results in 'water fall' erosion at the gully head, and deepening and widening of the gully below. Farmers interviewed say that most gullies were started by insignificant water flows in a footpath or stock track. However, once a gully has started it can grow rapidly by headward extension, scouring of the bed, and collapse of the walls.

There is no doubt that sheet, rill and gully erosion have taken an enormous toll of the soil resources of Machakos District, particularly in those areas which have been settled longest, and where a long period elapsed between the first recognition of the problem and the implementation of appropriate solutions.

There are other processes which occur locally, such as tunnel erosion, mass movement and watercourse erosion. Tunnel erosion (or piping) involves the lateral movement of water through the soil profile as a result of an impeded layer. This can lead to the removal of fine particles and the formation of tunnels. Eventually the surface collapses and a gully is created. It is most often seen on poor sandy soils. Mass movement, involving land slipping or slumping, is not very common, but does occur occasionally on steep land after periods of heavy rainfall. It is sometimes associated with bench terracing of steep slopes, where increased infiltration leads to high pore water pressures, and reduced shear strength causing failure of the embankments. Landslides have been reported in Kangundo, Mbooni and Kilome areas.

Watercourse erosion occurs in river beds where stream velocity is concentrated against the river bank, and where turbulent water causes eddies. Farmers observed that there has been a substantial widening and deepening of some watercourses.

The term 'hoe erosion' has been used by some writers to describe the steady downward movement of soil on steep slopes that takes place during hand cultivation.

In this Section, the progress of erosion in Machakos District during the period, 1930-1990, is assessed, using three approaches:

1. an historical approach using baseline and time-series data;

2. a measurement approach, reviewing the results of field experiments and computed indices of the rate of erosion; and

3. assessments of the trend in erosion on different classes of land, taking management into account and the progress of conservation works in particular.

2. AN HISTORICAL PROFILE OF EROSION

Reconstruction of soil erosion history is handicapped by a lack of baseline data of a quantitative nature for the beginning of the period of study. In the 1930s there were several descriptive accounts, but systematic inventories were not attempted (with the exception of Hobbs' data, discussed below). Attempts to quantify the rate and distribution of soil erosion began in the 1970s. This reconstruction, therefore, has to bring together descriptive assessments and inferences from the early period with the results of field measurements, air surveys, systematic interviewing and observations from the last two decades.

2.1 Origins

At the end of the nineteenth century, the Wakamba were mostly concentrated in the hills, and although the indigenous forest had mainly disappeared, the areas that were not cultivated were well covered with thorn bush or grass (Lindblom, 1920). The plains between the hills were used by the Wakamba for grazing, and sometimes by the Maasai. In his description of the vegetation in about 1910, Lindblom (pp.25-6) made no mention of erosion features, though he observed that the hillslopes had all been cleared for farming, and that the grass on the plains grew 'in patches, between which the soil is bare'.

Barnes (1937:1-2) interviewed Wakamba elders, European settlers and the missionary, Dr.Boedaker, in order to reconstruct the soil conditions of the country around the time of the British occupation. He describes bushland and grassland on the hills, absorbent topsoils and an absence of storm run-off; on the flatter country there was dense high grass, trees and a rich topsoil. The larger streams were perennial. Forest patches were rare. However, it is significant that on the hills 'there were some gulleys [sic] but they were covered with vegetation', and that 'there were a few stony patches in the Mbuti area where grass was poor'. This area (Muputi) was densely populated.

In 1898-99 there was an exceptional drought when the numbers of people and livestock were greatly reduced, and in 1909 the cattle population was decimated by rinderpest. It is reasonable to conclude, therefore, that during the early years of the century there were relatively few signs of denudation or erosion. 'Glowing reports are found [in travellers' accounts] of the wonderful grass to be seen on the caravan route' (Peberdy, 1958:2).

According to Barnes' Wakamba informants (pp.3-6), settled administration removed the fear of Maasai attacks, and they extended cultivation and grazing into the lower country, burning the long grass frequently to obtain short grass for the livestock, and destroying the bush trees for fuel and boma construction. Veterinary services and protection from theft increased their stock until, in drought years, grazing areas were trampled to dust and subsequent rain carried the topsoil away, filling streams with sand. The administration's encouragement of private land demarcation put a stop to shifting cultivation. Continuous cropping, together with extensive ploughing without conservation measures, led to soil exhaustion.

The Reserve was gazetted in 1906, and surrounded by European farms on the north-west and south, Crown land on the north-east, and uninhabited, tsetse-infested bush on the south-east. In 1913, Wakamba were banned from grazing unoccupied European farms, and in 1924 grazing on Crown land on the Yatta Plateau was stopped (Otieno, 1984:62) and later permitted on licence after payment of a fee. Thus encircled, the Wakamba lost access to large areas of free grazing to which they later laid customary claim, and which were especially important during drought. Overgrazing led to the degradat'on of the natural pastures and erosion of the soil.

Stock limitation became a prime objective of the administration, since to extend the Wakamba's access to grazing land was politically unacceptable:

> *It would be impolitic weakness, now to open the question of grazing lands. Instead, every inducement should be made to encourage the sale of surplus stock* (Annual Report, Ukamba Province, 1912; quoted in Otieno, 1984:61).

Serious droughts occurred in 1907-8, 1910, 1913-14, and 1917-18 (see Section A of this paper). Livestock mortality was inevitable, especially during the dry seasons, and especially of cattle.

> *It cannot be denied that the position is serious and that large numbers of native cattle die annually, literally from starvation. The granting of privileges outside the Reserve is however open to objection . . . it is certain that the more facilities the Kamba obtain, the more they will need in future* (Annual Report, Machakos District, 1922; quoted in Otieno, 1984:62).

Notwithstanding the administration's belief that the Reserve was overstocked, the first stock census in 1918-1919 (Peberdy, 1958:6) estimated that 963,000 acres of grazing were needed to carry the existing livestock - only 70% of the Reserve as defined in 1932.

Peberdy (1958) quotes the District Commissioner, Machakos writing as follows in 1927:

Since 1917 the reserve has become desiccated beyond all knowledge. Large areas which were good pasture land, and in some cases thick bush, are now only tracts of bare soil.

Cobb et al. (1929) reported that

A journey through the area east and south of Machakos reveals that over large stretches of hillsides vegetation has been almost wholly removed. The soil has been eroded down to the subsoil and its removal will continue at an ever increasing rate. On less steep slopes and on better land, vegetation persists and though Wakamba are primarily a pastoral tribe patches of cultivation are in evidence. But even there, the grazing has been so persistent that the ground is all beaten down into little stock paths and has in turn become open to erosion.

And in the same year the Hall Commission (para 121) reported that 'It is not too much to say that a desert has already been created'. It appears that the period from 1929-30 saw a significant deterioration. Famine occurred in 1929 on account of low rainfall and locusts, and Kioko (1973) dates the rapid deterioration of land in Kalama from this time.

From 1931 to 1936 there were six moderate or severe droughts in ten seasons, in only three of which the Rainfall Index was positive (see Section A). Beckley (1935) reported that in the Reserve, only areas with a high prevalence of tsetse fly were free from severe erosion, hills once forested were denuded and formerly perennial streams had become seasonal sand rivers. In 1935 the District was so badly denuded that a Reconditioning Committee was set up to formulate and carry out plans for rehabilitating African farming areas (see Conservation Profile).

2.2 Baseline assessments

The Kenya Land (Carter) Commission visited Machakos in 1932 and the publication of its report drew more attention to soil erosion there. In 1937, two substantial studies provided the most ambitious attempts so far to document soil erosion in the Ukamba Reserve. These were written by Maher (1937) and Barnes (1937). Shortly before, the agricultural officer, Hobbs, attempted to estimate the areas affected by erosion. His estimates were quoted by Maher and are reproduced below (Table B.1).

Maher began his Report by displaying his judgement in no uncertain terms (p.3):

The Machakos Reserve is an appalling example of a large area of land which has been subjected to uncoordinated and practically uncontrolled development by natives whose multiplication and the increase of whose stock has been permitted, free from the checks of war and largely from those of disease, under benevolent British rule.

Table B.1: Hobbs' estimates of eroded land (1937)

Location	*Area km²*	*Popn /km²*	*Cattle ha/animal*	*Sheep ha/animal*	*Goats ha/animal*	*Cultn %*	*Uncultivated land subject to erosion(%)*
1 Iveti	316	88	0.8	3.7	1.1	38	13
2 Kilungu	336	78	1.4	22.4	1.3	24	48
3 Mbooni	283	74	2.0	11.3	1.6	21	57
4 Kangundo	202	80	1.8	6.7	1.3	50	20
5 Matungu	182	86	1.4	9.1	2.6	51	22
6 Maputi	85	54	1.2	4.7	0.8	24	76
7 Kalama	170	47	1.4	6.8	1.5	29	59
8 Mukaa	243	51	1.8	11.0	2.0	25	50
9 Mwala	324	76	1.3	4.0	0.8	19	50
10 Masii	162	76	1.7	4.3	1.2	25	25
11 Kiteta	235	24	2.7	5.2	2.8	7	69
12 Kisau	250	17	1.8	11.4	1.4	7	f
13 Kibauni	648	12	8.6	25.9	4.6	3	f
14 Kaumoni	243	16	8.0	60.7	6.7	5	f
15 Nzaui	344	36	2.1	15.0	1.4	12	f
16 Mbitini	263	41	1.0	10.5	1.3	12	61
Total	4,283	50	1.7	8.5	1.6	19	56*

The location boundaries differ from the present ones and are shown in Map 1, Population Profile.
f = fly area * Locations 1-11 and 16 only.

> *Every phase of misuse of land is vividly and poignantly displayed in this Reserve, the inhabitants of which are rapidly drifting to a state of hopeless and miserable poverty and their land to a parching desert of rocks, stones and sand.*

Maher claimed that 'the greater part of the Ukamba Reserve has lost the topsoil through erosion. A considerable portion has also lost most of the sub-soil' (p.8). This was attributed, in descending order of importance, to the following: deforestation, overstocking, cultivation of slopes, overcultivation, ploughing, increases in the cultivated area, road drainage, and livestock damage. Thus farming as well as livestock systems were now seen as culpable. On the hills, he described the intensification of surface run-off as forests were removed, creating gullies up to 10m deep; and the stripping of the upper soil horizons ('black soils change to grey, grey changes to yellow, then . . . sharp quartz stones become seeded over the surface'). On the ridges he described ravines more than 100m deep, with 30-40% side slopes devoid of vegetation, every type of gully, exposure of the quartz stone lines ('stringers') by surface erosion, all due to overstocking - of cattle, and the 'ruin-bringing goat'- and shambas on unsuitable sites. The rivers, once perennial, were now but seasonal, liable to 'come down in spate, carrying tons of the soil of the Reserve towards the Indian Ocean' and drying again after a few hours. Maher proposed a scheme for reconditioning the

Reserve, arguing that 'strong and immediate measures are necessary' (see Working Paper: Conservation Profile).

In his more moderately written report, Barnes underwrote Maher's assessment.

> *I can say that there is really no part of the inhabited reserve that is free from erosion. Probably 75% suffers from severe erosion in various forms, parts of this almost amounting to complete destruction, 20% with less serious erosion and there may be 5% that is protected by trees or natural conditions* (p.6).

He offers a more detailed account of the Matungulu-Kangundo area,

> *. . . which must have been one of the finest stretches of agricultural land in Kenya . . . local natives say the land was not worked extensively until the War of 1914-1918. Prior to the War the slopes were covered with thick Bush Type Forest and had very fertile soil. One native told me that when he left to go to the War as a porter there was only isolated cultivation . . . [Now] In some parts cultivation is continuous for almost a square mile in a block, and there are only odd trees left all over the area.*
>
> *Now the whole area is suffering from erosion, natives will show you gulleys up to 30 feet deep with vertical sides that used to be paths through the bush. They say that many of these gulleys have increased from small watercourses to their present depth of over 20 feet in 10 or 20 years and two up to 18 feet deep in the last three years. The largest of these gullies are about a mile long. There is sheet erosion over the area and it is very severe to the north of Matungulu Government school.*
>
> *The reason they give for these gulleys is that the cover is now off the hills above but they do not realise that the enormously increased runoff is also due to the drop in humus content of these huge expanses of cultivation. They do attribute small washouts and gulleys to their own practice of marking out their plots with drains, which catch and concentrate the water.*
>
> *All natives agree that greatly increased areas are responsible for accelerated erosion on cultivated land. They rightly blame the use of ploughs without sufficient care and knowledge, many used to plough up and down hill. They also blame the use of cultivators with oxen* (p.4).

Hobbs' estimates of the extent of eroded land are reproduced in Table B.1 in percentage form, together with some related variables computed from his data. Hobbs' data are stated by Maher to be necessarily approximate; therefore, not too much should be made of them. A simple ranking test shows no significant correlation between the percentage eroded and any of the possible explanatory variables included in the table - population density, cultivated percentage or livestock densities. There is no way of knowing how reliable they are, nor are the criteria of 'eroded land' disclosed in the source.

The main value of the estimates is, first, an indication of the seriousness with which erosion was seen location by location, and second, the lower incidence of erosion estimated for the hilly locations Iveti, Kangundo and Matungulu. Although the lower and drier areas were badly affected, Masii stood out as an exception, which was attributed to less erodible soil and better vegetative cover.

The British Under Secretary of State for the Colonies visited Machakos District in August,1946, and the East African Standard reported that

> *He has now seen the worst-eroded parts of Kenya. In a tour through the Kamba reserve on Monday he drove mile after mile through hillsides and plains swept bare in many places to the solid rock, through areas where there was hardly a vestige of grass, through acre after acre of dead and wilted maize* (Peberdy, 1958).

2.3 Erosion in Kalama, 1948-74

The first attempt to use air photographs in erosion assessment was made by Thomas (1974) in the Wamui River basin in Kalama Location, which Hobbs considered almost 60% eroded in 1937. Thomas used air photography of February, 1948 (scale 1:25,000) and January, 1972 (scale 1:12,500). The results of his analysis in a sub-catchment of 1.73 km^2 are shown in Table B.2. A technique of micro-analysis at 29 controlled sites was applied to both sets of photographs.

Table B.2: Soil erosion and land use in a sub-catchment of the Wamui River Basin, Kalama, 1948-72

Feature	*1948*	*1972*	*Change*
Non-arable land:			
Moderate erosion %	22	26	+4
Severe erosion %	26	37	+11
Total erosion %	48	63	+15
Cultivated land %	*18*	*26*	*+8*
Contour banks (m/ha cultivated)	195	667	+462
Sisal rows (m/ha total area)	16	122	+106

Source: Thomas (1974).

Of the 29 sites, 10 showed no change in the extent of erosion, 5 showed a decrease and 14 an increase.

This study drew attention to a fundamental divergence between the impact of grazing and that of cultivation on erosion. No distinction had been made by Maher. But since the 1930s a massive programme of soil conservation had concentrated on cultivated land, whose increase could no longer be blamed for erosion:

> *There is no evidence to show that the increase in the area of erosion is a direct result of increased cultivation. The increase in the area of cultivated land reduces the land available for grazing. As the flatter land is taken for crops, livestock are concentrated on the steeper and more fragile slopes. An increase in the length of contour banks reveals a substantial input of time and effort into soil conservation. Although there is more cultivated land in 1972 than in 1948 it is also very much better protected against erosion* (pp 61-2).

Sisal rows also provided protection.

Notwithstanding the fact that crops provide poor ground cover in the early part of the rainy season, when rainfall intensity is high, estimates of ground cover at 19 sites on grazing land in 1974 showed that 42% of the surface was bare and soil was much more compacted than on cultivated land (pp 63-7).

Gully formation is an extension of the natural drainage network, and often occurs in cycles set off by natural or man-made events. The Kalama study showed that the main extension in channel length was completed by 1948, though the 1972 photographs indicated continuing widening, and ground surveys showed some deepening. Evidence obtained from informants who could remember the histories of gullies, together with an absence of any mention of them by travellers who passed through the area in the 1890s (Lugard, quoted in Perham, 1959; Gregory, 1896), lead to the following conclusion. Deterioration in ground cover led to high rates of runoff, rapid erosion and a rapid extension of the drainage network through the incision of watercourses and gullying between about 1915 and 1950, with peak rates of deterioration in the 1930s and 1940s. During these decades the incidence of drought was high (see Section A).

Zöbisch (1986) studied air photographs for 1948, 1967 and 1978 of four catchments varying in size from 166-307 ha. The results for two catchments (Kalusi and Makulani) are presented in Table B.3. They show that between 1948 and 1978 an increase of 50%-100% in the area of land under cultivation, and a marked increase in that which was protected by conservation measures. During the same period the total area of bush/grazing land declined, and the percentage with good cover, which was already low, dropped even further. Erosion on the cultivated land was reduced owing to the installation of conservation measures, but it increased on the grazing land owing to concentration of livestock on a smaller area. It appears that only in the late 1980s was a major reduction of erosion on grazing land, attributable to better management, taking place. Figures to support this contention are not yet available.

Table B.3: Land use change in two catchments

Study catchment	*Kalusi*			*Makulani*		
Size (ha)	*238*			*166*		
Year of photography	*1948*	*1967*	*1978*	*1948*	*1967*	*1978*
1 Arable Areas Total (%)	31.5	59.5	48.8	16.3	24.7	37.5
2 Without soil conservation (%)	22.1	15.3	2.9	15.7	12.7	6.7
3 With soil conservation (%)	9.4	44.2	45.8	0.6	12.0	30.7
4 Bush and grazing total (%)	67.3	38.8	50.5	83.7	75.3	62.5
5 Poor cover <50%	53.3	33.5	44.8	75.3	66.0	59.9
6 Sufficient cover 50% or over	14.0	5.3	5.8	8.4	9.3	2.7
7 Woodland and forest (%)	1.2	1.7	0.7	0	0	0
8 Soil conserving land use (3+6+7) (%)	25	51	52	9	21	33
9 Homesteads (%)	15	51	59	6	10	24
10 Roads, tracks (%)	1.20	2.03	3.06	0	1.35	2.13

Source: Zöbisch, 1986:102.

2.4 Erosion in 1981-85

An assessment of soil erosion in the District in 1981 was carried out by Reid (1982), using low level colour air photographs taken in a reconnaissance sample frame (Ecosystems, 1982), and other sources. Erosion 'events' - gullies, rills on agricultural land, sheetwash and streambank erosion - were quantified in 25 km^2 cells. The gullies were analyzed in terms of a number of possible explanatory variables. It was found that (p 23):

(a) gully frequency tends to increase with slope up to about 6° but is not significantly greater than average on steeper slopes, except in agro-climatic zone 5.[1]

(b) gullies are more frequent on grazing land than on cultivated; especially on slopes of 4-15°; (Figure B.1)

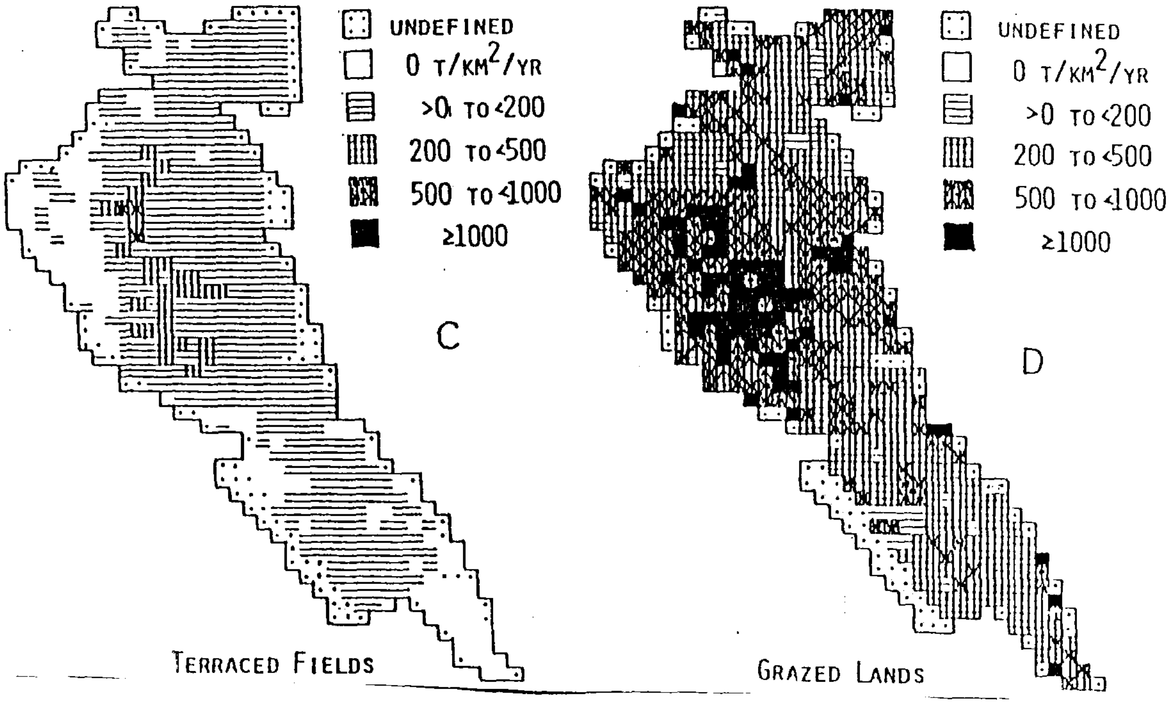
(c) on grazing land, gully frequency increases with stocking density, and so do gullies on steeper slopes;

(d) in agro-climatic zone 5, gullies are more frequent than in zones 4 and 2/3;

---

[1] The zones used correspond only approximately to our agro-ecological zones (see Sombroek et al, 1982 and Jaetzold and Schmidt, 1982).

Figure B.1: Sediment production rates from rill and sheetwash erosion
C: terraced fields; D: grazing lands (after Reid, 1982:Maps 5B, 5D)



(e) other things being equal, gullies are more frequent on free draining inceptisols and less frequent on black clay vertisols than the average.

It was also concluded that the bulk of gully erosion had already occurred, confirming Thomas' interpretation.

Using the Universal Soil Loss Equation (USLE), Reid estimated the relative soil loss from gullying, and from sheetwash and rill erosion on different types of land use (Figure B.1). The results show the relative importance of erosion on grazing land.

A second set of low level photographs were taken 4.5 years later, in 1985 (Ecosystems, 1985-6, vol.4). Between the two surveys, there were three successive drought seasons: in the long rains of 1983 (a severe drought), the following short rains (a moderate drought), and the long rains of 1984 (severe). Ecosystems derived an erosion index from the areas subject to gully erosion, bare ground, and arable land showing rills and sheetwash. The indices (Table B.4) show an increase in the extent of erosion between 1981 and 1985.

However, the values given to the erosion index and to its components (ibid., Table 2.13) are very low in relation to estimates of the extent of eroded land obtained by field researchers. The sampling method used non-coincident sets for the two years. The reliability of this deteriorating trend is considered to be uncertain.

That this was a temporary setback in an otherwise declining long term trend cannot be in doubt, for reasons given below. The changes show a clear relationship with ecology. Even though the locational boundaries fit clumsily into agro-ecological zones, when the locations are so allocated, it appears that the average erosion indices for 1985 were lowest in zones 2/3 and highest in zones 5/6, and the percentage changes in the average erosion indices vary in the same way (Table B.4). If we accept that the deterioration during the period was due to drought, this table demonstrates the susceptibility of the drier areas to drought-induced degradation, and the greater vulnerability of conservation efforts in such areas.

Table B.4: Erosion indices and AEZ, 1981-1985

AEZ	*Average erosion index*		
	1981	*1985*	*Change (%)*
2/3 (average of 8 locations)	2.9	3.2	10
4 (average of 15 locations)	4.2	5.4	29
5/6 (average of 14 locations)	3.7	6.8	84

Based on Ecosystems 1985-6, vol 2, Table 3.33; 1985 vol.3, Table 2.26.

3. MEASURING THE RATE OF EROSION

Studies on soil loss, runoff and sedimentation were carried out by various workers in the 1970s and 1980s using rainfall simulation (Barber et al., 1979; Moore et al. 1979); small runoff plots (Styczen, 1983); large runoff plots (Ulsaker and Kilewe, 1983; Kilewe, 1987); and catchments (Wain, 1983, Edwards, 1979, Thomas et al. 1981 and Muya, 1990).

A small rainfall simulator was used to compare runoff rates and soil loss from crop land at Katumani and from grazing land at Iiuni under four different conditions: (1) bare and compacted, (2) newly established grass, (3) permanent grass with good cover and (4) land with a surface layer of quartz (Barber et al., 1979; Moore et al., 1979; and Thomas et al., 1981). Extensive areas of denuded grazing land were noticeable at this time, and the high runoff rates from such land pointed to the urgent need for revegetation, and the tendency for the denuded condition to persist in the absence of measures to improve infiltration.

The studies at Iiuni were linked to measurements of stream flow and sediment yield from a catchment of 11.3 km^2 and the following estimates were made of the rates of erosion.

During the current study estimates of erosion were made at Makueni by measuring the exposure of tree roots and grass clumps. The erosion rates were obtained by dividing the eroded depth with the number of years since settlement had taken place. It was noted that a number of bushes were left on residual mounds about 30cm above the surface, and since the area was settled 40 years previously, the erosion rate amounts to about 7.5 mm/yr, roughly equivalent to about 90 t/ha/yr. Such a figure is comparable with those reported by Moore et al. (1979) and Thomas and Barber (1983), though higher than those quoted above (Table B.5).

Table B.5: Estimated soil loss from the Iiuni catchment

Land use	*Percent of area*	*Soil loss (t/ha/yr)*
Degraded grazing land	37	53.3
Cultivated land	43	16.0
Good grazing/bush/woodland	20	1.1
Weighted mean soil loss at source		26.8
Catchment soil loss		5.4

Source: Thomas et al. 1981

Wain (1983) calculated the average annual sediment yield for the Thwake river basin at 12.7 t/ha/yr and compared this with an estimate of 15.0 t/ha/yr for the Maruba river made by Edwards (1979). He concluded that the figure of 5.4 t/h/yr for the Iiuni catchment, which is within the Thwake river basin, was below the average. Styczen (1983) obtained soil losses of 20-30 t/ha/yr from small plots of rangeland with low cover, and showed that if cover exceeds 30%, losses are much reduced.

In all these studies, it is important to note that high rates of erosion do occur locally where ground is severely denuded, especially if it is sloping. However, within any give catchment there are some areas that are well vegetated and conserved, and there are areas of deposition as well as erosion. Overall rates of catchment erosion are therefore much less than soil loss at source from denuded ground (Table B.5).

A recent study by Muya (1990) investigated the sedimentation of the Kwa Miui and Ndoloni reservoirs near Salama and related this to land use within the catchment. The Kwa Miui reservoir is typical of many in the District. It was constructed around 1955 and filled rapidly with sediment to the level of the spillway, which broke in 1970.

Reid (1982) estimated the rates of soil loss from gullying and from rill and sheetwash erosion throughout the District. For estimating soil loss from rill and sheetwash erosion, she used the USLE with local values for the indices (rainfall erosivity, soil erodibility, slope, cropping factor and management or conservation factor). The results (see Figure B.1) show a sharp differentiation in the rates of erosion and in the proportions of soil loss contributed by grazing land, cultivated land, roads and gullies. Assuming that all cultivated land is well terraced, the major contribution to soil loss comes from grazing land though under a less favourable management assumption, cultivated land makes a much larger contribution. Roads have the highest rates of soil loss, but cover a small area. The data is reproduced in the Appendix to this Section.

The overall conclusion from the data available is that erosion rates have been very high, especially on grazing land which was denuded of ground cover, on cultivated land where there were no conservation measures, and on unpaved roads. As noted by Barber (1983) most estimates are liable to gross errors and should be used with caution. Although there is little data, there are strong reasons to believe that the rate of soil erosion on crop land and on grazing land has been much reduced in recent years. The reasons for this are discussed in the next section.

4. EROSION ON CROP LAND

Erosion is commonly associated with lack of cover and where annual crops are grown there is normally little cover to the ground for the first month after planting, when crops are germinating and becoming established. This is generally the time at which the heaviest rains can be expected (Fisher, 1978). If land is sloping and there are no conservation measures, erosion can be rapid. However, at the present time, almost all cropland has some form of erosion control. At one end of the spectrum there is land which has excellent terraces that retain all rainfall in situ and from which there are no losses of soil or water. At the other end there is crop land from which the movement of soil and water is only partially restricted by narrow strips of uncultivated land, planted grass or trash lines.

Clearly the steeper the land the greater the likelihood of erosion. However, the steeper land is generally that which has been settled longest and on which the greatest effort at erosion control by terracing has been expended. Also being mainly in the hills it has a more humid climate and perennial crops, such as coffee and bananas, are common. Once these are established they can provide a fair measure of ground cover and are certainly much more effective than annuals in erosion control. Appendix 1 shows that the erosion index is lowest in the hill areas such as Kangundo, Lower Mbooni and Kilungu.

Erosion on crop land is therefore associated mainly with annual crops, with perennials during the early years of establishment, with sloping land that lacks effective conservation measures, and with terraces that are incorrectly laid out, poorly constructed or not stabilised with grass.

One area that reveals serious erosion problems on cropland is near Mavindini in Kathonzweni Location. On the 1978 aerial photos many of the fields can be seen to have rills running from the upper to the lower part of the slope and crossing the conservation structures. These rills appear whitish indicating that the upper organic soil horizon has been removed and a less fertile subsoil exposed. It is noticeable, however, that in some fields the upper part, nearer the homestead, appears to have better terraces and few if any rills.

A visit to the site showed that the rills do indeed cross the existing conservation structures and that soil is continuing to move. It can be postulated that when the area was settled in the late 1950s or early 1960s and land was cleared from tall *Acacia/Commiphora* bushland, cultivation began with little attention to conservation structures. After some years and probably some heavy storms, rills began to appear and sooner or later most farmers started to make terraces or leave narrow strips of grass on the contour. Terracing generally starts near the homestead and when resources of labour are available is continued to the lower slopes. For the farmer with limited resources this process may take years, during which time erosion continues and the lower slopes become progressively more dissected.

After new land is cleared for cultivation, the organic matter levels can be expected to decline and if farmers fail to install effective conservation measures, the risk of erosion is high especially on sloping land. The farmers who settled in the drier areas, were, by and large, those with limited resources, who did not have a significant income from employment or business. Priority would be attached to building an adequate house and the urgency of making proper terraces might not become apparent till rills had appeared and damage had already been done. Once rills have developed, it is more difficult to make effective conservation structures owing to the concentration of runoff.

The time lag between the start of erosion processes soon after clearing, the recognition of erosion as a problem and the implementation of effective solutions may have been in the order of ten to twenty years or more, which is long enough for permanent and irreversible damage to take place on the rather infertile soils of the basement complex.

In certain circumstances where erosion is severe, soils are shallow, and nutrient status is low, the land may decline in productivity so rapidly that cultivation has to be abandoned. Evidence from the Kambu area near Kibwezi suggests that this can happen within twenty to thirty years of settlement. Lack of title to land may be responsible for delay in undertaking conservation work.

Farmers are now well aware of the significance of the erosion hazard, the need to control it and the ways in which this can be done. They are also well aware that land is severely restricted and free land is no longer available. They are therefore putting much more effort into soil conservation than in the past. The time lag between clearing new land for cultivation and installing suitable conservation measures is much less now than in the past (as in areas of Ngwata settled in the 1970s). It can be assumed that the rate of erosion on crop land is being reduced.

Shortening the time lag between the risk or onset of erosion and efforts to prevent it may be attributed to many factors (see Conservation Profile).

5. EROSION ON GRAZING LAND

Erosion of grazing land in Machakos District has been noted since the early years of the century and has been one of the hardest problems to deal with (Pole-Evans, 1939; Pereira and Beckley, 1952; Peberdy, 1958). The problem was aggravated by periodic droughts, when the activities of termites became even more noticeable than usual, and areas of bare or nearly bare ground expanded and coalesced in the manner of a skin disease. With the extension of cultivation on the flatter land, livestock became confined to the steeper slopes which are more prone to degradation.

Although the problem appeared for a long time to be almost insoluble, it is clear that changes have been taking place and the situation is now much more hopeful than in the past. One major reason for this is that most land has been demarcated and registered. Boundaries are now generally recognised and respected and it is not uncommon to find one farm with well managed grazing land separated only by a sisal hedge from another with poor cover.

Another reason for the improvement in grazing management is the change in attitude to livestock. The importance of livestock for social functions such as bride price has declined. The increased value attached to education and to improved housing together with the growth of the urban market and improved prices has stimulated the sale of livestock. Furthermore, livestock are no longer the only form of security as the ways of income generation have multiplied and the employment sector has grown. Although oxen are still the main form of power for cultivation there has been an increasing trend towards fodder growing and stall feeding which has, on certain farms and to some extent, reduced the pressure on natural pasture and the hazard of erosion.

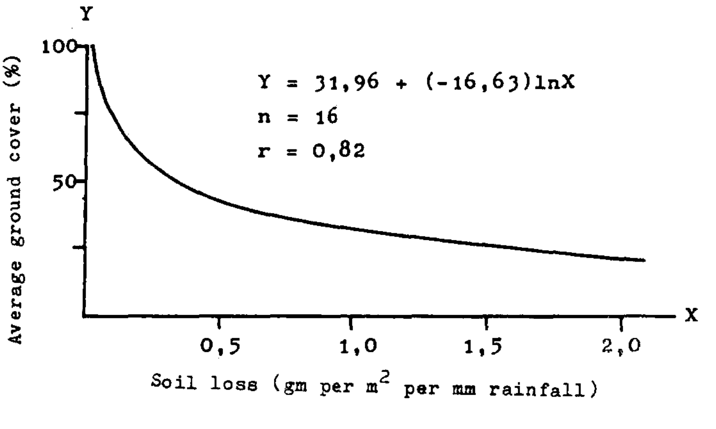
Finally, it is now recognised that there is no new land available and failure to care for what there is will jeopardise future production. Improved management of grazing land can be seen in the efforts made to enclose the land in paddocks and to remove unwanted bush.

An improvement in the general condition of grazing land in recent years is also attributable to better rainfall, and there will no doubt be a deterioration in cover when the next sequence of dry years occurs (see Table B.4). And there are certain areas near water supplies where livestock are concentrated that continue to degrade, due to the combined effects of grazing pressure and livestock tracking and trampling (Muya, 1990). This problem is somewhat diminished due to improvements in water supply and distribution but is likely to continue as long as communal water points are needed.

But there are still patches of bare land which are not connected with water points and a study of aerial photos indicates that some of them have been bare for a very long time. An example of the above is the patches of denuded land at Kamweleni, about 10 km southeast of Machakos town, which are bare now and were bare at the time when the 1948 aerial photos were taken. Examination of these bare patches reveals lines running across the surface that are due to a ploughshare digging into the subsoil at some time in the past when the land was under cultivation. As the topsoil has since gone the lines are now on the surface. What appears to have happened is that the land was cultivated until yields declined to the point at which it was abandoned. Due to the slope of the ground, the tendency of the soil to cap, and its diminished fertility, a high rate of runoff and erosion continued, and natural vegetation failed to establish itself (Chepkwony, 1980). Measurements from erosion pins suggest that a loss of soil depth of up to 7 mm per annum is possible on such areas (Thomas and Barber, 1983).

Studies on the erosion of grazing land were carried out by Zöbisch (1986) using 16 Gerlach troughs, 0.5m long, collecting runoff and eroded soil from grazing land sites with good, medium and poor vegetative cover. The slope lengths varied from 9-15 m and the percent slope was in the range of 14-42. Results showed that soil loss was closely correlated with ground cover and that an increase in cover from 20-40% led to a major reduction in soil loss (Figure B.2) This emphasises the importance of a management strategy that will permit an adequate degree of vegetative cover to be maintained. Zöbisch also found that measurements of soil loss from erosion pins exceeded the loss measured by Gerlach troughs.

Figure B.2: Influence of vegetative cover on soil loss (Zöbisch, 1986:123)



One factor which influences the rate of erosion on grazing land is the presence of a quartz layer on the surface. A quartz horizon 1-2 m below the surface is a common feature of the soils derived from metamorphic rocks. Where there is quartz at the surface, it is commonly an indication that the upper soil horizons have been stripped off by erosion (Leslie et al., 1979). A surface layer of quartz decreases the erosion rate in a number of ways. In the first place, stones intercept raindrop energy and runoff scour forces; second, they retard runoff and allow more time for infiltration; and third, they facilitate the establishment and survival of grasses and other plants which are less easily grazed down to the roots or trampled out of existence (Thomas and Barber, 1983). In certain areas it is noticeable that there are patches of ground where the soil surface is sealed and bare, adjacent to quartz covered land which is well vegetated. It is possible therefore that the rate of erosion on grazing land has decreased not only because of better management, but also because of the removal of the most easily eroded material.

Overall the picture is one of gradual improvement in cover on grazing land and it can be assumed from research carried out in Kenya and elsewhere that there will be a concomitant reduction in the rate of erosion. The increase in the area of crop land, and the improvements which have taken place in the condition of grazing land in recent years, suggest that the proportion of total sediment derived from grazing land may have declined.

6. OTHER TYPES OF EROSION

Gully erosion is currently stabilising in the areas of the District which have been settled longest. In some places gully side slopes have reached stable angles and have become revegetated with bushes and grass. In others, the process of stabilisation is not yet complete and slumping of side walls and increase of top width is still taking place.

Some areas which have been recently settled show signs of gully initiation, and the rate at which gullies have developed indicates the need for urgent measures to prevent irreversible damage. As in the past, gully initiation is frequently associated with stock tracks and footpaths and is particularly noticeable around watering points.

Most streams and rivers are ephemeral, except for those which derive their flow from underground sources, such as the Kibwezi and Kambu rivers. Those arising directly from the basement land surface receive the biggest proportion of flow from surface runoff. In the past, many of these watercourses have been choked with sand, and water can usually be found in the dry season by digging below the surface. Hundreds (perhaps thousands) of masonry or concrete 'sand dams' assist in the storage of sand and water. The growing demand for sand for building construction has led to extraction which exceeds the rate of renewal in stretches of certain rivers.

One consequence is to deprive the inhabitants of water in the dry season. The conflict of interests over sand has actually led to some violence in which a few people have died. Another consequence is an increase in river bank erosion, due to a lowering of the level where runoff joins the river, and to lorries creating tracks that have led to the formation of gullies (Mburu, 1990). Assuming that improvements in conservation practices are leading to reduced sediment yields from hillslopes, the rate of replenishment of sand may be lower now than in the past.

7. CONCLUSIONS

1. A reconstruction of the history of erosion in Machakos District has shown that erosion has been reduced since the 1930s but has by no means ceased. Its intensity is highly variable over the District.

2. Field measurements of the rate of erosion suggest rates in the range 5-15 t/ha/yr for whole catchments, but much higher figures have been obtained from badly eroding sites.

3. The greater proportion of soil loss continues to occur on grazing land but the relative contribution from cultivated land varies according to the quality and maintenance of the terraces.

4. Erosion on crop land has been reduced as a result of improvements in terracing rather than changes to the cropping system. Greater awareness appear to have shortened the time lag between opening new land for cultivation and installing terraces to control erosion.

5. Erosion on grazing land has been reduced due to land demarcation and registration, as a result of which boundaries are respected and communal grazing has almost disappeared. It has also been due to changing attitudes to land and livestock and greater awareness of the need to maintain cover. The higher rainfall in the last few years has aided the recovery of some areas which were formerly denuded. However erosion around communal stock watering points is still a threat.

6. The rainfall record, taken in conjunction with the evidence on soil erosion, and the observations made at the time, suggests a strong link between periods of drought, denudation of grazing lands, and intensified erosion.

7. Erosion is still occurring alongside roads and in certain places where road drainage has been discharged from culverts onto steep slopes without proper measures for stabilisation.

8. Erosion from gullies, other than those caused by road drainage, has been reduced partly because many of the older gullies, extremely active 50-60 years ago, have now become stabilised. Gullying associated with livestock tracking may have declined due to a possible reduction in stock number and improvements in water distribution.

9. Erosion from streambanks has in some places increased due to the extraction of sand for building.

APPENDIX TO SECTION B

SEDIMENT PRODUCTION VOLUMES AND RATES ACCORDING TO ADMINISTRATIVE LOCATIONS

Division (1981)	*Location*	*Erosion Index*[1]		*Avg. sediment production (t/km^2-yr)*[2]				*Avg. erosion rate (t/ha-yr) per unit area of given land use*			
		1981	*1985*	*Grazed land*	*Terraced land*	*Roads*[3]	*Gullies*	*Grazed land*	*Terraced land*	*Roads*[3]	*Gullies*
Yatta	Masinga	4.3	5.6	480	40	70	40	6.5	2.0	70	0.4
	Matuu	6.7	8.9								
	Ndalani	3.5	3.9	590	40	160	40	7.1	3.5	100	0.4
	Ndithini	3.4	3.6								
	Kinyatta	1.4	5.1	450	40	50	3	6.0	1.2	50	0.03
Kangundo	Matungulu	1.5	2.4	560	60	150	8	7.3	4.2	100	0.1
	Mbiuni	3.3	6.6	550	100	160	30	8.2	4.7	130	0.3
	Kangundu	1.5	1.5	870	160	360	40	12.0	9.6	240	0.4
	Mwala	4.1	4.8	500	50	140	40	6.9	1.9	70	0.4
Iveti North	Wamunyu	9.1	14.1	680	60	150	90	9.6	2.7	100	0.9
	Mitaboni	1.3	6.3	820	270	310	20	13.0	13.0	280	0.2
	Masii	6.2	3.3	630	60	190	40	8.6	3.3	150	0.4
Iveti South	Iveti	1.4	1.3	1100	120	420	10	14.0	12.0	310	0.1
	Maputi	5.2	2.5	1200	230	310	170	17.0	14.0	280	1.7
	Settled Area	0.4	1.7	650	10	60	8	8.8	1.8	50	0.1
Kilome	Mukaa	2.7	3.2	900	70	150	30	11.0	5.6	140	0.3
	Kalama	9.2	9.0	1200	200	240	50	16.0	13.0	250	0.5
	Kilungu	5.8	1.7	1600	210	390	20	20.0	25.0	290	0.2
	Ukia	1.9	2.3	1300	130	280	20	16.0	12.0	230	0.2

(continued / ...)

Division (1981)	*Location*	*Erosion Index*[1]		*Avg. sediment production (t/km²-yr)*[2]				*Avg. erosion rate (t/ha-yr) per unit area of given land use*			
		1981	*1985*	*Grazed land*	*Terraced land*	*Roads*[3]	*Gullies*	*Grazed land*	*Terraced land*	*Roads*[3]	*Gullies*
Mbooni	Muthetheni	7.6	6.6	470	60	160	40	7.5	2.0	90	0.4
	Mbooni	5.5	1.8	1000	220	340	40	15.0	14.0	320	0.4
	Kiteta	2.1	7.5	480	100	190	70	8.4	3.2	140	0.7
	Kisau	3.4	11.5	700	100	140	40	11.0	5.6	120	0.4
	Kibauni	6.3	16.9	1000	60	120	70	13.0	4.7	80	0.7
Makueni	Makueni	6.7	4.0	500	40	60	40	7.0	1.6	60	0.4
	Kathonzweni	4.9	5.3								
	Nzaui	4.1	6.5	710	70	180	40	9.1	5.2	150	0.4
	Mbitini	2.0	3.7	1000	100	130	40	13.0	10.0	220	0.4
Kibwezi	Kikumbulyu	2.9	4.8	410	8	20	7	4.7	0.9	40	0.1
	Makindu	1.2	11.3								
	Ngwata	0.7	3.5	350	10	20	3	4.2	0.6	30	0.03
	Mtito Andei	0.2	6.2								
	Tsavo N.P.			310	0	5	10	3.1	0.6	30	0.1

Notes:

1 Derived from the area of gully erosion, bare ground, and arable land subject to rills or sheetwash.

2 values assume actual distribution of land use. In Masinga, for example, there are an average of 480 t of sediment produced annually from that proportion of a km^2 which is, on average, grazed.

3 Rates calculated for third-order roads, which are most common.

Source: Ecosystems (1985, Vols 2, 3); Reid (1982, Table 13.)

C. SOIL FERTILITY

J.P. Mbuvi

1. INTRODUCTION

This section addresses the question of the degradation of the physical, chemical and biological properties of soils under arable or grazing management. It is now recognised that the fertility losses caused by erosion are as important as the physical removal of soil, and need to be addressed by conservation strategies (Stocking, 1984; Stocking and Peake, 1985; Young, 1989). The monitoring of soil properties over time is not normally included in the mandates of soil survey organisations, and few systematic attempts have been made to do it (Young, in press). Methods for assessing soil degradation at the world scale are at an early stage of development (FAO, 1979), and have rather limited practical value at the local scale (Stocking, 1986).

In the present study we aimed to make use of existing materials and to supplement these, where necessary, with small scale sampling and analysis of topsoils. Two methods are available: the longitudinal method and the spatial analogue method. In the first, soils are monitored at a number of controlled sites over a period of time. This requires baseline samples and analytical results of at least a decade ago, if significant changes are to be detected. The second is a fall-back method where baseline materials are not available. Samples are analysed from sites with known management regimes (cultivation, grazing) and compared with samples from control sites under natural vegetation, and the nature of changes through time are inferred from the differences.

2. THE LONGITUDINAL STUDY

2.1 Baseline materials

In addressing the question of soil degradation in Machakos District, a search was first made for baseline materials. It was hoped that soil samples from soil surveys undertaken at least a decade ago might be located, in order to re-analyse them alongside fresh samples of topsoil from the same sites (this method has been tried in Nigeria: Mortimore, Essiet and Patrick, 1990). However, the soil archives of the Kenya Soil Survey were destroyed a few years ago. It was therefore decided to use the recorded analytical data from surveys conducted in 1977 (Van de Weg and Mbuvi,1975; Sketchley et al.,1979; Muchena et al., in prep.) as a baseline, to search in the field for the profile pits used, and to collect fresh composite samples of topsoil from the vicinity of each pit for laboratory analysis. The analyses were carried out in the laboratories of the Kenya Agricultural Research Institute, using identical procedures.

The distribution of available samples is less than ideal from the perspective of the present study. Of 30 located, 26 are in the Makueni area and only 4 in the northern Machakos area. The data files for samples collected in the Kangundo and Wamunyu areas, and most of those collected in the Machakos area, could not be found, and some analytical work was still uncompleted in 1990. Also, the original samples were all collected from pits on uncultivated land, and only seven are currently under cultivation.

Most of the profile pits were still open as they were located on uncultivated areas. Even in places where cultivation had taken place, the profile sites were left clear. Therefore it follows that the data presented below are from the same points as those sampled in 1977 or earlier. The soil samples were collected from four different sites around each pit. These samples were mixed together and a sufficient amount collected for analysis from the composite sample.[1]

The most common soils sampled belong to the Ferralsols and Luvisols groups according to the FAO classification; Arenosols, Cambisols, Nitosols, Phaeozems and Vertisols are represented, but infrequent.

2.2 Results (Tables C.1 and C.2)

In 1977, all sites were uncultivated. In 1990, some of them had been under cultivation for two seasons, so their results are shown in a separate column of the tables.

Readily available plant nutrients (Table C.1) are for the greater part stored in the soil organic matter. The soils under investigation contain as a whole very little organic matter. Percentage carbon varies from 0.2 to 1.5. The majority contain less than 1.0% carbon, implying that they are low on organic matter. Again, the soils are low on nitrogen, as all except one contain less than 0.2%.

A majority (22 of 30 sites) declined in carbon percentage during the period, and the trend in both cultivated and uncultivated land, in both areas, was downwards. But in nitrogen, there was no significant general trend.

Available phosphorus figures are generally low; 18 profiles have less than 20 ppm, indicating a rather acute deficiency in both 1977 and 1990. Six were moderately supplied in 1977 but

---

[1] All the soil samples were taken to the National Agricultural Research Laboratories for analysis. Once in the laboratory, the samples were broken up of aggregates by carefully pounding with pestle and mortar and sieving through a 2 mm sieve. Extraction of the soil was done by shaking for one hour at a 1.5 ratio with 0.1N HC1/0.025N.

H2SO4, Ca, K and Na are determined by EEL flame photometer, with addition of Lanthanum Chloride for Ca.

Mg is determined colorimetrically with Thiazol yellow reagent. For P, the vanadomolybdophosphoric yellow method is used. Mn is measured colorimetrically using phosphoric acid-potassiumperiodate for colour development (Mehlich et al.,1962).

Table C.1: Soil chemical properties, 1977 and 1990

Property	*Year*	*Makueni area* *Uncultivated (19 sites)*	*Cultivated (7 sites)*	*Northern Machakos area (4 sites)*
Carbon (%)	1977	0.88	0.86	0.96
	1990	0.67	0.75	0.72
Nitrogen(%)	1977	0.11	0.09	0.09
	1990	0.10	0.10	0.09
Phosphorus(ppm)	1977	23.0	17.0	5.0
	1990	22.0	9.0	7.0
Calcium (me%)	1977	3.5	4.1	1.5
	1990	3.7	4.7	1.9
Potassium(me%)	1977	0.56	0.53	0.48
	1990	0.44	0.43	0.39
Magnesium(me%)	1977	1.8	2.1	1.5
	1990	1.9	1.9	1.9
Sodium (me%)	1977	0.07	0.02	0.03
	1990	0.28	0.30	0.27
Soil pH (H20)	1977	5.4	5.9	6.2
	1990	5.8	5.9	5.6

Table C.2: Soil physical properties, 1977 and 1990

Property	*Year*	*Makueni area* *Uncultivated (13 sites)*	*Cultivated (4 sites)*	*Northern Machakos area (4 sites)*
Sand (%)	1977	59	65	57
	1990	64	67	63
Silt (%)	1977	10	10	12
	1990	9	7	9
Clay (%)	1977	30	25	30
	1990	27	25	28

are now deficient. These lost 50-88%. Of 20 profiles which were deficient in available phosphorus in 1977, eight showed some gains in 1990, while the remaining 12 showed losses, as high as 67%. Only four had a low to moderate supply both in 1977 and in 1990.

Table C.1 shows that significant average losses of phosphorus only occurred on cultivated sites, and that the losses were noticeable, notwithstanding their short history of cultivation (two seasons).

Other available bases vary from low to moderately adequate. There was a small increase in calcium and a small decrease in potassium in all three groups, no significant trend in magnesium, and a noticeable increase in sodium. Exchangeable acidity (pH) is not a major problem in the area.

The soil reaction varies from strongly acid to near neutral, but the majority of the profiles range between moderately acid to slightly acid. There was no clear trend in soil pH during the period.

The textural characteristics (Table C.2) show a trend towards more sand, at the expense of the silt and clay fractions, though clay held up on the cultivated sites. The measured changes are, however, small.

2.3 A profile of soils on grazing land

Since all these sites were uncultivated in 1977, and 23 of them remained so in 1990, the longitudinal analysis offers little guidance on the impact of cultivation, but does suggest a picture of trends on grazing land, with the proviso that the findings are limited by the sample distribution to the southern part of the District, and may not be applicable in full to the northern hilly areas. They suggest that soils, generally low in organic matter, carbon and nitrogen, and phosphorus, have tended to decline further in carbon content. No clear trend in nitrogen has been shown. Exchangeable bases have shown small changes (positive for calcium and negative for potassium), or no change (magnesium), with the exception of sodium, which appears to have increased noticeably. Phosphorus has remained stable except under cultivation, where it declined. Infiltration and runoff have brought about a small increase in the sand fraction of the soils. However, there is a high degree of variation between sites, as would be expected.

3. THE SPATIAL ANALOGUE STUDY

3.1 Sampling

The longitudinal method failed to generate data on changes in soil properties under cultivation because none of the sites chosen in the baseline study were on cultivated land. The alternative method was therefore used with the objective of inferring change from the differences between soils under cultivation and grazing management regimes and those on control sites under natural vegetation.

Twenty-seven samples were collected from Kilungu Location. The samples were collected from three categories of site, representing different land uses.

Site 1 represented areas which have not been cultivated for over sixty years and are under natural vegetation cover. Ground cover is 100% including much litter. Slopes are 5-35°. The vegetation consists of large and small trees, shrubs, herbs and some grasses. Soils are dark brown with a good crumb structure and little mineral content is visible. The only management is occasional removal of litter as field manure and perhaps fuel cutting.

Site 2 represented areas which have been fallow for twenty years or more and are currently used as grazing land. Ground cover is 60-90% and the slopes 10-40°. The vegetation is lightly wooded shrubland with herbs, sometimes cut to encourage the growth of the grasses. The soils are reddish brown with quartz or mica fragments sometimes visible.

Site 3 represented areas which have been under annual cultivation for 40-60 years or more without any known additions of fertilizer and little manuring. In one area, site 3 was on a terrace; in the other two areas, it had not benefitted from any land improvement. Ground cover (during the dry season) was 20-50%, including weeds and some standing crops. The slopes are 15-20°, unterraced, and 10-15° on the terrace. The soils are light in colour and sandy, with quartz fragments on the surface and sometimes larger stones a little deeper in the profile.These sites represent the low end of the fertility range on cultivated land, cropped with maize and beans (also cassava and bananas in one area) year after year, with low yields.

Three areas were chosen, and in each area, three sites. Three composite samples were collected at each site, thus giving 27 samples in total. The methods of analysis were the same as those described in note 1.

3.2 Results (Table C.3)

The analyses show a definite trend of decline from sites 1 to 3. The only exception to this trend is found in available phosphorus. This nutrient is deficient at all three sites (uncultivated, grazing, and cultivated). Available bases at site 1 range from moderately adequate to rich, except for phosphorus which is low. At site 2, the range is from moderately adequate to low. At site 3, all the bases are low, except for potassium which is still moderately adequate.

Of particular significance from the point of view of agriculture is the sharp fall in the nitrogen and carbon content to very low levels relative to those of uncultivated soils. Even long term fallow, under some grazing, which carries some woody vegetation, is closer on the average to cultivated than to uncultivated land in respect of nitrogen and carbon.

Table C.3: Chemical properties of Kilungu soils

Property	*Areas* *1*	*2*	*3*	*Average*
Uncultivated (Site 1)				
Soil pH (water)	5.3	5.8	5.8	5.5
Potassium (me%)	0.34	0.74	0.61	0.56
Calcium(me%)	2.4	14.3	9.5	8.7
Magnesium (me%)	2.4	4.3	3.6	3.4
Phosphorus (ppm)	12.0	43.0	15.0	23.0
Nitrogen (%)	0.21	0.50	0.33	0.35
Carbon (%)	1.94	3.16	2.37	2.49
Grazing land (Site 2)				
Soil pH (water)	5.6	5.7	4.9	5.4
Potassium (me%)	0.31	0.51	0.37	0.40
Calcium (me%)	2.9	3.1	1.1	2.4
Magnesium (me%)	1.4	1.5	1.3	1.4
Phosphorus (ppm)	12.0	14.0	15.0	14.0
Nitrogen (%)	0.21	0.17	0.15	0.18
Carbon (%)	1.71	1.12	0.93	1.25
Cultivated (Site 3)				
Soil pH (water)	4.6	5.6	4.8	5.0
Potassium (me%)	0.21	0.37	0.29	0.29
Calcium (me%)	0.7	1.9	0.7	1.1
Magnesium (me%)	0.8	1.5	0.5	0.9
Phosphorus (ppm)	11.0	17.0	10.0	13.0
Nitrogen (%)	0.14	0.10	0.09	0.11
Carbon (%)	0.95	0.64	0.63	0.74

3.3 A profile of cultivated soils

If the Kilungu soils are representative, as they are thought to be, of the hill masses in the densely and long settled areas of the District, they give a graphic picture of the impact of permanent cultivation (without compensating inputs) on the natural soils of the area. A comparison of the analytical results from sites 1 and 3, averaged for the three areas, shows falls in carbon (by a factor of about 3.5), nitrogen (3.0), phosphorus (0.5), calcium (8.0), magnesium (3.5) and potassium (0.5). Soils have also become somewhat more acid.

Inspection of the soils reveals that the dark brown surface horizon of the naturally wooded sites gives way to lighter coloured, sandy soils with quartz fragments noticeable at the surface, an accompanying deterioration of structure and a diminution of plant remains in the surface layers. The evidence is consistent with the view expressed in the 1930s (Barnes, 1937; Maher, 1937) that the topsoil was being removed by erosion over extensive areas.

Given that the cultivated soils sampled represent the bottom of a range (no fertility inputs, and in two cases, no terracing), it can be concluded that soil properties on better managed land must improve according to the management. They are highly variable. Variation is caused by site factors. In addition, soil properties vary over very small distances according to position relative to terrace structures and ditches, maintenance, crop residue management, and manure or fertilizer placement in preceding seasons. A very large sample would be required to assess average soil properties in these circumstances, and this was beyond the scope of the study.

On the supposition that site 2 soils were first cleared for cultivation, before reverting to fallow or grazing, the data show that long term closure to cultivation may not be sufficient to restore the nutrient status of soils to their former levels. Carbon, nitrogen and exchangeable bases have improved relative to the cultivated soils, but by factors of less than 1.0 (with the exception of calcium); and phosphorus is unchanged.

The chemical properties of the uncultivated soils sampled for the longitudinal study in 1990 are expected to resemble those of sites 1 or 2. A comparison (Tables C.1 and C.3) shows that this so for phosphorus and soil pH (site 1 soils), and exchangeable bases (site 2 soils). But in nitrogen and carbon content, they resemble site 3 soils, even though there is no history of long term cultivation. This may reflect the drier ecology of the Makueni area.

4. CONCLUSION

The following conclusions can be drawn on the impact of management over time on soil fertility in Machakos District, subject to verification in other sampled areas.

1. Areas which have been maintained under natural vegetation with minimal disturbance are still fertile lands which are well supplied with the necessary plant nutrients.

2. Areas which were cultivated at one time and have been fallowed for a long time, or which have experienced bush clearance and extensive grazing, but are still under a reasonable ground cover which prevents the soil from being eroded away, have a moderate to low supply of plant nutrients.

3. Areas which are under long term continuous cultivation without inputs, or intensive grazing pressure, have a low supply of plant nutrients. This may be as a result of the removal of the top horizon by erosion. The fertility of cultivated soils depends on their management.

4. The soils of the area are naturally low in phosphorus, irrespective of soil management.

D. NATURAL VEGETATION

Kassim O. Farah

1. INTRODUCTION

This section evaluates changes in the natural vegetation resources of Machakos District. It is assumed, on the basis of the climatic evidence presented in Section A, that vegetational change is attributable to management and not to climatic change.

However the nature of the interaction between herbivory by domestic livestock and vegetational change is presently the subject of a major paradigmatic shift (Ellis and Swift, 1988). Moreover the nature and usefulness of some concepts central to sustainable management of the communal rangelands in arid and semi-arid sub-Saharan Africa - for example, carrying capacity and grazing - induced land degradation - are being questioned increasingly by ecologists and development specialists (Warren and Agnew, 1988; Mortimore, 1989; De Leeuw and Tothill, 1990; Perrier, 1990; Mace, 1991). It is not practicable to separate the evidence of vegetational change from its supposed causes because observers habitually mingled the two. In the 1930s, it was believed that 'The chief cause of erosion in Machakos and Kitui is overstocking ... The only solution is to reduce the number of stock to the capacity of the country' (Annual Report, Ukamba Province, 1933; quoted in Otieno,1984:64). The vegetation of Machakos is also affected by cultivation and woodcutting, but grazing management (or mismanagement) has dominated the literature. Therefore, this chapter addresses both the nature of vegetational change and its possible causes.

Most of the former Kamba Reserve was covered by managed, rather than natural vegetation at the beginning of our study period (1930-1990). In order to test hypotheses on the impact of grazing on natural vegetation, therefore, study sites in the southern, recently settled part of the District have been chosen. For these sites, baseline materials are available and management is known. The major part of the chapter is devoted to this investigation. On the basis of the conclusions reached, an hypothesis of vegetational change in the north of the District is proposed.

The major investigation addresses the following objectives:

1. To determine changes in the vegetation structure of sample areas of natural grazing lands in Machakos District since available baseline surveys.

2. To evaluate the extent and direction of change in the woody component of the vegetation, by determining density by size class of a selected desirable woody species, and a 'normal' woody species.

3. To assess the extent to which changes in plant community structure can be related to known management practices on the grazing lands.

2. BASELINE DESCRIPTIONS

Trapnell (1958) described nine ecological zones in northern Machakos, and Parsons (1952) provided a description of five vegetational types in Makueni. These are summarised below.

Northern Machakos

1. Forest scrub. Formerly evergreen forest on the hills above 4,500 ft, replaced by bracken, planted wattle, and eucalypts, or a shrub formation of *Carissa, Rhus, Erythrina, Grewia*, and tall or woody herbs.

2. Forest clumps. Evergreen thicket clumps in grassland, on the highest of the Mua Hills.

3. Hill Combretum. A community found on steep slopes and with *Combretum gymnospora* and *Faurea* characteristic, often destroyed and invaded by *Acacia seyal.*

4. Moist Combretum. Combretum woodland on moist upland from 4,000 to 5,500 ft, mixed in the Kangundo area with *Euclea, Pavetta teitiana, Vangueria sp, Strychnos* sp, and *Croton macrostachys*; in the Mbooni area with *Croton dichogamus, Pavetta teitiana* and *Uvaria sp*; and in the Okia area with *Uvaria sp.* and *Piliostigma thoningii.* These three subtypes probably represent a moisture and altitudinal gradient from north to south.

5. Euclea and Euclea-Combretum. A localised semi-evergreen type found on the drier western slopes, often denuded and replaced by *Acacia seyal.*

6. Dry Combretum. An extensive type found mainly on drier upland on the tertiary land surface at 4-4,500 ft, mainly on sandy Kiteta soils. Outliers occur near Makaveti and Tala. *Combretum spp.* and *Terminalia brownei* are dominant with *Rhus* spp, *Albizzia sericocephala* and others. On red soils, *Acacia* spp. and *Dichrostachys* spp. may invade.

7. Acacia tortilis. In the lower hotter valleys between 3,500 and 4,500 ft, *A. tortilis* is the principal tree with *A. mellifera, Commiphora* spp, *Balanites*, and *Chloris myrlostachys* in the grass layer. It was considered to have evolved from dense bushland of a *Commiphora-Grewia-Acacia* type. *Acacia pennata* thickets in the upper Thwake valley, and *Croton dichogamus* indicate former thicket elsewhere. Under similar conditions of rainfall, this type was differentiated from type (6) by red soils and higher temperatures.

8. High level Acacia. *Acacia* spp. with *Rhus, Grewia, Commiphora* and *Pennisetum mezzianum* in the grass layer, found in the high rain-shadow areas west of the hills.

9. Black clay grasslands. *Pennisetum mezzianum* and *Themeda* grasses interspersed with stunted *Acacia drepanolobium* and *Balanites* are found on the dry cracking clays in the north-west of the District.

Makueni

10. Riverine woodland. Large evergreen trees and shrubs in belts from a few metres to over 100 m in width along the river banks.

11. Forest. Continuous canopied deciduous woodland with *Acacia* spp. (especially *A. mellifera*) or *Commiphora* spp. dominant, and a shrub layer below.

12. Thicketed bush. Thorny, sometimes impenetrable shrub growth 6-8 ft (2-3 m) high with scattered trees, occurring in patches or continuously over large areas. It may occur as a secondary type after the destruction of forest. When the thicket has reached a certain density, it is resistant to fire.

13. Orchard. Well spaced trees, 10-20 ft (3-7 m) high with grass between and occasional thicket. *Combretum* spp. dominates wetter areas and ridges, *Commiphora* spp. drier areas. Extensive areas have a park-like appearance.

14. Open plains. Grasslands on black soils (rare).

These 14 types may not include the vegetation of the south-eastern lowlands.

3. STUDY SITES

Two locations, Kathonzweni and Ngwata in Makueni and Kibwezi Divisions of Machakos District, were selected. The choice was based on two criteria:

1. Both sites occur in Ecozone 5, and support natural vegetation which is predominantly used for livestock production on an extensive basis under free ranging conditions.

2. The two locations represent areas of recent human settlement - the 1950s for Kathonzweni and the 1960s for Ngwata - and, therefore, can serve to bring out the impact of human activities on vegetation over time.

Makueni (the nearest rainfall station to Kathonzweni) has a mean annual rainfall of 650mm which is distributed bimodally. Potential evapotranspiration always exceeds rainfall, and is estimated to be 3.4 times the mean annual rainfall (Braun, 1977). Rainfall is characterised by extreme spatio-temporal variability, between years, seasonally, and within seasons, especially with respect to time of onset (Section A). Ngwata Location has a mean annual rainfall of 580mm. As in Makueni, rainfall in Ngwata displays great variability both in space and time. Potential evapotranspiration is estimated to be 3.7 times the mean annual rainfall (Braun 1977).

Predominantly, the soils in Makueni and Ngwata have been described as Luvisols or Oxisols which are deep and well drained, but are nevertheless deficient in nutrients (Hussain, Shirin Ali, et al, 1982; Nyanyintono 1986). In both locations, land use is mainly agropastoralism. Average land per household is approximately 20ha, of which 6ha are cultivated, and the rest is used for livestock production. Natural vegetation varies from place to place, but is mostly shrubland to dense wooded shrublands, with some areas supporting sufficient perennial grasses to qualify as grassed shrubland.

4. METHODS

Black and white aerial photographs of the two locations (1960 at 1:50,000 and 1978 at 1:20,000) were used as benchmarks for evaluating physiognomic changes in vegetation. The 1978 aerial photo was also used for vegetation stratification, to increase the efficiency and precision of sampling by reducing heterogeneity and the sample size required to overcome experimental error (Stoddart et al. 1975; Green 1979).

A field inventory of the vegetation was undertaken in August/September 1990 using the belt transect method. Actual location of sampling plots was determined by consideration of two factors:

1. They should be in an area where the predominant land use was agropastoralism, and croplands intergrade with natural grazing lands.

2. They should be in an area that supports substantial stands of natural vegetation that was used for subsistence and extensive livestock grazing.

In areas where these conditions were met, the vegetation was stratified using the 1978 aerial photographs. However, when interpreted photographic information was combined with the soils and topomaps, it was discovered that, at the descriptive level, two 5km belt transects would suffice to characterize the vegetation of each location. This resulted from the fact that major soil types form approximately 80% of both Makueni and Kibwezi Divisions. The transects were laid so that they radiated from a cultivated area into the natural grazing lands. At intervals of 1.0km along the 5km belt transect, 20m x 20m plots were marked. In each sample plot, several vegetation parameters were measured. These include:

1. Species list.
2. Percent cover of each species by life form.
3. Density and heights of a selected desirable woody species.

The percent cover of woody species was measured using the line transect method, while the point method was used to determine cover of grasses (n = 1,000 points). The Point Centred

Quadrat method was used to determine the density of the selected woody species (Kershaw 1973; Mueller-Dombois and Ellenberg 1974; Cook and Stubbendiek 1986). For both study areas *Acacia tortilis* was selected as the desirable woody species on which density by size class was determined. The choice of *A. tortilis* was based on its multiple values in semi-arid rangelands of Machakos, which include the following:

1. As a legume, it fixes nitrogen and thus increases or at least maintains soil fertility. This is important in the face of declining soil fertility reported for cultivated portions of lower Machakos (Hussain, Shirin Ali, et al., 1982).

2. It is a source of feed for both cattle and small ruminants during the critical dry season when livestock feed supply is very limited.

3. It provides high quality charcoal.

4. It provides much needed shade for both man and his livestock during the dry and hot season.

Combretum exalatum and *Commiphora schimperii* were selected for Ngwata and Kathonzweni respectively as woody species which are ecologically significant in these habitats but are nevertheless not under much utilization pressure from man and livestock, compared with *A. tortilis*. The sizes of all individuals (n = 32) of the selected woody species were determined by measuring diameter at breast height (dbh) and plant height, with a view to establishing the population's size class structure. Within the vicinity of the two belt transects, four paired 20m x 20m plots of lightly grazed (utilization of <40%) and heavily grazed (utilization >60%) areas were identified and inventoried. Utilization levels were determined using the ocular estimate method (Stoddart et al. 1975; Cook and Stubbendiek 1986).

Management was established from interviews.

Changes in the floristic composition of the vegetation cannot be derived from the method outlined above. This is because it is difficult, if not impossible, to decipher taxonomic units from aerial photographs at a scale of 1:20,000 (1978) much less 1:50,000 (1960). Analysis of vegetation change thus is necessarily limited to physiognomic criteria. To characterize the physiognoms of the vegetation from the aerial photos, it was necessary to locate the transects on them. This was done on the basis of terrain and physiognomic units. Different life forms were determined from stereoheight, tone, texture, and pattern. An ocular assessment of the percent cover of each life-form in various strata was recorded. An overall determination of the physiognomic class was based on dominant life-forms and classification (e.g: grassed shrubland) following Pratt and Gwynne (1977), as modified by Pomery and Service (1986).

5. RESULTS

Field analysis showed that the vegetation of Kathonzweni and Ngwata locations are physiognomically similar and can be described as dense wooded shrubland, although the percent cover of woody species is much greater in Ngwata. Conversely, the herb cover is greater at Kathonzweni than at Ngwata (Table D.1). There is, however, some difference in the floristic composition of the vegetation at the two locations. At Kathonzweni, the dominant woody species are *Acacia mellifera* and *Commiphora schimperii* while at Ngwata they are *Acacia tortilis* and *Combretum exalatum*. *Eragrostis superba* and *Aristida kiniensis* are the dominant grasses at Kathonzweni, whereas *Chloris roxburghiana* and *Aristida kiniensis* are dominant at Ngwata.

Table D.1: Species composition by life-form of the vegetation of Kathonzweni and Ngwata locations, Machakos District (Aug/Sept. 1990)

	Kathonzweni			*Ngwata*	
Life form	*Species*	*% cover*	*Life form*	*Species*	*% cover*
Trees	*Acacia tortilis*	3	Trees	*Lannea triphyla*	4
	Acacia mellifera	12		*Acacia tortilis*	7
	Total trees	**15**		**Total trees**	**11**
Shrubs	*Grewia bicolor*	5	Shrubs	*Combretum exalatum*	8
	Acalypha fruiticosa	15		*Boscia coriacea*	10
	Aspillia mossambicensis	8		*Tenantia senii*	7
	Commiphora schimperii	9		*Grewia bicolor*	5
	Solanum incanum	5		*Solanum incanum*	8
				Hoslundia opposita	2
				Tephrosia villosa	4
				Grewia similis	3
	Total shrubs	**42**		**Total Shrubs**	**47**
			Herb Forbs	*Sida ovata*	5
				Achyranthera spp.	4
				Pupalia lappaceae	2
				Ocium bassilicum	2
				Lepidagathis scariosis	1
				Total forbs	**14**
Herb grasses	*Eragrostis superba*	8	Herb grasses	*Chloris roxburghiana*	5
	Chloris roxburghiana	4		*Cenchrus ciliaris*	3
	Aristida kiniensis	5		*Aristida kiniensis*	4
	Sporobolus marginatus	2		*Enteropogon macrostachys*	3
	Chloris virgata	1		*Bothriochloa insculpta*	3
	Enteropogon macrostachys	1			
	Total grasses	**21**		**Total grasses**	**18**

There was a marked increase of the woody component of the vegetation in both locations between 1960 and 1990 (Table D.2). In both, the vegetation has changed physiognomically from grassed shrubland to dense wooded shrubland. It is significant to point out that Ngwata's vegetation had become dense wooded shrubland by 1978, whereas Kathonzweni remained a grassed shrubland until after 1978. A range condition rating based on Clemensian climax theory would suggest that the semi- arid grazing lands of Machakos District are improving, because vegetation is progressing towards a higher successional status. On the contrary, because these grazing lands primarily support cattle, increased shrubs or woodland means a lowered capacity of the primary grazing resource.

Table D.2: Changes in the vegetation structure of Kathonzweni and Ngwata between 1960 and 1990

Year	*Life form (% cover)*			*Physiognomic*
	Trees	*Shrubs*	*Grasses and forbs*	*classification*
Kathonzweni				
1960	2	39	59	GS
1978	9	35	51	GS
1990	15	38	29	WSD
Ngwata				
1960	1	37	62	GS
1978	6	45	19	WSD
1990	11	62	18	WSD

GS: grassed shrubland WSD: dense wooded shrubland

Table D.3: Comparison of vegetation composition in lightly and heavily grazed areas at Kathonzweni, Makueni

	Lightly grazed area		*Heavily grazed area*	
Life form	*Species*	*% cover*	*Species*	*% cover*
Trees	*Acacia tortilis*	2	*Acacia tortilis*	4
	Acacia mellifera	2	*Acacia mellifera*	14
	Total trees	**4**	**Total trees**	**18**
Shrubs	*Acalypha fruiticosa*	10	*Acalypha fruticosa*	22
	Ocimum bassilicum	7	*Solanum incanum*	10
	Maerus edulis	5	*Ocimum bassilicum*	10
	Aspillia mossambicensis	4	*Commiphora schimperii*	8
	Total shrubs	**26**	**Total Shrubs**	**50**
Herb grasses	*Eragrostis superba*	30	*Aristida kiniensis*	10
	Chloris roxburghiana	20	*Chloris roxburghiana*	5
	Chloris virgata	2	*Erogrostis superba*	1
	Aristida kiniensis	2	*Sporobolus marginatus*	2
	Total grasses	**54**	**Total grasses**	**18**

Lightly and heavily grazed portions of the two study areas show a marked difference in vegetation structure and composition (Tables D.3 and D.4), suggesting that grazing plays an important role in structuring the vegetation. These results are in agreement with established principles of range management and most community ecology literature regarding the impact of herbivory on plant community structure (Heady 1975; Stoddart et al. 1975; McNaughton 1979; Crawley 1983; Harrington et al. 1984).

Table D.4: Comparison of vegetation composition in lightly and heavily grazed areas at Ngwata location

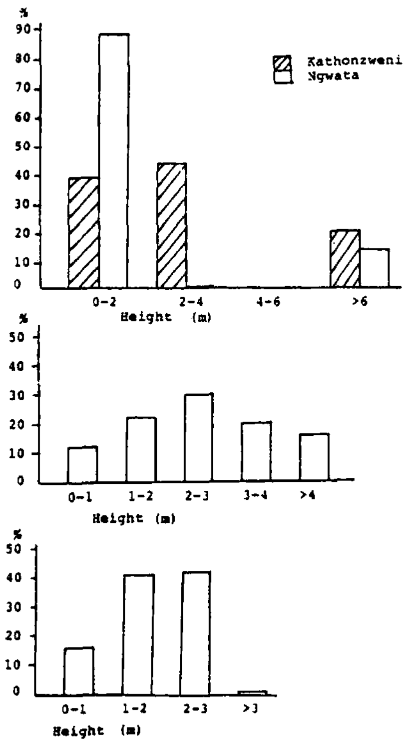
	Lightly grazed area		*Heavily grazed area*	
Life form	*Species*	*% cover*	*Species*	*% cover*
Trees	*Lannea triphyla*	4	*Lannea triphyla*	3
	Acacia tortilis	3	*Acacia tortilis*	12
	Total trees	**7**	**Total trees**	**15**
Shrubs	*Combretum exalatum*	4	*Combretum exalatum*	10
	Boscia coriacea	11	*Boscia eoriacea*	10
	Tenantia senii	10	*Tenantia senii*	5
	Grewia bicolor	7	*Solanum incanum*	18
	Entada absyinica	3	*Grewia bicolor*	4
			Hoslundia opposita	4
			Grewia similis	5
			Tephrosia villosa	2
	Total shrubs	**35**	**Total Shrubs**	**48**
Forbs	*Achyranthera spp.*	5	*Ocimum bassilicum*	3
	Pupalia lappaceae	2	*Sida ovata*	6
	Monechma debille	1	*Pupalia lappaceae*	2
	Lepidagathis scariosis	1	*Achyranthes aspera*	3
	Total forbs	**9**	**Total forbs**	**14**
Grasses	*Bothriochloa insculpta*	4	*Enteropogon macrostachyss*	2
	Chloris roxburghiana	7	*Digitaria velutina*	4
	Enteropogon macrostachyus	4	*Chloris roxburghiana*	2
	Aristida kiniensis	1	*Aristida kiniensis*	11
	Cenchrus ciliaris	6		
	Total grasses	**22**	**Total grasses**	**19**

In both Makueni and Kibwezi Divisions, the principal domestic livestock is cattle (Consortium - Ottley et al. 1978; see Production Profile). Cattle are graziers and their grazing on a continuous basis usually shifts vegetation composition towards woody types. This occurs with greater likelihood when utilization intensity on the grasses is relatively high. Evidence of high intensity (>60%) on perennial grasses was seen in many areas. In heavily utilized areas, there was an increase in increaser species (e.g. *Solanum incanum*) which further supports the inference that cattle grazing is a significant factor contributing to a change in vegetation structure towards woody species. It can thus be stated that with respect to cattle production, the vegetation of both Kathonzweni and Ngwata is degrading and grazing capacity is on the decline.

Additional evidence of vegetation degradation is shown by the high depletion rates of the desirable woody species (Fig. D.1). At Ngwata, 87% of individuals sampled had a height less than 2m, and at Kathonzweni, 81% of sampled individuals were less than 4m in height, suggesting that most mature plants have been removed by selective cutting. On the other hand, two ecologically dominant woody species, *Commiphora schimperii*, in Kathonzweni and *Combretum exalatum* in Ngwata, which possess much less range value than *A. tortilis*, display an unskewed size class structure.

Figure D.1: **Height class distribution of selected woody species**

A: *Acacia tortilis* at Kathonzweni and Ngwata
B: *Commiphora schimperii* at Kathonzweni
C: *Combretum exalatum* at Ngwata



6. GRAZING MANAGEMENT AND LAND DEGRADATION

The results of this study are in complete disagreement with the widely held belief, based on extant literature, that the semi-arid grazing lands of Machakos District are characterized by land degradation (in the forms of soil erosion and surface sealing) caused by overstocking and overgrazing (e.g. Thomas 1978; Consortium: Ottley et al., 1978; Hussain, Shirin Ali, et al, 1982). There are two issues that need to be resolved before discussing the divergent viewpoint that emerges from this study; (1) how is land degradation defined? (2) what is the yardstick used to judge that these grazing lands are overstocked i.e, that stocking rates exceed carrying capacity?

The first question is currently under heated debate among ecologists, but is generally accepted to mean the stage at which an ecosystem looses its resilience (Hollings 1973; Walker et al, 1981; Walker and Noy-Meyer, 1982; Harrington et al., 1984) thus resulting in a permanent decline in productive capacity (Abel and Blaikie 1990). With regard to the second question, all the authorities cited above have used a beef ranch model as their yardstick of acceptable stocking rates and carrying capacities. As I will argue later, such an approach is totally inappropriate for subsistence livestock production systems in lower Machakos. First, however, it is useful to review briefly some key literature related to grazing lands of Machakos.

Ottley et al. (Consortium 1978) allude to overstocking and grazing-induced soil erosion in the semi-arid grazing lands of Machakos thus:

> *for the most part pasture land is extremely overgrazed, even with heavy death losses incurred in recent drought years. Improved pasture must be a pre-requisite to any worthwhile livestock industry and this can be done only when livestock numbers and production capacity of the land are brought into proper balance. It must be further understood that soil erosion will continue to be a major problem until this is done.*

These authors view Kamba pastoralism as economically irrational, and based on conservative cultural attitudes that impede the adoption of good livestock management.

> *On the positive side some ranches in the semi-arid lands of Machakos are models of good management. Cattle are well fed, pastures rotated, disease controlled, and no overstocking is permitted. Animals are sold on schedule and at a profit. Bulls used (Boran) are of outstanding quality. Residents living in the area are fortunate to have such a model to follow.*

They explicitly assume that Kamba subsistence agropastoralism is best improved and developed in the framework of a commercial beef ranch, and in so doing they overlook a very important consideration, i.e. that the production goals of the two systems are different.

Thomas (1977) drew attention to degradation on grazing land, but asserts that it is reversible:

. . . much grazing land is bare . . . degradation is taking place quite rapidly and nothing is being done about it. The extent of erosion is shown by the way roots are exposed. On a number of farms grazing land has been protected and the contrast with the surrounding denuded areas proves a useful reminder that the land is capable of supporting a good cover of grass.

In the same vein, Ottley et al. also state that in the semi- arid grazing lands of Machakos, it takes only two years to regain the productive potential of the land. It would, therefore, be safe to conclude that none of the authors has been able to document grazing-induced land degradation to the extent that such a stage in the degradation process is irreversible.

A causal relationship between overstocking, overgrazing, and soil erosion, and by extension land degradation, is also reported by Hussain et al. (1982) for Makueni Division. They argue that poor livestock management (e.g. retaining 30% males in shoats) and traditional non-commercial attitudes towards livestock development, resulted in overstocking and soil erosion. They report that 60% of all farmers interviewed overstocked their grazing land. In arriving at this conclusion, they relied on a comparison between recommended stocking rates for poor and good rangelands and actual stocking rates. Again the question arises: What assumptions underlie the derivation of these recommended stocking rates? It is evident that they were based on a commercial beef ranch production system.

Scoones (1989) elucidated the issue of carrying capacity in the semi-arid Communal Areas of Southern Zimbabwe by distinguishing between ecological and economic carrying capacities. He further convincingly argued that economic carrying capacity is a function of producer economic objectives and largely depends on a producer's definition of livestock productivity. In commercial beef production, economic objectives emphasize such parameters as weight gain, weaning weight, and offtake. Under these circumstances, the tendency will be to maximize production per head. Subsistence agropastoralists, because they have multiple uses for cattle (e.g. meat, milk, draught), tend to maximize production on a per area basis (Cossins 1984, 1985; Behnke 1985; Coppock et al. 1985). High stocking rates in the semi-arid grazing lands of Machakos, as in the communal areas of Zimbabwe, are rational to the extent that their production goal transcends that of beef production.

A very important question that needs to be addressed is whether stocking rates maintained by the agropastoralists of Machakos are ecologically sustainable. Evidence against this must ultimately come in the form of irreversible grazing-induced land degradation. The results of this study indicate that this has not yet occurred in Lower Machakos.

On the other hand, vegetational change having negative implications for cattle production has occurred in both study areas.

Fire is an ecological factor that tends selectively to kill woody vegetation and promote graminoid species, mainly because the perennating organs of the former are above the ground and hence killed. In the management of rangelands, the prescribed burning is used inter alia for regulating the relative proportions of woody and grass species (Stoddart et al. 1975; Heady 1975; Valentine 1981; Harrington et al. 1984). In post-independent Kenya, fire (especially on State and Trust lands) has been proscribed. However, early vegetation descriptions identified fire as one of the determinants maintaining some vegetation types, for example the Orchard type of Makueni (Parsons, 1952; Trapnell 1958; see above). It is, therefore, probable that increased woodiness may be explained in part by lack of fire. Interaction of grazing pressure and fire control with an episodic and fluctuating rainfall regime has probably led to increased woodiness.

Grazing-induced land degradation, in the form of soil loss, a widely held belief among conservationists and development planners, is not supported by the results of this study of the impact of grazing on natural vegetation in Lower Machakos during the last four decades.

7. NORTHERN MACHAKOS

In Northern Machakos there is a longer history of grazing management and it was here that the linkage with land degradation was first suggested.

According to Lindblom (1920) and Barnes' (1937) reconstruction from interviews, the Reserve was much more wooded at the turn of the century. All sources agree that most of the forests had been removed from the settled hills before the late nineteenth century, except for the sanctified 'podo' patches.

> *The flatter country surrounding the hills and in the Mabuti-Kiteta areas was [at the time of the British occupation] practically uninhabited, it was covered with dense high grass and bush trees, and also had rich top soil* (Barnes, 1937:1).

These areas were

> *often of the savanna type, but usually overgrown with a more or less dense bush which, with its thorns of all shapes and sizes, is a plague to travellers* (Lindblom, 1920:24).

This seems to be the distinction between 'orchard' and thicket recognised in types (12) and (13) of the vegetation classes described above.

> *Large trees are seldom to be seen; only those of medium height and under. They do not grow close together, but scattered about; a coarse kind of grass grows between them though not, as in northern Europe, in continuous sward, but in patches, between which the soil is bare. Different species of acacia and mimosa are predominant among the trees. Typical of the drier bush are varieties of the genus Sansevieria . . . further up on the hillsides grow species of Euphorbia . . . around the villages, and as weeds in the fields, grow Rhinus communis in abundance, often attaining the height of a small tree* (Lindblom, 1920:25-6).

Deforestation was evidenced by solitary trees and immense stumps on some of the hillsides (taken over for cultivation), and in one area,

> *A small, thickly populated district close to Machakos is called mutituni ('in the forest') and the old people say that it was once entirely overgrown with forest and the haunt of elephants. Now the district is almost entirely devoid of even fuel, to procure which women have laboriously to dig up the remains of trees long since dead* (ibid.).

These accounts, and descriptions provided later by Edwards (1940) and Trapnell (1958) lead to the conclusion that at one time, northern Machakos was as wooded as southern Machakos was when it was settled in the 1950s and 1960s, and that the vegetation communities, below the hills, were similar.

Since the results reported above show that the effect of continuous grazing by cattle is to increase the woody component of the vegetation, an explanation has to be sought for its reduction - nearly to vanishing point - in large areas of northern Machakos. There can be little doubt that the chief agent of this reduction was fire. Fire is a recognised tool of range management (Pratt and Gwynne, 1977:132). Lindblom's description, quoted above, implies the existence of areas of 'savanna type' woodland or 'orchard' (Parsons, 1952), whose development and maintenance is furthered by fire. When the livestock owners moved from the hills to the lower country,

> *The areas which are now [1937] devastated were long grass and bush and stock owners burned the grass frequently to get short grass for their stock ... Bush trees they say were destroyed and many cut to make bomas and for firewood . . .* (Barnes, 1937:2).

The clearance of woodland from the hillslopes (as in Mutituni, described above) had already created a fuelwood shortage. As the population increased and shifted downslope, the remaining trees, never large or abundant (according to Lindblom) would have come under exponential pressure. The photographs taken by Barnes in 1937 (perhaps the nadir of deforestation), show that some natural regeneration of woody plants occurred nearly everywhere. But where individuals can be discerned, they are sparse, small, ill-formed and heavily cut.

Increasingly deprived of browse, the rapidly growing livestock population became dependent almost entirely on grasses and forbs which are prone to fail in drought. Tufted grasses leave much ground bare, which was noticed by Lindblom in the first decade of the century. Such bare patches, enlarged during drought, would be prone to surface sealing on the resumption of rainfall, preventing seed regeneration, and increasing runoff and sheetwash. Areas of *mangalata* with stony surfaces were noticed in Maputi early in the century (see Section B). The presence of woody canopies, on the other hand, protects the surface from rainsplash, enriches the soil with leaf litter, prevents sealing and obstructs runoff.

The demarcation of private rights to land, including the *kisese* or grazing land, was encouraged by the administration from the 1930s onwards, and the registration of individual title was progressively extended to more and more locations. The enclosure of *kisese* permitted it to be managed as an integrated grazing, fuelwood, charcoal and beekeeping resource, as well as permitting produce to be harvested from multipurpose trees (Gielen, 1982:47). Increasing woodiness of grazing lands in northern Machakos is not, however, due to shrub regrowth under heavy cattle grazing but to the managed regeneration of canopied trees.

Evidence in support of this hypothesis is provided at two sites on managed grazing land in Masii Location in August, 1990 (Table D.5). Site 1 corresponds to Type (6), 'dry Combretum' vegetation on the sandy soils characteristic of this area, dominated by *Combretum zeyheri* and *Terminalia kilimendscherica*. Site 2 corresponds to Type (7), 'Acacia tortilis', on the red soils, and dominated by *Acacia* and *Commiphora* spp.

Table D.5: Vegetation at two sites on managed grazing land in Masii Locations

	Site 1		*Site 2*	
Life form	*Species*	*% Cover*	*Species*	*% Cover*
Trees			*Acacia tortilis*	21
Shrubs	*Combretum zeyheri*	3	*Acacia nilotica*	7
	Terminalia kilimendscherica	14	*Acacia brevispica*	3
	Lantana camara	11	*Commiphora campestris*	10
	Rhus natalensis	3	*Commiphora schimperii*	4
	Griidia latifolia	5	*Lantana Camara*	36
			Griidia latifolia	6
	Total shrubs	**63**	**Total shrubs**	**34**
Grasses	*Enteropogon macrostachys*	12	*Digitaria macroblaphera*	15
	Digitaria macroblaphera	18	*Enteropogon macrostachys*	8
	Aristida kiniensis	6	*Aristida kiniensis*	10
	Bothriochloa insculpta	10	*Bothriochloa insculpta*	11
	Eragrostis superba	5	*Eragrostis superba*	3
			Cenchrus ciliaris	2
	Total grasses	**51**	**Total grasses**	**49**
	Litter	40	Litter	38

Note: The data were obtained from four randomly selected plots of 20 x 20m at each site. Canopy and ground cover were measured using the methods described earlier.

The management histories of the two sites are as follows.

Site 1 is ancestral land forming the larger part of the family holding, and used continuously for grazing and fuelwood collection. It has not been cultivated within memory. Free range grazing is restricted to the rainy seasons; in the dry seasons, the livestock are fed on crop residues, and in this way erosion is controlled. *Terminalia kilimendscherica* and *Combretum molle* (not recorded on the plots) have decreased, under pressure for charcoal making (being hard wood) and construction timber. *C. zeyheri* is no less useful, but needs no protection as it regenerates vigorously. The trees are thought to suppress most shrub growth, which is not a problem, and since erosion is not serious, *Lantana camara* and *Griidia latifolia* have not obtained a foothold. Implicit in the above is careful control of stocking levels.

Site 2 was purchased in 1950 in a badly denuded condition (described as *mangalata*), thought to be due to overgrazing. Sheet and rill erosion were common. The trees included *Acacia tortilis, A. mellifera* (very common), *Commiphora schimperii, C.Campestris*, a few *Combretum* and *Terminalia*; *Acacia brevispica* grew by the stream courses.

The site was closed to grazing for ten years after purchase (the owner had alternative grazing for his livestock). He tried planting star grass (*Cynodon plectostachyus*), collected from the riverside. He is aware of a natural succession: *Aristida kiniensis, A. adscensioni* were followed by the perennial grasses including *Chloris roxburghiana, Latipes senegalensis, Enteropogon macrostachys* (common under trees), *Heteropogon* which grows on sandy pockets associated with *Eragrostis superba, E.caesipitasa* and *Themeda triandra* which is now disappearing. Where the ground cover is incomplete, *Microchloa kunthii* characterises the succession.

With regard to shrubs, *Griidia latifolia* was the indicator species of denuded land in 1950. *Lantana camara* was introduced to the area from Machakos in the 1970s, as a plant for live hedges, and is now being spread by birds, suppressing the pasture grasses in places. However in colonising denuded land, it protects the surface from runoff and helps restore fertility, being replaced by other woody plants in time. Goats are used to control thick bush.

Grazing was resumed in the 1960s, but the owner's livestock were decimated by the droughts of the 1970s (from 18 cattle to 6, seven dying and five being sold). Although the land deteriorated it was better than when he bought it. In the droughts of 1983-84 his cattle herd had recovered to 12, but the same thing happened again. He now owns eight, including a grade animal, and would prefer more grade animals to a larger herd. His goats have decreased through sales. By the 1980s he was grazing the site on a seasonal rotation though he cannot afford to make paddocks. There is no burning.

Charcoal burning (for sale to Machakos) was the primary factor that prevented regeneration from taking place before the land was bought, but now that it is under the owner's control, offtake is limited, though both fuelwood and charcoal are still obtained from it.

The owner's management objective is to undergraze the land so that it can be subdivided on inheritance by his two sons in viable condition. He has never received technical advice and has no off-farm income now.

If these sites are representative, it can be concluded that grazing areas in northern Machakos are coming under increasingly conservationary management. They are important as fuel resources (see Hayes,1986). Increasing woodiness is not here an unwanted byproduct of cattle grazing but the result of protecting trees. Bush control may even benefit from browsing by the maligned 'ruin-bringing goat' (Maher,1937).

Such a reversal of what appeared to be a strongly degradational trend admits the possibility of an earlier decline in pasture productivity, but shows that it is perceived to be reversible. Soil degradation of an irreversible kind is restricted to gullies and severely denuded sites.

On the old grazing areas of northern Machakos, some evidence (reported in Section B) shows that rates of soil loss may be high. Such rates, if continued indefinitely, threaten a loss of pasture productivity and ultimately irreversible land degradation. On the other hand, the examples of smallholder management described above indicate that the present conditions are right for methods designed to maintain or improve productivity.

REFERENCES

Abel, N. O. J. and Blaikie, P.M. 1990, *Land degradation, stocking rates and conservation policies in the communal rangelands of Botswana and Zimbabwe*. ODI Pastoral Development Network paper 29a. London: Agricultural Administration Unit, Overseas Development Institute.

Anyamba K. and Ogallo 1990, 'Meteorological causes of the 1984 drought in Kenya.' Paper presented in Environment 2000 Conference on Kenya's State of the Environment. Nairobi: United Nations Environment Programme.

Barber, R. G. 1983, 'The magnitude and sources of soil erosion in some humid and semi-arid parts of Kenya and the significance of soil loss tolerance values in soil conservation in Kenya.' In: Thomas, D. B. and Senga, W. M., (eds.) *Soil and water conservation in Kenya: Proceedings of the second national workshop, Nairobi, 10-16 March 1982*. IDS Occasional Paper No.42. Institute of Development Studies, University of Nairobi. pp.20-46

Barber, R. G. and Thomas, D. B. 1979, 'Measurement of soil loss and runoff from simulated rain storms at Kabete, Katumani and Iiuni.' Paper presented at 3rd Annual General Meeting of the Soil Science Society of East Africa, July 25-27 1979 at Muguga, Kenya.

Barnes, R. O. 1937 'Soil erosion: Ukamba Reserve. Report to the Department of Agriculture.' DC/MKS/10A/29/1. Kenya National Archives, Nairobi.

Beckley, V. A. 1935, *Soil erosion*. Bulletin No.1. Nairobi: Department of Agriculture.

Behnke, R. H. 1985, 'Measuring the benefits of subsistence versus commercial livestock production in Africa.' *Agricultural Systems*, 16:109-135.

Braun, H. M. H. 1977, *Average monthly rainfall as a percentage of the annual rainfall in Kenya and Tanzania, with particular reference to Kenya's Eastern and Coastal regions*. Miscellaneous Paper No.M14. Nairobi: Kenya Soil Survey Project.

Consortium for International Development; Ottley, R. A.; Wanjaiya, J. K. and Martin, N. L. 1978, 'Kenya Marginal/Semi-Arid Lands Pre-Investment Inventory: Report No.8 Livestock and range management: Final report.' Prepared for the Government of Kenya.

Chepkwony, P. K. 1980, 'Restoration of vegetation cover on degraded grazing land in a low rainfall area of Machakos District.' Postgraduate Diploma project report, Department of Agricultural Engineering, University of Nairobi.

Cobb, E. P.; Dobbs, C. M.; Evans, W.; Kirkwood J. G.; Harper, J. F. H.; Maxwell, G. V.; Tucker, W. K. and Tyson, W. 1929 *Report of the Agricultural Commission*. Nairobi: Government Printer.

Cook, C. W. and Stubbendieck, J. 1986, 'Range research: Basic problems and techniques.' USA: Society of Range Management.

Coppock, D. L.; McCabe, J. T.; Ellis, J. E.; Galvin, K. A. and Swift, D. M. 1985, 'Traditional tactics of resource exploitation and allocation among nomads in an arid African environment.' Paper presented at International Rangelands Resources Development Symposium, Salt Lake City, Utah, USA.

Cossins, N, J, 1984, 'Resource conservation and productivity improvement under communal land tenure.' Paper presented at Fourth International Rangelands Congress, Adelaide, Australia.

Cossins, N. J. 1985, 'The productivity and potential of pastoral systems.' *ILCA Bulletin*, (International Livestock Centre for Africa), No.21:10-15.

Cousins, B. 1986, *People, land and livestock.* Masvingo, Zimbabwe: Belmont Press.

Crawley, J. M. 1983, *Herbivory: The dynamics of animal-plant interactions.* Lanham, MD, USA and London: University of California Press.

De Leeuw, P. N. and Tothill, J. C. 1990 *The concept of rangeland carrying capacity in sub-Saharan Africa, myth or reality?* Pastoral Development Network Paper 29b. London: Overseas Development Institute.

Ecosystems 1986, 1987 'Baseline survey of Machakos District 1985: Report to the Machakos Integrated Development Programme.' Nairobi: Ecosystems Ltd. 4 vols.

Edwards, D. C. 1940, 'A vegetation map of Kenya with particular reference to grassland types.' *Journal of Ecology*, 28:377-85.

Edwards, K. A. 1979, 'Regional contrasts in rates of soil erosion and their significance with respect to agricultural development in Kenya.' In: R. Lal and D. Greenland, (eds.) *Soil physical properties and crop production in the tropics.* Chichester, UK: John Wiley.

Ellis, J. E. and Swift, D. M. 1988, 'Stability of African pastoral ecosystems: Alternate paradigms and implications for development.' *Journal of Range Management*, 41(6):450-459.

FAO 1979 *A provisional methodology for estimating soil degradation.* Rome: Land and Water Development Division, FAO.

Fisher, N. M. 1978, *Cropping systems for soil conservation in Kenya. In: Soil and water conservation in Kenya. Report of a workshop University of Nairobi, 21-23 September, 1977.* Occasional Paper No.27. Institute for Development Studies, University of Nairobi.

Gachimbi, L. N. 1990, 'Land degradation and its control in the Kibwezi area, Kenya. ' MSc thesis, University of Nairobi.

Gielen, H. 1982, 'Report on an agroforestry survey in three villages of northern Machakos, Kenya.' Report from Wageningen Agricultural University, Netherlands and International Council for Research in Agroforestry, Kenya.

Gilles, J. L. and Jamptgaard, K. 1981, 'The commons reconsidered.' *Rangelands*, 4:51-54.

Green, R. H. 1979, 'Sampling design and statistical methods for environmental biologists.' New York: Wiley Interscience.

Gregory, J. W. 1896, *The Great Rift Valley*. London: Frank Cass.

Harrington, G. N.; Wilson, A. D. and Young, M. A. 1984, *Management of Australia's rangelands*. Australia: Commonwealth Scientific and Industrial Research Organization.

Hayes, J. J. 1986, 'Not enough wood for the women: How modernization limits access to resources in the domestic economy of rural Kenya.' MA dissertation, Clark University.

Heady, H. F. 1975, *Rangelands management*. New York: McGraw Hill.

Hollings, C. S. 1973, 'Resilience and stability of ecological systems.' *Annual Review of Ecological Systems*, 4:1-23.

Hussain, Shirin Ali; Landstra, W.; Manda, D. R. B.; Medland, J.; Paraico, E. G. S. and Schnabel, J. 1982, *The farming system in Makueni location, Machakos, Kenya*. ICRA Bulletin no.8. Wageningen, Netherlands: ICRA.

Jaetzold, R. and Schmidt, H. 1983, *Farm management handbook of Kenya* Vol.2: *Natural conditions and farm management information*. Part C: *East Kenya (Eastern and Coast Province)*. Nairobi: Ministry of Agriculture.

Kashasha, D. A. R. 1982, 'A study of effective rainfall for crop production.' MSc thesis, University of Nairobi.

Kenya Land Commission 1934, *Report*. 3 vols. London: Her Majesty's Stationery Office.

Kershaw, K. A. 1973, *Quantitative and dynamic plant ecology*. London: Edward Arnold.

Kilewe, A. M. 1987, 'Prediction of erosion rates and the effect of topsoil thickness on soil productivity.' PhD thesis, University of Nairobi.

Kilewe, A. M. and Mbuvi, J. P. 1987, 'The effects of crop cover and residue management on runoff and soil loss.' *East African Agriculture and Forestry Journal*, 53:193-

Kioko, J. N. 1973, 'Report on soil conservation in Kyangala sub-location, Kalama location, Machakos District.' Mimeo report, Ministry of Agriculture, Machakos.

Lesslie, A. and Mitchell, A. J. B. 1979, 'Geomorphology, soils and land use of Utangwa, Iiuni, Kitui and Kune catchment areas. Report to the Institute of Hydrology, Wallingford.' Vol.1. Project Record 32: Kenya-03/REC-32/79, from Land Resources Development Centre, Surbiton, UK. Unpublished report (restricted document).

Lindblom, K. G. 1920, *The Akamba of British East Africa.* Uppsala: Appelborgs Boktrycheri Aktieborg.

Mace, R. 1991, 'Overgrazing overstated.' *Nature,* 349:280-281.

Maher, C. 1937, 'Soil erosion and land utilisation in the Ukamba Reserve (Machakos).' Report to the Department of Agriculture. Rhodes House Library, Oxford: MSS.Afr.S.755.

Mburu, D. M. 1990, 'The role of sand dams in water supply in arid areas.' MSc thesis, University of Nairobi.

McNaughton, S. J. 1979, 'Grazing as an optimization process: Grass-ungulate relationships in Serengeti.' *American Naturalist,* 113:691-703.

Mehlich et al 1962, 'Mass analysis method for soil fertility evaluation.' Nairobi: Ministry of Agriculture.

Moore, T. R. 1979, 'Land use and erosion in the Machakos Hills.' *Annals of the Association of American Geographers,* Vol.69:419-431

Moore, T. R.; Thomas, D. R. and Barber, R. G. 1979, 'The influence of grass cover on runoff and soil erosion in the Machakos area, Kenya.' *Tropical Agriculture (Trinidad),* 56(4):339-344.

Mortimore, M. 1989, *Adapting to drought: Farmers, famines and desertification in West Africa.* Cambridge University Press.

Mortimore, M. 1989, *The causes, nature, and rate of soil degradation in the northernmost states of Nigeria.* Environment Working Paper No.17. Washington, DC: The World Bank.

Mortimore, M.; Essiet, E. U. and Patrick, S. P. 1990, 'The nature, rate and limits of intensification in the farming system of the Kano close-settled zone, Nigeria.' Report to the Federal Agricultural Coordinating Unit, Ibadan, Nigeria.

Muchena, F. N. et al. In preparation. 'Soils of Makueni area.' Reconnaissance Soil Survey Report No.5. Nairobi: Kenya Soil Survey.

Mueller-Dombois, D. and Ellenberg, H. 1974, *Aims and methods of vegetation ecology.* Chichester, UK: John Wiley.

Munuve, J. M. 1989, 'Overview on catchment studies in semi arid areas: The influence of land use on water and soil conservation.' Paper presented at Water Conservation Seminar, Laikipia District, 7-11 August, 1989.

Musingi, K. 1990, 'Effective rainfall and bean yield in a tropical semi-arid environment: A case study of south-eastern Machakos District, Kenya.' MSc thesis, University of Nairobi.

Mutiso, S. K. 1988, 'Water resources and crop production in Machakos District, Kenya.' PhD thesis, University of Reading.

Muya, F. S. 1990, 'Reservoir sedimentation and catchment land use.' MSc thesis, University of Nairobi.

NES 1985, 'CBS/NES survey of drought responses: Preliminary findings.' Nairobi: National Environment Secretariat.

Nieuwolt, S. N. 1978, 'Seasonal drought in East Africa.' Nairobi: University of Nairobi.

Nyanyintono, R. M. 1986, 'Report of preliminary findings: The Kibwezi maternal/child care planning/nutrition base-line survey, Jan/Feb 1985.' Nairobi: AMREF.

Otieno, A. K. 1984, 'Soil erosion in Ukambani: A geographical and historical perspective.' MA thesis, University of Ohio.

Palutikof, J. F. 1986, 'Drought strategies in East Africa: The climatologists's role.' *Climatic Change.*

Parry, M. L., Carter, T. R. and Konijn, N. (eds.) 1987, *The impact of climatic variations on agriculture.* Vol.2: *Assessments in semi-arid regions.* Dordrecht, Boston and London: Kluwer Academic Publishers.

Parsons, B. T. 1952, 'Makueni vegetation.' Unpublished manuscript, Kenya National Archives.

Peberdy, J. R. 1958, 'Machakos District Gazetteer.' Machakos District Office, Ministry of Agriculture.

Pereira, H. C. and Beckley, V. R. S. 1952, 'Grass establishment on eroded soil in a semi-arid African reserve.' *Empire Journal of Experimental Agriculture*, 21(81):1-14

Perham, M. (ed.) 1959, *The diaries of Lord Lugard.* Vol.1. London: Faber & Faber.

Perrier, G. K. 1990, *The contextual nature of range management.* Pastoral Development Network Paper 30c. London: Overseas Development Institute.

Picardi, A. C. and Seifert, W. W. 1976, 'A tragedy of the commons in the Sahel.' *MIT Technology Review*, May:42.

Pole-Evans, I. B. 1939, *Report on a visit to Kenya.* Nairobi: Government Printer.

Pomery, D. and Service, M. W. 1986, *Tropical ecology.* Harlow, Essex, UK: Longman.

Pratt, D. J. and Gwynne, M. D. 1977, *Rangeland management and ecology in East Africa.* London: Hodder and Stoughton.

Reid, L. 1982, *Soil erosion in Machakos District.* Nairobi: Ecosystems Ltd.

Scoones, I. 1989, *Economic and ecological carrying capacity implications for livestock development in the dryland communal areas of Zimbabwe.* ODI Pastoral Development Network Paper No.27b. London: Agricultural Administration Unit, Overseas Development Institute.

Silberfein, M. 1989 *Rural change in Machakos, Kenya: A historical geography perspective.* Lanham, MD, USA and London: University Press of America

Sketchley, H. R.; Mbuvi, J. P.; Wokabi, S. M. and Scilley, F. M. 1979, *Reconnaissance soil survey of portions of Machakos-Kitui-Embu area.* Washington: Soil Conservation Service, United States Department of Agriculture..

Stewart, J. I. and Hash, C. T. 1982, 'Impact of weather analysis on agricultural production and planning decisions for the semi-arid areas of Kenya.' *Journal of Applied Meteorology*, 21(4):477-494.

Stewart, J. I. and Wang'ati, F. J. 1980, 'Research on crop water use and drought responses in East Africa.' Proceedings of the International Workshop on the Agroclimatological Research Needs of the Semi-arid Tropics, Hyderabad. Patancheru, India: ICRISAT. pp170-180.

Stocking, M. 1984, *Erosion and soil productivity: A review.* FAO Manuals and Reports Series No.22. Rome: Land and Water Development Division, FAO.

Stocking, M. 1986, *A working model for the estimation of soil loss suitable for underdeveloped areas.* Occasional Paper No.15. Norwich, UK: Centre for Development Studies, University of East Anglia.

Stocking, M. and Peake, L. 1985, *Erosion induced loss in soil productivity: Trends in research and international cooperation.* Rome: Land and Water Development Division, FAO.

Stoddart, L. A.; Smith, A. D. and Box, T. W. 1975, *Range management.* New York, USA: McGraw Hill.

Styczen, M. 1983, *Research activities carried out by the Soil and Water Conservation Section.* Katumani, Kenya: National Dryland Farming Research Centre.

Thomas, D. B. 1974, 'Air photo analysis of trends in soil erosion and land use in part of Machakos District.' MSc thesis, University of Reading.

Thomas, D. B. 1978, 'Some observations on soil conservation in Machakos District, with special reference to terracing.' In: *Soil and Water Conservation in Kenya: Report of a workshop held at University of Nairobi 21-23 September 1977.* Occasional Paper No.27. Nairobi: Institute for Development Studies and Faculty of Agriculture, University of Nairobi. pp.25-39

Thomas, D. B. and Barber, R. G. 1978, 'Report on rainfall simulator trials in Iiuni, Machakos, Kenya.' Department of Agricultural Engineering, University of Nairobi.

Thomas, D. B. and Barber, R. G. 1983, 'The control of soil and water losses in semi-arid areas: Some problems and possibilities.' *The Kenyan Geographer*, No.5:1-2, 72-79

Thomas, D. B.; Edwards, K. A.; Barber, R. G. and Hogg, I. C. G. 1981, Runoff, erosion and conservation in a representative basin in Machakos District, Kenya.' In: R. Lal and E. W. Russell, (eds.) *Tropical agricultural hydrology and watershed management.* Chichester, UK: John Wiley. pp.395-417

Trapnell, C. G. 1958, 'Notes on ecological zones in North Machakos.' Unpublished manuscript, Kenya National Archives.

Ulsaker, L. G. and Kilewe, A. M. 1983, Runoff and soil erosion for an alfisol in Kenya.' *East African Agriculture and Forestry Journal*, 44:210-241 '

Valentine, J. F. 1981, *Range development and improvements.* Utah: Brigham Young University Press.

Van der Weg, R. F. and Mbuvi, J. P. (eds.) 1975, *Soils of the Kindaruma area.* Reconnaissance Soil Survey Report No.1. Nairobi: Kenya Soil Survey.

Wain, A. S. 1983, 'Athi River sediment yields and the significance for water resource development.' In: Thomas, D. B. and Senga, W. M. (eds.) *Soil and water conservation in Kenya: Proceeding s of the second national workshop, Nairobi, 10-16 March 1982.* IDS Occasional Paper no.42. Nairobi: Institute of Development Studies, University of Nairobi. pp.274-293.

Walker, B. H.; Ludwig, D.; Hollings, C. S. and Peterman, R. M. 1981, 'Stability of semi-arid savanna grazing systems.' *Journal of Ecology*, 69:473-498.

Walker, B. H. and Noy-Meyer, I. 1982, 'Aspects of the stability and resilience of savanna ecosystems.' In: Huntley, B. J. and Peterman, R. M. (eds.) *Ecology of tropical savannas.* Berlin: Springer-Verlag .

Warren, A. and Agnew, C. 1988, *An assessment of desertification and land degradation in arid and semi-arid areas.* Paper No.2, Dryland Programme. London: International Institute for Environment and Development.

Young, A. 1989, *Agroforestry for soil conservation.* Nairobi: International Council for Research in Agroforestry.

Young, A. Forthcoming, 'Soil monitoring: A basic task for soil survey organizations.'

Zöbisch, von M. A. 1986, 'Erfassung und Bewertung von Bodenerosionsprozessen auf Weideflächen im Machakos-Distrikt von Kenia [Registration and evaluation of soil erosion processes of grazing land in Machakos District, Kenya].' *Der Tropenlandwirt,* 1986:no.27.

46: The IMF in the 1990s: Forward to the Past or Back to the Future
Graham Bird, 1991, £3.50, ISBN 0 85003 153 2
47: What Can We Know About the Effects of IMF Programmes?
Tony Killick, Moazzam Malik and Marcus Manuel, 1991, £3.50, ISBN 0 85003 154 0
48: Country Experiences with IMF Programmes in the 1980s
Tony Killick with Moazzam Malik, 1991, £3.50, ISBN 0 85003 155 9
49: Evaluating the Impact of NGOs in Rural Poverty Alleviation: India Country Study
Mark Robinson, 1991, £5.00, ISBN 0 85003 157 5
50: Evaluating the Impact of NGOs in Rural Poverty Alleviation: Bangladesh Country Study
Sarah White, 1991, £5.00, ISBN 0 85003 158 3
51: Evaluating the Impact of NGOs in Rural Poverty Alleviation: Uganda Country Study
John de Coninck, 1991, £5.00, ISBN 0 85003 159 1
52: Evaluating the Impact of NGOs in Rural Poverty Alleviation: Zimbabwe Country Study
Ann Muir, 1991, £5.00, ISBN 0 85003 160 5
53: Environmental Change and Dryland Management in Machakos District, Kenya: Environmental Profile
edited by Michael Mortimore, 1991, £4.00, ISBN 0 85003 163 X
54: Environmental Change and Dryland Management in Machakos District, Kenya: Population Profile
edited by Mary Tiffen, 1991, £4.00, ISBN 0 85003 164 8
55: Environmental Change and Dryland Management in Machakos District, Kenya: Production Profile
edited by Mary Tiffen, 1991, £5.00, ISBN 0 85003 166 4
56: Environmental Change and Dryland Management in Machakos District, Kenya: Conservation Profile
F. N. Gichuki, 1991, £4.00, ISBN 0 85003 167 2

Overseas Development Institute
Regent's College
Inner Circle
Regent's Park
London NW1 4NS
England
Telephone: 071-487 7413
Fax: 071-487 7590
Telex: 94082191 ODIUK