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LAND USE PLANNING AND QUANTITATIVE MODELLING IN TANZANIA WITH PARTICULAR REFERENCE TO AGRICULTURE AND DEFORESTATION: SOME THEORETICAL ASPECTS AND A CASE STUDY FROM THE WEST USAMBARA MOUNTAINS

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ABSTRACT

Land use planning in Tanzania is an important issue due to serious land use problems caused by a host of factors. One of the reasons causing the general land use problem is stiff competition between forestry and agriculture. In the forest sector *per se* we find problems related to competition between the production of wood products, watershed protection, tourism, nature conservation, deforestation through encroachment, both legal and illegal logging activities. All these activities very much influence the future prospects of natural forest reserves. In agriculture land use problems emanate basically from inefficient farm management practices caused by socio-economic factors.

The broad objective of this study has been to improve on the body of knowledge related to land use planning, modelling and management of the land use in Tanzania with particular relevance to an integrated management of forestry, agriculture and nature conservation.
The more specific objectives are to: (i) present an overview of major land use planning problems in Tanzania in general and in the Usambaras in particular; (ii) evaluate some of the existing planning models regarding their suitability for application in multiple land use planning in Tanzania and discuss the optimal balance between quantitative modelling and qualitative aspects in land use planning and multiresource management; (iii) develop linear programming and compromise programming models for analyzing farming systems at the village level in the West Usambaras.
This has been done in the enclosed four reports:

Report 1: Forest related land use in Tanzania: some policy and socio-economic aspects.

Report 2: Land use in the West Usambara Mountains: analysis of ecological and socio-economic aspects with special reference to forestry.

Report 3: A theoretical review and application of some land use planning models with relevance for application in Tanzania.

Report 4: Application of economic analyses and mathematical programming in land use planning at the village level in West Usambara Mountains.

The application of quantitative modelling in Tanzania has been fairly limited, yet this study has indicated that there are considerable prospects for increased scope of application. The analysis of this study, *inter alia*, indicates that the present farming systems in the West Usambaras are not sustainable for more than about 30 years, and that the pressure from agriculture on forest lands would be high. This suggests that, in order to make the existing farming systems sustainable, it is important to improve farming technology which could increase crop production through improvements of land productivity and increase income from other sources. The government has failed to provide adequate measures to counter-balance the effect of population increases, thereby setting in motion a devolutionary cycle of increasing population densities and declining welfare. Therefore, as a matter of policy, it is important to redress this downward trend through a combined effort of politicians, extension workers and the farmers themselves. The overriding strategy should be to ensure long-term maintenance and improvement of the welfare of the local populace.

ADDITIONAL KEY WORDS: Land use, land use planning, sustainability, farming systems, decision making, quantitative methods, qualitative approaches, mathematical programming, linear programming, multiobjective planning, compromise programming.

PREFACE

My interest in land use planning, especially from farming and forestry point of view, is based on the fact that I was born and brought up in a peasantry society. Our village lies in the immediate environs of a natural forest reserve from which we obtain a variety of materials. During my childhood I grew up with increasing realization of the importance of forests and farming activities. Therefore it is not by chance that I took interest in analyzing farming systems in this study.

In pursuit of this study I received assistance and cooperation from various institutions and individuals. The Norwegian Agency for Development Cooperation (NORAD) provided financial sponsorship for the study. The Department of Forestry, Agricultural University of Norway, accepted me as a *Dr. Scient.* student and provided logistical support. I spent one year (1990/91) doing course-work at the School of Forestry, Northern Arizona University, U.S.A., where I received academic and logistical support from both faculty and administrative staff. Sokoine University of Agriculture, Morogoro, granted me study leave to pursue the Ph.D programme.

Professor Dr. Birger Solberg, The Norwegian Forest Research Institute, initiated, inspired and guided me diligently throughout the study period, and has read and commented on all four reports. Dr. Prem Sankhayan, Senior Economist at the Centre for Sustainable Development, Agricultural University of Norway, encouraged me in mathematical modelling, and has read and commented on Report Number 4 of this study. Prof. Dr. Aaron S.M. Mgeni, Department of Mensuration and Management, Sokoine University of Agriculture, has read and commented on Reports 1 and 2. Mr. Gerald C. Monela, Lecturer, Department of Forest Economics, Sokoine University of Agriculture, has read and commented on Reports 1 and 2 as well as chapter 3 of Report Number 4. Dr. Stein T. Holden, Associate Professor, Department of Economics and Social Sciences, Agricultural University of Norway, has read and commented on Reports 1 and 2. Prof. Dr. Aku O'Kting'ati, Head, Department of Forest Economics, Sokoine University of Agriculture provided logistical support during field work in Tanzania.

Ms. Grethe Delbeck typed and retyped Report Number 3 of the study. Ms. Kari Solberg, as a true mother, gave me moral support during the course of the study.

Finally my family has had to tolerate my long absence from home. I missed my mothers sweet porridge! Prof. Shabani A.O. Chamshama took great care of the family during my absence.

To all these institutions and persons I wish to say SHUKRAN.

Ås-NLH
Summer 1993

Abdallah R.S. Kaoneka

TO MY BELOVED PARENTS

Mama Rukia Saguti, your love is everlasting.
The words you taught me during childhood
are the language of this work.
Mzee Rashidi Kiondo Kaoneka, you showed and
taught me the art and science of forestry
at a tender age of NINE. It is an
everlasting knowledge.
You TWO are the embodiment of goodness.
Above all the Almighty Allah (S.W.)-You
blessed me with the faculty of understanding
and the physical strength to accomplish this
important task. It is a product of struggle
and sacrifice.

ALHAMDULILLAH

CONTENTS

SUMMARY

Introduction

Land use planning in Tanzania is an important issue due to serious land use problems caused by a host of factors. One of the reasons causing the general land use problem is stiff competition between forestry and agriculture. In the forest sector *per se* we find problems related to competition between the production of wood products, watershed protection, tourism, nature conservation, deforestation through encroachment and both legal and illegal logging activities. All these activities very much influence the future prospects of natural forest reserves.

On the agriculture side we encounter land use problems relating to improper cultivation practises on hilly areas and along river courses, excessive burning of grass and bushes, poor farming implements, shifting cultivation with very short fallow period, complete absence of adequate and proper farming technology. Others include lack of knowledge to farmers in identifying which kind of soil is best suited to grow a particular type of crop, continuous cultivation or growing of one type of crop on the same parcel of land for a long time and farmers' reluctance to use fertilizers are some of the important problems that do not only reduce production but also cause a considerable damage in terms of land degradation.

Furthermore within the agriculture sector there are land use problems emanating from competing production alternatives in particular cash crops versus food crops. The decision on which type of crops to be planted by a farmer is very much dependent on the existing socio-economic structure. These factors coupled with rather high population growth rate, which averages 2.8% per annum for Tanzania at present add to the severity of the problems. Further, these land use problems do not provide a conducive environment for sustainable use of land-based resources.

Overall objectives of the study

The broad objective of this study is to improve on the body of knowledge related to land use planning, modelling and management in Tanzania with emphasis on integrated management of forestry, agriculture and nature conservation.

The more specific objectives are to: (i) present an overview of major land use planning problems in Tanzania in general and in the Usambaras in particular; (ii) evaluate some of the existing land use planning models for their suitability in the context of multiple land use planning and discuss the optimal balance between quantitative modelling and qualitative aspects of analysis (iii) develop linear programming (LP) and compromise programming (CP) models and use them to analyze farming systems at the village level in the West Usambaras.

This has been done in the enclosed four reports:

Report 1: Forest related land use in Tanzania: some policy and socio-economic aspects.

Report 2: Land use in the West Usambara Mountains: analysis of ecological and socio-

economic aspects with special reference to forestry.

Report 3: Review and evaluation of some land use planning models with relevance for application in Tanzania.

Report 4: Application of economic analyses and mathematical programming in land use planning at the village level in West Usambara Mountains, Tanzania.

Main findings

Report 1

The report discusses the state-of-the-art of land use planning in Tanzania, especially policy issues and socio-economic aspects. The specific objectives of the report are to review: (i) the concept of land use planning and how it influences the management of land-based natural resources with special reference to Tanzania; (ii) the general economy of Tanzania; (iii) the existing land use problems and the policies which influence land use planning in Tanzania.

Both general and case studies are reviewed. Most of the previous studies did not integrate the relationship between land use, land degradation, policy issues and socio-economic aspects. However, there was a general consensus among the authors that Tanzania is faced with land use conflicts which contribute to land (and environmental) degradation. Main issues raised were incompatible land tenure and ownership arrangements, absence of a comprehensive and multisectoral land use policy, and insistence of a top-down (centralized) form of decision making process. Derived land use problems observed relate to resentment against government policies especially those which deprive local people of property rights, poverty and inefficient agricultural practices among peasants coupled with fast growing population. The combined effect of these factors works against sustainable use of land-based resources and maintenance of sound ecological balance. By way of illustrating the issue of land degradation in Tanzania a case of Kondoa is reviewed. The review concentrates on the extent of the problem, measures taken to combat it and the successes and failures of the measures. In general the authors in the previous studies contend that the land use problems are considerable and the measures so far taken to redress the problem are not adequate. Further, they contend that the land use problem requires a multisectoral approach in order to harmonize and mitigate conflicting interests.

Land use planning as a process of decision making seeks to allocate available land-based resources among competing alternatives in order to optimize over time the returns from land-based resources and various land use activities and minimize conflicts among interest groups. In particular, the land use planning process is designed to prevent degradation of the environment and maintain ecological balance. It can be looked upon as a tool to foster sustainable use of land-based resources.

The main features of Tanzania's economy are agriculture (including livestock production), forestry (including fisheries), wildlife, mining and manufacturing industry. The contribution to the national economy and general development trends of these sectors is discussed. Each of the sectors has its share in the economy although the extent of contribution is variable. Further it is observed that the contribution of these sectors can be enhanced and improved through proper management systems. The Tanzanian economy has been characterized by turbulent trends caused by both internal problems and external shocks. The symptoms of the ailing economy were attributed to lack of foreign exchange, persistent trade deficit and poor balance of payment coupled with inefficient domestic production. It is observed that despite the influence of external shocks, the real remedy to an ailing economy lies in the development of internal systems or structures that can mitigate economic problems more efficiently. Thus the decision by the government of Tanzania to liberalize trade, promote privatization and freeing of monetary institutions is a "positive" measure to improve the internal structures and improve production sector.

The paper also reviews some government sectoral policies which are considered relevant in land use planning. The more important policies and/or legislation are villagization programme, land use planning policy, agricultural development policy, forest policy, wildlife policy, livestock policy and nature conservation legislation. The review showed that the initial intent in developing these policies is "good". However, problems are encountered in relation to implementation and socio-economic development. In particular the policies fail to provide a workable framework for implementation because they are of general nature. Socio-economic development increases the conflict among interest groups. Allocative provisions in the sectoral policies are not adequate enough to harmonize and mitigate these conflicts.

Further, sectoral policies are biased, thus fail to adequately address the issue of multiple use of land-based resources. In some cases the policies are rather too old to be efficiently operational, in the ever changing economic environment. Thus various authors propose a revision of the policies to meet the present socio-economic challenges.

The major factors which cause land use problems in Tanzania are identified as: land tenure and ownership policy, extension services, infrastructure, socio-economic factors, government failures in relation to land use problems, *viz*, the Arusha declaration and public policy, foreign exchange policy, fiscal policies, public investment policy and demographic factors. The effect of these factors is seen to be "multi-dimensional" and in some cases localized considering the vastness of Tanzania's land area. However, the general observation is that all these factors have a bearing on land use problems, either directly or indirectly. Thus efforts to redress the issue of land use problems, especially land degradation have to take into account all these factors.

Based on the coverage and discussion presented in this report, it can be said that there is no single proposal to redress land use problems. Nevertheless, the insights gained through the discussion can be looked upon as a point of departure for more detailed and case specific studies.

<u>Report 2</u>

Land use problems in the Usambaras are viewed with great concern because they threaten the existence of the remaining tropical rain forests which have high ecological and socio-economic value. This paper attempts to analyze the relationship between the ecological and socio-economic aspects related to land use in the Usambaras. The more specific objectives are to: (i) examine ecological and socio-economic aspects in relation to land use problems; (ii) present an account of the historical background which has a bearing on land use problems and discuss the major factors which cause these problems; (iii) identify research aspects which should be given high priority in the Usambaras.

As a starting point the paper presents a description of ecological and socio-economic aspects characterizing the Usambaras. The description covers aspects related to location, soils, geology, climate, biodiversity, population, agroecological zones and major land uses. These aspects are considered to represent basic data for subsequent analysis.

The paper also reviews the historical perspectives of land use in the Usambaras which covers the pre-colonial period, the colonial period, *viz,* under German rule and British rule, and post independence era. It is envisaged that these historical perspectives have had an influence on land use trends in the Usambaras. The paper elucidates the contradictions in each historical period and the implications for the present land use.

The major land uses in the Usambaras are agriculture, pastoralism, forestry and others which include human settlements. The general development and present status of agriculture and forestry, which constitute the main land uses, is presented in more detail. These two sectors seem to contribute substantially to the existing land use conflicts in the Usambaras.

The paper discusses the existing land use problems in the Usambaras. The main land use problems are fast population growth which has led to increased derived demand of land for agriculture, human settlements and expanded cash crop production; extensive mechanized logging and uncontrolled pitsawing. Additional factors are poverty, inefficient farming practices and the effect of macro-policy issues, *viz*, structural adjustment programmes and overall weakness in government fiscal policies. These factors have a bearing on land use problems either directly or indirectly. A further analysis of the land use problems is carried out using the general framework of household economic theory.

Finally the paper reviews the SECAP (Soil Erosion Control and Agroforestry Project) approach which is a major attempt, in the recent times, to redress and improve land use practices in the West Usambaras. Also a set of proposals based on an evaluation of the SECAP approach is outlined.

Generally, the seriousness of land use problems in the West Usambaras and the need to redress the same is appreciated. It is, therefore, recommended that detailed case studies could form a baseline for developing comprehensive, embracing and more acceptable land use plan for the West Usambaras. Such an effort is likely to enhance and improve sustainable use of land-based resources in the Usambaras.

Report 3

The broad objective of this report is to present a theoretical review of selected models relevant for land use planning in Tanzania with particular reference to forestry and agricultural lands. The paper also presents a comparative discussion between quantitative versus qualitative approaches to land use planning. The more specific objectives are to: (i) review models applied in land use planning in Tanzania; (ii) evaluate some selected land use planning models with relevance for application in Tanzania and in the West Usambara mountains; (iii) examine the essence, utility and limitation of quantitative and qualitative land use planning and (iv) discuss the relationship between quantitative and qualitative land use planning.

The models applied in Tanzania which are reviewed are; Noninferior set estimation (NISE) and linear programming (LP). NISE was applied in forestry planning problem in Dodoma region, Central Tanzania. Linear programming was applied to three cases for analyzing the agroforestry farming system, economic evaluation of large scale forest-based factory and planning forest plantation management regimes at the project level.

The application of the models in all four cases were judged to be satisfactory with respect to the stated objectives and hypotheses. Further, the model results could be used as a basis for future studies. There is need to widen the scope of future model application as well as incorporating more data to render the models more realistic. Finally, it can be said that the application of models in Tanzania is still at its infancy and that increased scope is desirable.

The models that are reviewed regarding their relevance for application in Tanzania and West-Usambara mountains were ECOSIM, TEAMS and ILWIS. ECOSIM stands for Ecosystem Simulation Model, which is an integration of models representing resources, process and practices involved in forest management. The system has the capability of simulating tree growth and stand development given a set of management prescriptions. TEAMS stands for Terrestrial Ecosystem Analysis and Modelling System. It has a composite structure made up of nine programs linked together. These include data base, simulator and optimization models. The main purpose of developing TEAMS was to use it as a tactical planning system designed to aid forest managers in developing site specific management schedules that will conform to standards and guidelines specified by forest plans and achieve the stated goals. ILWIS stands for Integrated Land and Watershed management Information System. It combines conventional Geographical Information System (GIS) procedures with image processing capabilities and relational data base. The system uses both vector and raster graphics storage data. ILWIS serves as a decision support tool to assist decision makers in evaluating proposed development and conservation plans.

The review indicates that each of the three models has it strengths and weaknesses. Therefore, none of the models are universally applicable. Regarding model selection, there is no universal criterion that can be used as a guide in selecting a particular model. The choice of a model is very much dependent upon the structure of the problem, stated objectives and hypotheses as well as the subjective preference of the decision maker. A model is presented as a tool of analysis and the choice of application is vested upon the decision maker. In choosing a particular model, it is assumed that the decision maker understands its limitations and weaknesses.

The discussion on quantitative versus qualitative approaches to land use planning showed that each of the two methods has strengths and weaknesses. The strength of quantitative methods hinges upon mathematical modelling and the ability to generate quantitative data which can be used in the decision making process. The method is limited, *inter alia*, by the fact that not all pertinent factors in land use planning can be quantified and modelled. The strength of the qualitative approach is attributed to its ability to integrate qualitative information into a decision making framework using managerial intuition. The approach is limited, however, because the use of managerial intuition invariably introduces biases and subjective value judgement. It is concluded, therefore, that none of the two approaches, quantitative and qualitative, is "perfect". Hence it could be more realistic to apply a combination of the two approaches in decision making process.

Report 4

The main objective of this study is to apply a combination of welfare economic theory and mathematical programming to analyze the existing farming systems, socio-economic relations between agriculture and forest lands and assess the sustainability of the present agriculture practices given the increase in population, and the effect of risk aversion on land use pattern.

More specifically micro-economic procedures are used to analyze the profitability and returns to labour of the present farming systems. In mathematical programming two techniques, linear programming (LP) and compromise programming (CP) are used to analyze the present farming systems, the effect of population on land use pattern, per capita cash income and consumption from own farm and the effect of risk aversion. Finally the intention of this study was to examine the sustainability of the present farming systems in light of population growth and income constraints.

The analysis indicates that population growth creates considerable pressure on forest lands especially where arable land is limited. The pressure emanates from increased demand for food necessitating the expansion of farmlands. In areas of limited arable land such expansion is achieved by way of clearing forest lands. Therefore population growth accelerates the rate of deforestation as long as it remains profitable to the farmer.

The increased demand for food compels the farmer to divert more land and family labour to the production of subsistence crops from the cash crops. It is rather a vicious cycle. Due to limited cash income labour hiring is hardly possible. Consequently, the allocation of more labour to the production of subsistence crops reduces the available labour for cash crop production.

The diversion of large proportion of land and labour to the production of subsistence crops has the effect of reducing the amount of cash income earned by a household. Hence the per capita cash income declines to the extent that farmers rely on agricultural activities for generating cash income. The reduction in per capita cash income affects the welfare of the farmer because it implies that the ability to purchase market goods becomes limited.
Experience indicates, however, that in the rural sector of Tanzania, particularly in the West Usambaras, population growth is seldom matched with a corresponding socio-economic growth. Therefore a decline in per capita income is not surprising.

The analysis presented in this study has indicated that the present farming systems can sustain the present population growth rate (2.1% per annum for Lukozi Village) and per capita income for a maximum duration of between 25 and 30 years. Thus the present farming systems cannot sustain even one human generation (life expectancy in Tanzania is over 45 years). Furthermore the assessment of soil productivity indicated that removal of soil nutrients through crop harvests alone are higher than the amount added to replenish soil fertility. The decline in soil nutrients causes a decrease in crop yields over time due to land degradation.

The analysis has further brought out that risk aversion, especially the risk associated with over time variation in crop yields and product price has the effect of reducing per capita income and cultivated land area. In an extreme case, if the farming situation is perceived to be very risky, a farmer may produce only enough to meet the subsistence needs and attempt to earn cash income from off-farm activities. The risk elements are important to a farmer due to the biological nature of crop production and market variability of agricultural crops. In essence, therefore, the inclusion of risk makes the model more realistic and increases its utility.

Concluding remarks

Population growth appears to be the main cause of land use problems in Tanzania and the West Usambaras. The growth in population increase the demand for food and thus causes considerable pressure on forest lands. The key question is, thus, how to feed the growing population and increase their material living standard without indulging in ecological degradation.

The analysis indicates that the present farming systems are not sustainable for more than about 30 years and that the pressure for deforestation would be very high in the future. This suggests that, in order to make the existing farming systems sustainable it is important to improve farming technology which could enhance crop production through increased per unit land productivity. Therefore, as a matter of policy, it could be important, for instance, to extend an appropriate credit facility to enhance the purchasing power of the farmer to buy farm market inputs. The availability of capital can also stimulate the expansion of agricultural production. Such a strategy will secure satisfaction of increased food demand as well as limiting the expansion of farmlands through forest clearing. In addition, the welfare of the farmer and general rural populace could be enhanced and improved.

Also it could be important to develop a policy that will limit the population growth to levels that can be sustained by the present farming systems. This can be achieved, for instance, through family planning and birth control measures. In the long run it might be necessary to develop a comprehensive population policy which is non-existent at present. Such a policy will certainly reduce the pressure on forest lands.

FOREST RELATED LAND USE IN TANZANIA: SOME POLICY AND SOCIO-ECONOMIC ASPECTS

Report Number 1

SUMMARY

The main intent of this report is to discuss the state-of-the-art of land use in Tanzania. In particular the discussion concentrates on policy issues and socio-economic aspects. The specific objectives of the report are: to review the concept of land use planning and how it influences the management of land-based natural resources with special reference to Tanzania, to review the general economy of Tanzania, to review the policies which influence land use planning in Tanzania and to examine the existing land use problems in Tanzania.

As a starting point, the paper outlines a profile of Tanzania. The profile covers aspects related to biophysical and socio-economic environment. The profile is intended to provide basic data about Tanzania.

The paper reviews previous studies on land use in Tanzania. Both general and case specific studies are reviewed. Previous studies did not integrate the relationship between land use, land degradation, policy issues and socio-economic aspects. However, there was a general concensus among the authors that Tanzania is faced by land use conflicts which contribute to land (and environmental) degradation. Main issues raised were incompatible land tenure and ownership arrangement, absence of comprehensive and multisectoral land use policy, and insistence of top-down (centralized) form of decision making process. Derived land use problems observed relate to resentment of government policies especially those which deprive local people of property rights, poverty and inefficient agricultural practises among peasants coupled with fast growing population. The combined effect of these factors works against sustainable use of land-based resources and maintenance of sound ecological balance. By way of illustrating the issue of land degradation in Tanzania a case of Kondoa is reviewed. The review concentrates on the extent of the problem, measures taken to combat the problem, successes and failures of the measures. In general the authors in the previous studies contend that the land use problems are considerable and the measures so far taken to redress the problem are not adequate. Further they contend that the land use problem require a multisectoral approach in order to harmonize and mitigate conflicting interests.

A review of components of land use planning process is presented. The review covers aspects related to definition and concept of, essentials, methodologies and multiresource approach in land use planning. Land use planning as a process of decision making seeks to allocate available land-based resources among competing alternatives in order to optimize, over time, returns from land-based resources and various land use activities; and minimize conflicts among interest groups. In particular land use planning process is designed to prevent degradation of the environment and maintain ecological balance. It can be looked upon as a tool to foster sustainable use of land-based resources.

A review of the main features of Tanzania's economy is presented. The main features covered are agriculture (plus livestock), forestry (plus fisheries), wildlife, mining and manufaturing industry. The contribution to the national economy and general development trends of these sectors is discussed. Each of the sectors has a share in the economy although the extent of contribution is variable. Further it is observed that the contribution of these sectors can be enhanced and improved through proper management systems. The review shows that

Tanzania's economy has been characterized by turbulent trends caused by both external shocks and internal problems. The symptoms of the ailing economy were attributed to lack of foreign exchange, persistent trade deficit and poor balance of payment coupled with inefficient domestic production. It is observed that despite the influence of external shocks, the real remedy to an ailing economy lies in the development of internal systems or structures that can mitigate economic problems more efficiently. Thus the decision by the government of Tanzania to liberalize trade, promote private production and freeing of monetary institutions are seen as "positive" measures to improve the internal structures and improve production sector.

The paper also reviews some government sectoral policies which were considered relevant for land use planning. The policies and/or legislations reviewed were villagization programme, land use planning policy, agricultural dvelopment policy, forest policy, wildlife policy, livestock policy and nature conservation legislations. The review showed that the initial intent in developing these policies was "good". However, problems were encountered in relation to implementation and socio-economic development. In particular the policies failed to provide a workable framework for implementation because they were of general nature. Socio-economic development increased the conflict among interest groups. Allocative provisions in the sectoral policies were not adequate enough to harmonize and mitigate those conflicts.

Further, sectoral policies had biased or unilateral orientation, thereby failing to adequately address thc issue of multiple use of land-based resources. In some cases the policies were rather too old to be efficiently operational, in the ever changing economic climate. Thus various authors propose a revision of the policies to meet the present socio-economic challenges.

Finally the paper discusses the major factors causing land use problems in Tanzania. The major factors covered are: land tenure and ownership policy, extension services, infrastructure, socio-economic factors, government failures in relation to land use problems *viz* the Arusha declaration and public policy, foreign exchange policy, fiscal policies, public investment policy and demographic factors. The effect of these factors is seen to be "multidimensional" and in some cases localized considering the vastness of Tanzania's land area. However, the general observation is that all these factors have a bearing on land use problems, whether directly or indirectly. Thus efforts to redress the issue of land use problems, especially land degradation have to take into account these factors.

Based on the coverage and discussion presented in this report, it can be said that there is no single proposal regarding measures to redress land use problems. Nevertheless, the insights gained through the discussion can be looked upon as a point of departure for more detailed and case specific studies.

ACKNOWLEDGEMENT

Several individuals and institutions contributed to the success in writing this report. The Norwegian Agency for Development Cooperation (NORAD) provided financial sponsorship for the study. The Department of Forestry, Agricultural University of Norway, accepted me as a *Dr. Scient.* student and provided logistical support. Sokoine University of Agriculture, Morogoro, granted me study leave to pursue Ph.D programme.

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To these individuals and institutions I wish to say SHUKRAN.

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LIST OF ABBREVIATIONS

EIU	=	Economist Intelligence Unit
TAS	=	Tanzanian Shilling
GDP	=	Gross Domestic Product
GNP	=	Gross National Product
IUCN	=	International Union for Nature Conservation
TANU	=	Tanganyika African National Union
CCM	=	"Chama Cha Mapinduzi"
HADO	=	"Hifadhi Ardhi Dodoma"
SUA	=	Sokoine University of Agriculture
TFAP	=	Tanzania Forestry Action Plan
URT	=	United Republic of Tanzania
MDB	=	Marketing Development Bureau
LRDC	=	Land Resource Development Centre

METRIC UNITS

mm	=	millimetre
cm	=	centimetre
m	=	metre
km	=	kilometre
ha	=	hectare
g	=	gramme
kg	=	kilogramme
t	=	tonne
ct	=	carat

1.0 INTRODUCTION

1.1 The profile of Tanzania

1.1.1 Location

Tanzania has an area of about 939,700 km^2. It is the largest country in East Africa. It is located South of the Equator between latitudes 3°S and 12°S and longitudes 29°E and 41°E. Tanzania is bordered by Kenya to the North, Uganda to the North-West, Rwanda, Burundi and Zaire to the West, Zambia to the South West and on the South by Malawi and Mozambique (see also Map.1). The country is bordered by the Indian Ocean to the East.

1.1.2 Climate

In general, Tanzania has a tropical, sub-humid to semi-dry climate mitigated largely by variations in altitude which influence both rainfall and temperature. The rainfall averages 750 mm and 1800 mm per annum in central-western areas and northern-coastal areas respectively.

The variation in rainfall greatly influences the pattern of land use and population distribution. The population is generally concentrated in highland areas which receive fairly high rainfall, hence conducive for agriculture. Livestock keeping is concentrated largely in drier areas such as central parts (Dodoma) and North-West (Shinyanga) which are free from tsetse flies.

1.1.3 Population

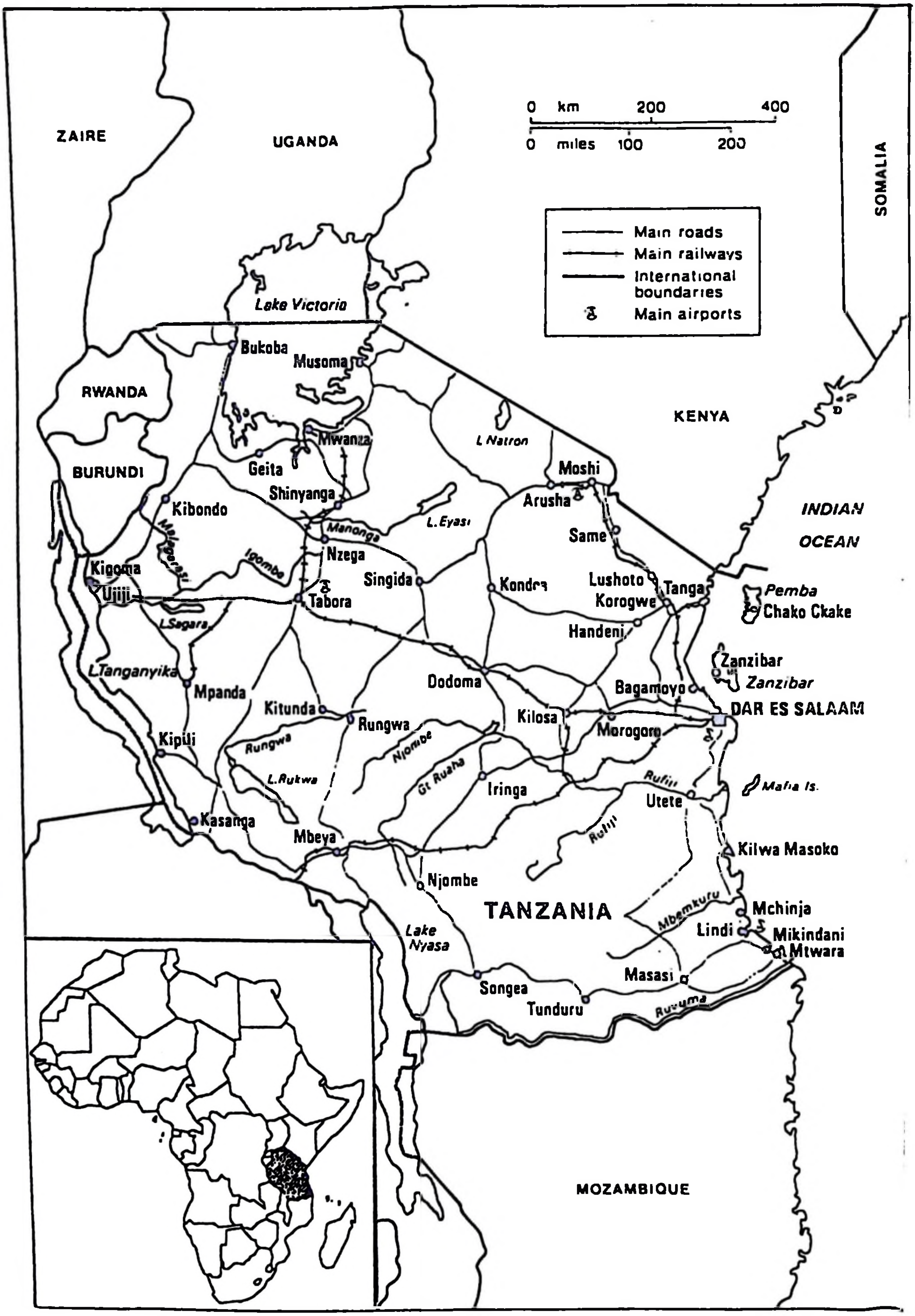
The demographic information is given in Table 1.1. It is based on the 1988 census (URT 1991). Normally census in Tanzania takes place every 10 years. Compared to the 1978 census there is an increase in both the total population size and population density. The total population increased from 17.5 million people in 1978 to 23.2 million in 1988. The population density increased from 19.3 persons per km^2 in 1978 to 25.5 persons per km^2 in 1988.

However the average population growth rate dropped from 3.2% in 1978 to 2.8% in 1988. Also there was a decline in the rate of urban population growth although the exact figure was

Table 1.1 Demographic statistics as per 1988 census

Category	1988	1978
Population size	23,173,336	17,512,610
Growth rate (%)	2.8	3.2
Population density (persons/km^2)	25.5	19.3

Source: URT (1991)



Map 1 Geographic location of Tanzania and her neighbours (adopted from EIU 1992)

not given. An estimated 20% of the population live in urban and sub-urban areas. About 80% of the population live in the rural areas in about 8000 villages (Mgeni 1992). The rural populace can be categorized into peasants, agropastoralists and nomadic pastoralists.

1.1.4 Vegetation

The vegetation types occuring in Tanzania can be grouped into afro-alpine heath and moorlands, forests, woodlands, savannas and grasslands, bushlands and thickets, and swamps (Mgeni and Malimbwi 1990).

Afro-alpine heath and moorlands are mountain vegetation types occuring between 2500 m and 5000 m above sea level (*ibid*). Forests can be classified into closed high forests, montane and submontane forests which occur in highland and mountain areas, on the windward sides of the mountains between 2000 m and 2500 m above sea level. In these areas it is possible to find evergreen or semi-deciduous moist montane forests. Closed forests make up about 17,700 km^2 and require a minimum rainfall of 1000 mm per annum (O'kting'ati and Kowero 1990).

Most closed forests are found in highland areas of Mountains Meru, Kilimanjaro and the Usambaras. Some are also found on Mbulu highlands, Rungwe, Uluguru, Udzungwa and Livingstone Mountains (Lind and Morrison 1974). The intermediate and lowland forests are divided into moist intermediate and semi-deciduous, and evergreen types. The moist intermediate and lowland forests are located on lower altitude, eastern sides facing slopes of the Usambara, Nguru and Uluguru mountains (Lundgren 1975). These forests are considered to have the highest diversity of flora and complex vegetation type in East Africa (Mgeni and Malimbwi 1990).

Miombo woodlands cover a total of 203,800 km^2 (O'kting'ati and Kowero 1990) which constitute about 90% of the total reserve areas or 13% of the total land area (*ibid*). Miombo woodlands occur within the range of 0-600 m above sea level in areas with rainfall in the region of 600 mm to 1200 mm falling in a single season. These are the most widespread in Tanzania and occur in such areas as Mpanda, Tabora and Lindi and are characterized by long dry seasons.

Savannas and grasslands cover an area of about 158,000 km^2 of the total land area and have tree and shrub canopy closure of < 50% (O'kting'ati and Kowero 1990). They constitute a habitat whose occurence is very much variable and prone to annual grass fires especially during the dry season. Savannas are capable of ecological transformation into other types of vegetation such as forests if properly protected. However, due to heavy grazing by both domestic livestock and wildlife, savannas seldom reach the climax stage (Lundgren 1975).

Bushland and thicket vegetation types cover about 260,000 km^2 with a canopy closure of > 50% and general height of 1-10 m (*ibid*). They are characterized by a mantle of small trees of bushy habitat (branching or forking from the base) and shrubs growing in semi-arid areas with average annual rainfall of between 400 and 800 mm (Mgeni and Malimbwi 1990). The plant composition of bushland and thickets is variable with *Commiphora* and *Acacia* dominating whereas *Adansonia digitata* is one of the emergent tree species.

Mangroves are edaphic tree species occuring largely in intertidal lands with saline or brackish conditions. Mangrove communities are composed of tree species which have no taxonomic relationship. Mangrove vegetation is concentrated in coastal zone which includes the Rufiji Delta, Kilwa, Lindi, Tanga, Pangani, Bagamoyo, Zanzibar, Pemba and Mafia covering a total of 115,500 ha (Semesi 1991). The distribution of mangroves by administrative blocks is shown in Table 1.2.

Table 1.2 The distribution of mangroves in Tanzania by administrative blocks

Administrative block	Forested area (ha)	Non-forested areas (ha)
Tanga and Muheza (D)[1]	9,403	3,528
Pangani (D)	1,756	1,279
Bagamoyo (D)	5,636	3,548
Dar es Salaam (R)[2]	2,168	1,045
Kisarawe (D)	3,858	2,193
Mafia (D)	3,473	892
Rufiji (D)	53,255	14,357
Kilwa (D)	22,429	14,308
Lindi (D)	4,547	2,754
Mtwara (D)	8,942	4,408
Total	115,476	48,213

Source: Semesi (1991)
Note: [1] D = District
[2] R = Region

The forest resources provide a variety of products and benefits which include, woodfuel, timber, non-wood products such as honey, fodder, herbal medicines, wild fruits, ornamentals, soil conservation, gene pool conservation, environmental stability through mitigating the effects of climatic fluctuations, providing a stable micro-climate for animal and plant production and water catchment (Pocs 1988; Mgeni 1992). Furthermore active forestry development diversifies the economy by providing export products such as sawn timber, paper associated products and flooring slabs, offering employment complimentary to agricultural activities especially in forest industries which tend to be labour intensive with modest skills.

1.1.5 Economy

The mainstay of Tanzania's economy is agriculture and accounts for 62% of GDP, 90% of export earnings and 90% of employment (EIU 1992; Mgeni 1992). The agriculture sector is dominated by smallholder farmers contributing about 75% of the agricultural export earnings and constitutes about 85% of the total area under crop production (Mgeni 1992). The contribution of manufacturing industry is small and confined largely to semi-processing agriculture produce. Mining sector has also its share on the export basket but only marginally.

The forestry sector contribution to the economy is marginal, in the region of 13.5% (Sharma 1992), but is considered to be a renewable resource base of high economic potential once properly managed. A more datailed analysis of Tanzania's economy is given in chapter 4.

1.2 Objectives of the paper

Land use problems *vis-a-vis* the degradation of land-based resources in Tanzania has been documentated by many authors (Chillumba 1984; Rwechungura 1985; Östberg 1986; Mugasha and Nshubemuki 1988; Mnzava and Riihinen 1989; Hofstad 1990; Jerve 1990; Kowero 1990; Mwalyosi 1990; Christiansson, Kikula and Östberg 1991); Mascarehnas 1991; Mitzlaff 1991; Mung'ong'o 1991). A detailed review of these studies is given in chapter 2. However, it may suffice to mention that there is a general concensus among the authors that land use problems in Tanzania are considerable and require immediate attention in order to enhance sustainable use of land based resources.

In an effort to mitigate land use problems it is considered important to develop land use plans at the village, district, regional and national levels (TFAP 1989). Land use planning may not solve all problems related to the mismanagement of land-based resources, but will undoubtedly, enhance the mitigation of conflicting alternative land uses.

The general objective of this report is, therefore, to discuss the state-of-the-art of land use in Tanzania. In particular the discussion concentrated on policy issues and socio-economic aspects. Previous studies did not integrate the relationship between land use, land degradation, policy issues and socio-economic aspects. The more specific objectives are:

(i) To review the concept of land use planning and how it influences the management of land-based natural resources with special reference to Tanzania.

(ii) To review the general economy of Tanzania.

(iii) To review the policies which influence land use planning in Tanzania.

(iv) To examine the existing land use problems in Tanzania.

2.0 REVIEW OF PREVIOUS STUDIES ON LAND USE IN TANZANIA

2.1 Preliminary remarks

Land use planning in Tanzania is necessary to sustain the multiple use of land-based natural resources which are deteriorating at an increasing rate. The effect of deterioration of resources is reflected by, rapid decline of forest cover, accelerated soil erosion, reduced rainfall, lower water tables, appearance of desert like climatic condition and general land degradation. The main agents causing the deterioration of land-based resources are bad cultivation practises especially on hilly areas and along river courses, excessive burning of grass and bushes, encroachment of natural forests by way of expanding farmlands, fuelwood collection and illegal felling, primitive farming implements, shifting cultivation with very short fallow period, absence of adequate and proper farming technology and conflicting objectives between immediate exploitation and long-term conservation of natural resources (Chillumba 1984; Mnzava and Riihinen 1989; TFAP 1989; Kowero 1990). The combined effect of these factors is further compounded by increasing population whose growth rate averages 2.8% per annum (URT 1991).

To be meaningful land use planning has to be based on empirical studies related to utilization of forest and other land-based natural resources. However at present only a few studies have been carried out in Tanzania on land use planning. The main purpose of this chapter is to review some of the previous studies on land use in Tanzania. The review covers studies by Chillumba (1984), Rwechungura (1985), Mnzava and Riihinen (1989), Hofstad (1990), Jerve (1990), Kowero (1990), Mwalyosi (1990), Mascarehnas (1991), Mitzlaff (1991) and case study of Kondoa based on Östberg (1986), Mugasha and Nshubemuki (1988), Christiansson, Kikula and Östberg (1991) and Mung'ong'o (1991).

2.2 The review of previous studies

Chillumba (1984) carried out a study in Lindi Region to assess the various land use practises in the region. The results of the study showed that the existing practises were inappropriate and inefficient. The main deficiencies of the practises were haphazard clearing of trees, superficial tilling using inferior hand tools, poor crop husbandry and the absence of manure and fertilizer application. The author of the report proposes the development of land use plans in order to avoid further degradation and improve sustained multiple use of land-based resources.

Rwechungura (1985) documented the general perspectives regarding land use planning in Tanzania on the basis of the available land and land-based resources. The report indicates that there are poor management practises of land-based natural resources which significantly hamper agriculture and socio-economic development trends and maintenance of a sound ecological situation. In particular, the author points out that the problem of soil erosion and general land degradation is serious due to unplanned human settlement, expansion of farmlands and extensive livestock movement.

Mnzava and Riihinen (1989) on a sectoral paper for the TFAP observed that, the major land use in Tanzania is agriculture. Thus the authors hypothesise that agriculture is the main cause of ecological degradation. In particular agriculture contributes towards environmental degradation through irrational and inefficient use of all natural resources (*ibid*). Further it was observed that one of redressing the problem of ecological degradation caused by agricultural activities is to develop "appropriate and organised expansion systems and agricultural practises". However such measures are likely to be constrained by several problems including: inconsistent and incomprehensive political decisions, improper legislation and related organisational and institutional set up, deficiencies in pricing mechanism (which removes economic incentive for efficient land management practises) and lack of responsibility due to the absence of land ownership and property rights especially on public lands (*ibid*). The net effect of these factors is the continuation of land degradation due to abuse and /or misuse of natural resources.

Hofstad (1990) argues that there exist a potential for some forests in Africa to sustain higher extraction rate than at present when properly managed. But there is a danger that majority of woodlands and forests are faced with depletion due to both external and internal factors. Emphasizing on the importance of internal factors with relevance to Tanzania, the author points out that excessive cutting of trees is an objective necessity for the local populace to meet their demand for energy and food. In most cases poverty limits the accessibility of rural people to substitute energy sources such as kerosine and electricity. Finally the author proposes the promotion of private and cooperative initiative in establishing woodlots for fuelwood as a viable alternative to reducing pressure on natural forests.

Jerve (1990), based on Rukwa and Shinyanga cases, contend that, the agricultural sector in Tanzania has not played a leading role in development to its fullest capacity. There is an increasing pressure on the exploitation of natural resources caused by population growth and inefficient land husbandry. Further, the policies and programmes initiated by the government and donor agencies have accelerated rather than contain or minimize land degradation (*ibid*). The deficiencies of government policies are due to coercive, blue-print and centralised agricultural policy (*ibid*). In this regard, the author argues that it could be appropriate to redress the problem by adopting participative process as opposed to coercive and blue-print administrative approaches.

Kowero (1990) observes that land use problems in Tanzania are caused by, *inter alia*, the existing land ownership pattern *viz* customary and "institutionalized" land laws. A deficiency common to both systems is the absence of ownership of land by individuals, hence absence of "private property". Whilst such public system of land ownership facilitated the creation/establishment of government forest reserves and plantations, it deprived individuals of an incentive to manage agricultural lands on a sustainable basis to the extent that there was no provision or guarantee for long-term ownership.

Mascarehnas (1991), in a report on deforestation in Tanzania, observed that deforestation and general land degradation is a process influenced by chains of factors creating a causal system (after Palo 1990). Several factors exert paralled influence including, population growth, poverty, accessibility, inefficient socio-economic set up, excessive livestock populations and historical trends (*ibid*). Thus any solution to the deforestation and general land degradation must address a causal system or system causality (after Palo 1990) rather than "simplistic explanations" (Mascarehnas 1991).

Mitzlaff (1991), based on a study in Mbulu District, attibutes land use problems to lack of responsibility on the part of villagers and absence of enthusiasm on conservation of natural forest reserves. This negative attitude is cultivated by the perceived danger to villagers' crops and livestock from wild animals. Also villagers accuse foresters as being managers of logging activities, many of which illegally, rather than protecting forest reserves. Furthermore, villagers feel that conservation of forest reserves deprive them of property rights to the extent that they are owned by the government. This resentment and mistrust of government officials renders the villagers irresponsible for the management of forest reserves. The author concludes that forest utilization, forest conservation and agricultural land must be treated as complementary entities in order to stimulate the participation of villagers.

Mwalyosi (1990) conducted a study in the Lake Manyara basin. The main hypothesis of the study was that proper utilization of resources and environmental conservation depends largely on the people's perceptions concerning the importance of keeping a sound ecosystem. In turn the correct perceptions lead to proper land use practises. The study attempted to analyze the historical trends in land use. Findings from the study showed that there was a high rate of deforestation caused mainly by direct utilization of fuelwood and building material; and the expansion of cultivated land area. The study showed that " as a result of soil 'mining', crop productivity dropped by approximately 50% during the last 30 years" (*ibid*). Further the study showed that over the last 10 years livestock per household decreased by about 50% forcing pastoral societies to cultivate crops, thereby contributing to the expansion of cropland at the expense of grazing and range lands. Overall increased cultivation and overgrazing has led "to increased soil erosion in the highlands and areas with undulating topography, and siltation in lowlands" (*ibid*). The strategy proposed by the author includes the following elements, that is, control of population growth, improvement of the existing land tenure legislation and the provision of techno-economic services that are sensitive to existing local ecological capabilities, utilization of wildlife resources and raising the carrying capacity of the affected areas.

Efforts have been and are still taken on individual cases to redress the land use problem. In the next section a review, based on various authors, is presented for Kondoa (hence referred to as the case of Kondoa).

2.3 A review of the Kondoa Case

2.3.1 Description of the area

This description is based on Mugasha and Nshubemuki (1988). Kondoa District covers 14,500 km^2 of Dodoma Region of central Tanzania. The District is characterized by semi-arid conditions. The mean annual rainfall varies between 500 mm and 800 mm. The rains are extremely variable, at times torrential, with January being the month with the highest daily rainfall intensity when the rain has the most erosive impact.

Östberg (1986) describes the soils of Kondoa Irangi as "texturally coarse loamy sands to sandy loams, being sandiest in the surface horizon. They are low to very low in organic matter, low in bulk density, low in water retention capacity and probably low in inherent fertility and base exchange capacity. On favourable terrain they are deep except where bedrock has been exposed by sheet erosion or gullying". The absence of adequate fertilization regimes coupled with shifting cultivation with short fallow periods exhausts fertility in only a few years (Mugasha and Nshubemuki 1988). Clearing trees, which is part-and-parcel of shifting cultivation exposes the soil to both water and wind erosion.

The vegetative ecosystem is rather fragile. Due to long dry periods in Kondoa Irangi, the regeneration of clearfelled areas is rather slow. Besides shifting cultivation, other agents of soil erosion are overgrazing, deforestation, poor farm management and uncontrolled fires.

2.3.2 Historical perspectives of the problem

The alarm of the problem of serious land degradation in Kondoa was raised by the British rulers as early as in the 1930s, especially due to the presence of "spectacular gullies and vast areas of depleted lands where people found it difficult to eke out a living" (Christiansson, Kikula and Östberg 1991)

The areas that were most degraded were closed in the 1940s and the inhabitants were resettled in other new lands (*ibid*). These measures were not especially appreciated by the local (Irangi) people who perceived them as "the general colonial oppression and wickedness" (Mung'ong'o 1991). The negative reaction can be paralled to that of the Shambaa people on the West Usambara Mountains who "resisted" the British measures to conserve soil against increased degradation (Kaoneka 1993b). Mung'ong'o (1991) attributes the resentment to the absence of psychological transformation which would otherwise change the attitudes of the people to perceive in a more positive way the soil conservation measures.

2.3.3 Rehabilitation measures: the HADO approach

The continued deterioration of Kondoa Irangi area prompted the government to take a "more objective" approach in the early 1970s by launching "Mradi wa Hifadhi Ardhi Dodoma" (commonly referred to as HADO project) in 1973 (Christiansson, Kikula and Östberg 1991). The project covered the most denuded area constituting a little less than 10% or 1256 km^2 of Kondoa District (*ibid*).

While the overriding objective remained that of rehabilitating the "badly degraded area" (*ibid*), the HADO project included other objectives as well which included, "to ensure that the people in Dodoma Region are self-sufficient in wood requirements; to encourage communal wood growing schemes in the region; to promote communal bee-keeping activities; to encourage the establishment of shelterbelts/windbreaks, shade avenues and fruit-tree growing; and to conserve soil and water and reclaim depleted land" (Mugasha and Nshubemuki 1988). The method used to rehabilitate the degraded land include closure of the area from grazing and agriculture; and the removal of livestock from the area except those intended for immediate slaughtering and those used as draught animals (Mung'ong'o 1991).

2.3.4 Successes and failures

Recent reports (*ibid*) show that some 90,000 domestic animals were removed from 19 villages covering an area of 125,000 ha. This activity had some effects on the socio-economic structure of the Irangi people. For instance they changed from being agropastoralists to pure agriculture (Mung'ong'o 1991). Further the measures have had some positive environmental impacts which merits scientific documentation (*ibid*).

Despite the aforementioned "positive effects", land degradation continued even after the HADO project was launched. For instance Mugasha and Nshubemuki (1988), observes that in 1982 mapping of Kondoa based on satellite imagery, showed eroded areas (with varying erosion intensity) that covers 125,600 ha of which serious gullies up to 10 m deep covered about 20% of the area and extensive splash and rill erosion covered 30%.

A review report of 1978 hinted some failures of the HADO project by observing that "conventional conservation methods could not solve the problem of rehabilitating the degraded lands of Kondoa" (Chritsiansson, Kikula and Östberg 1991).

2.4 Concluding remarks

This review has indicated the existence of considerable land use problems in Tanzania. The dimension of the problems varies by geographical location especially due to the vastness of the country. By the same token measures to redress the problems related to land use may be different from one place to the other. The main aspect lacking in these studies is a detailed link between macro and micro socio-economic factors in relation to land use problems. Further the studies have shown limited integration of land use in a multisectoral framework. This paper is an attempt, *inter alia*, to widen the scope and detail of understanding land use problems in Tanzania within the context of multiple use.

3.0 THEORETICAL REVIEW OF SOME ASPECTS OF LAND USE PLANNING

3.1 Definition and concept of land use planning

Camp (1974) defines land use planning as "the process of organizing the development and use of lands and their resources in a manner that will best meet the needs of the people over time while maintaining maximum flexibility for a dynamic combination of resource output for the future". This definition of land use planning will be adopted but with modification to reflect the purpose of the present study. Hence land use planning will be defined to mean the process of systematic classification of land into management units under specific land use pattern which will ensure the use of land-based resources on a sustaining basis for the present and future generations.

The term sustaining basis is used here to mean non-declining trends over time. That is properly utilized resources must be able to sustain people's welfare over time. The fast socio-economic development have resulted in many problems that are endangering not only future generations but also equality among nations and people, unless proper policies are made to guide these developments, whereupon land use planning is one of these policies that are needed (Van-Lier 1988). Land use planning is seen as a means to scheme improved practises and regulations which will assure sustainable use of resources in an effort to restore and maintain parity resource use and conservation of an ecologically sound environment (*ibid*).

Until the present century, traditional land use was, and by large, in harmony with the environment. That was because, over the centuries, societies had developed their own social customs and regulations which ensured sustainable use of land-based natural resources from one generation to the next generation. Individual land use practises were governed by those customs and regulations in such a manner that they were considered socially acceptable (Kowero 1990).

The rapid population growth and development in technology have weakened the traditional land-based natural resource management systems. This resulted into a disparity between consumptive and optional uses of land-based natural resources. Traditional practises are no longer adequate enough to support today's high population sizes (and densities). Moreover traditional systems have a rather too limited capacity to absorb new technologies due to poverty and at times low level of literacy.

The manifestation of growing problems associated with the use and management of land-based natural resources is reflected by environmental degradation, soil erosion, reduced soil fertility, disappearing of forests caused by encroachment, overgrazing and other human activities and emerging signs of desert-like physical conditions. These adverse effects constitute the main force behind the current effort to develop relevant and more efficient land use management systems. Such an objective can be achieved through land use planning.

Land use planning seeks to allocate available land-based resources among competing alternatives in order to optimize returns or net present value (NPV) and minimize conflicts among and between interest groups. The more specific objectives may vary according to the existing local conditions. For instance, according to Abdullah (1984) the specific objectives for land use planning for rural communities may include:

(a) more careful planning of physical infrastructure;
(b) proper allocation and development of settlements;
(c) establishment and maintenance of community woodlots;
(d) more intensive and efficient use of agricultural land.

Land use of an area is the aggregate of responses by individual occupiers of land to a wide range of impulses (*ibid*). The farmer's decision on how to use a particular parcel of land reflects individual perception of the possibilities as they relate to a given situation. In essence, therefore, land use planning embodies the concept of consumer soverignty and freedom of choice. Moreover, land use requires the application of various disciplines such as sociology, economics, politics and hydrology. Land use planning have to be part of the entire national planning policy so that it does not conflict with other socio-economic developments and policies (*ibid*). In the next section some of the features that are essential in land use planning are examined.

3.2 Essentials of land use planning

In ancient times, man lived in reasonable harmony with the environment. From it mankind received basic necessities ranging from food and shelter to clothing and tools. Over, time, the demands of man increased as a result of population growth and technological development. Today, man tends to over exploit the environment, stretching it beyond sustainable limits. As a result, the degraded environment threatens the continued existence of mankind itself. Therefore it is important to develop resource use policies that will not only change the existing balance between man and environment but will also ensure that the exploitation of natural resources is limited to levels that are sustainable for present and future generations. The development of amicable land use policies, and their faithful implementation, are absolutely essential if mankind is to survive and prosper (Van Lier 1988).

Land is a finite resource. In areas of high population density or rapid population growth, it is moreover a scarce resource compared to the demand for it (Kaoneka 1990). Land use planning aims at controlling the proportion of land allocated to various uses. The allocation is based on land capability. The term land capability is used here to mean "the inherent ability of land to be used without permanent damage" (Soil Conserv. Soc. Amer. 1970). Land use planning is essential to ensure proper exploitation (and use) of land-based resources both in the short-run and in the long-run as a means to sustain socio-economic development while at the same time keeping a sound environment. Sustainable development is not a fixed state of harmony, but rather a dynamic process of change over time in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with the future as well as present needs (Jerve 1990). In order to achieve sustainability there must be conscious awareness of the importance of proper utilization of resouces.

The increasing awareness of proper use of land-based resources leads to the development of land use planning systems designed to:

(a) prevent degradation of the environment and maintain ecological balance;

(b) optimize, over time, the production and utilization of forest and land-use based resources such as timber, fuelwood, agricultural crops, livestock, water, soils fisheries and wildlife;

(c) rationalize use of land for agriculture, human settlement, industrialization while maintaining an ecological balance.

The general aim of land use planning is, therefore, to enhance the use of land-based natural resources on sustainable basis (Weintraub, Adams and Yelling 1982; Abdul-Hye 1984).

Land use planning, when broadly applied, has three essential roles to play. First, to assess the suitability of land to assure that the land is allocated to its relevant alternative. Secondly, the demarcation of zones which can be assigned to different uses within rural communities for agriculture and residential zones; the urban industrial area, for say residential, commercial, recreational, educational and industrial zones. Third, the control on the use of land for commercial and even residential purposes through a set of regulations to prevent misuse and pollution in the surrounding areas (*ibid*). These three roles secure that a given parcel of land is put into its appropriate alternative use or opportunity cost. Owing to multiple use of land-based natural resources it may be appropriate to apply multiple goal management principle in order to harmonize the competing alternatives.

For instance commercial facilities and settlement are activities that basically compete with other land uses such as agriculture. Most often the expansion of industrial and residential areas are accomplished at the expense of forestry and agricultural opportunities. This sort of competition is a challenge to land use planners in that the demarcation of land on the basis of its suitability for a particular activity is necessary. Such demarcation may minimize the conflict between competing activities or alternatives and enhances the allocation of a parcel of land to its appropriate use in order to improve productivity.

Furthermore a land use plan takes into account, *inter alia*, three policy issues as advanced by Hussein (1984). First, unplanned use of land in population growth centres and human settlements is seriously straining the scarce land resources of the country, and causing health, sanitation, environmental and socio-economic problems. Such problems need control, regulation and guidance through legal and administrative intervention. Second, irrigation-based modern agriculture, especially through co-operatives, must have institutional support in relation to layout of distribution channels, unrestricted access to water and non-conflicting cropping patterns. Third, an overall rural development strategy by way of land reform, terminal changes and other related factors needed for optimum land use, has to be ensured through a legal framework. It goes without much emphasis that land use policy very much influences the success of any land use planning effort. In fact to be meaningful land use planning must be embodied into the national planning framework. After all it is the policy makers who have the final decision regarding the adoption of a land use plan. Therefore the participation of policy-makers in drawing up a landuse plan ensures their willingness to implement it. Obviously the participation of policy-makers should not be overemphasized such that the planning exercise is characteristic of top-down approach. It is necessary to consider the aspirations of the local populace who will ultimately implement the land use plan hence the need to use bottom-up approach by encouraging people's participation (TFAP, Technical Annexes Vol. II 1989). However, it may as well be noted here that land use planning is complex activity which demands the integration of expertise, technical factors and institutional factors such as land tenure system. A careful balance of the relevant factors is necessary in developing more acceptable land use plans for subsequent implementation.

3.3 Land use planning methodologies

3.3.1 Scope of land use planning at the national level

Land use planning can be undertaken anywhere by utilizing the knowledge, intuition and experience of present land users in combination with technical data collected by research institutions and government agencies. The degree of sophistication in land use plans depends largely on the level of detail available in the data relating to the quality of land, soil and water resources; the effectiveness of evaluations of current land uses; and the identification of alternative uses. In addition, it is necessary to consider socio-economic factors, particularly income per capita, population density and growth rates, distributional effects, and cultural and traditional habits. Other factors include environmental conditions, level of technology, planning capability and tenurial arrangement (Biswas *et al.* 1987). A summary of data required in land use planning is presented in Figure 3.1. These factors vary from one country to another.

The process of land use planning requires the integrated application of multiple disciplines such as hydrology, soil science, forestry, agronomy, land surveying, sociology, political science, social anthropology and economics. These and similar disciplines can provide quantitative data useful in landuse planning analyses and in the development of land use planning models.

Land use planning *per se* is a process involving a series of interrelated steps (Figures 3.1 and Table 3.1) . It is appropriate that these steps be undertaken in chronological order, as the earlier steps often serve as prerequisites for the execution of subsequent steps.

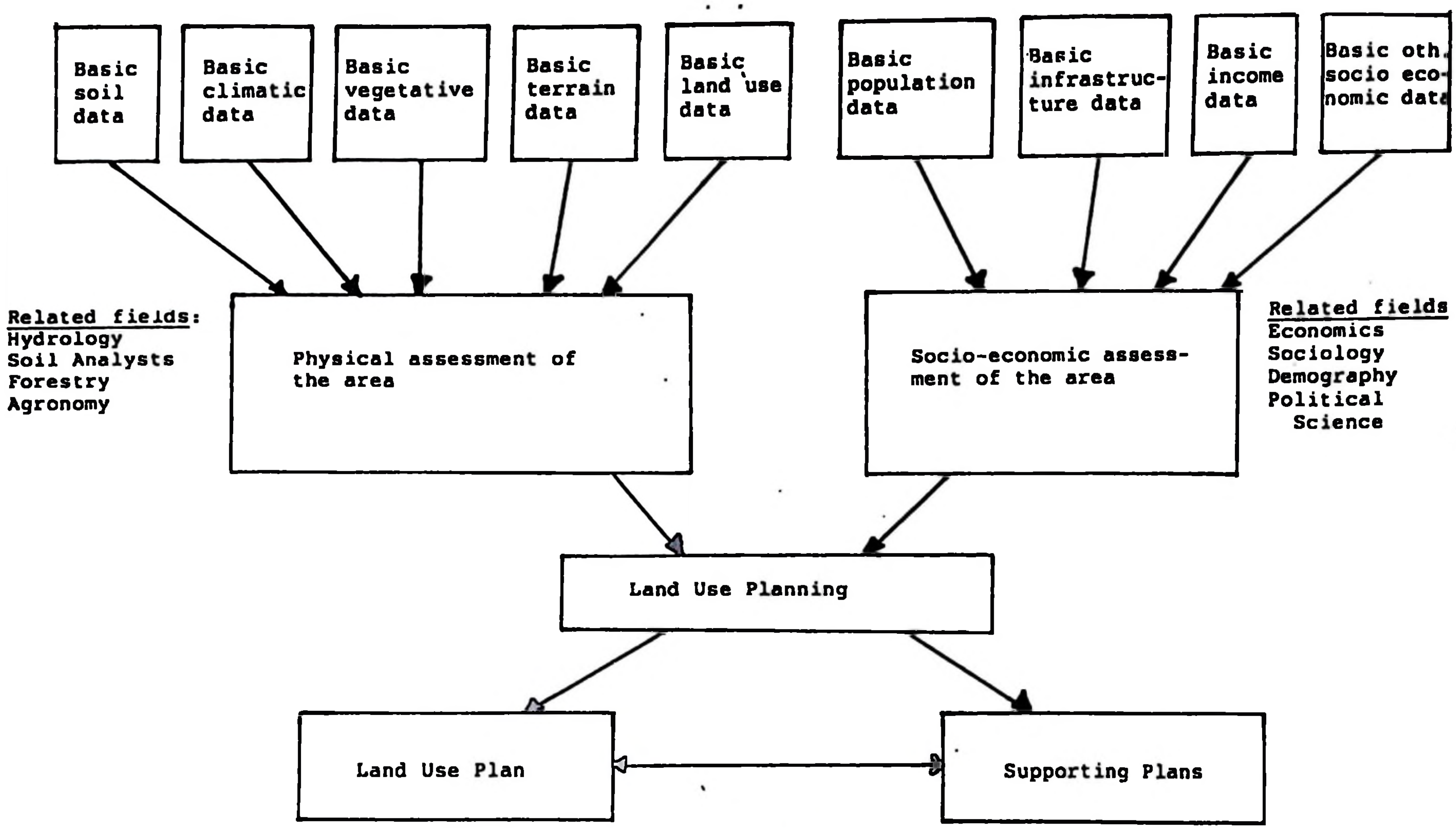


Figure 3.1 A conceptual framework of data needs in land use planning

Table 3.1 Conceptual framework in land use planning.

Description of activity	Implication
1.Recognition of the need for change	Problem definition
2.Identification of objectives	Definition of ends
3.Survey of land, soil and water resources	Reconnaissance
4.Delineation of different types of land and soil present in the area	Land classification
5.Identification of threats of environmental degradation through the overexploitation of resources and pollution	Ecological appraisal of the present land uses
6.Evaluation of the present income, population and land productivity	Socio-economic assessment
7.Selection of preferred use for each type of land	Assessment of land suitability.
8.Measures for environmental protection and appropriate resource management	Identification of the criteria for selecting among alternatives
9.Project design and design of appropriate institutional mechanism	Logistical support specification
10.Implementation through individuals, community, NGO's and government agencies	Land use plan application
11.Evaluation	Overall appraisal of the plan

3.3.2 Types of land use surveys

There are, essentially, three levels of planning intensity namely reconnaissance, semi-detailed and detailed intensities (Abdul-Hye 1984). These levels are normally reflected in the details of the land or maps.

Reconnaissance surveys are concerned with the production of broad inventory of resources and development potential. In this category land evaluation is very qualitative and economic analysis is undertaken in broad terms. The data from reconnaissance survey are used in drawing up plans, selection of development areas and setting up priorities.

The semi-detailed and detailed surveys are concerned with more specific aims and include feasibility studies of development projects. At this level land evaluation is quantitative and economic analysis is detailed.

3.3.3 Land evaluation and capability classification

The starting point in the process of land use planning is the recognition of the need for change in the use to which land is put. Recognition of this need is followed by the identification of the objective of the proposed change and formulation of general, as well as specific proposals. Having identified the problem the next step is land evaluation. The term land evaluation refers to the assessment of the inherent capability and managed suitability of land for variuous uses such as agriculture, forestry, settlements, hydrological and engineering (after Stewart 1968).

The land evaluation process aims at identifying the range of potential uses and the assessment and comparison of this with respect to each type of land identified in the area. This leads to the identification of one or a number of preferred kinds of use. The recommendations can then be used in the planning process for making decisions about the most desirable types of land use for each distinct part of the area. This is followed by further analysis of the most desirable and/or potential use on which implementation of the project subsequently takes place. This is achieved by way of a socio-economic assessment.

Both socio-economic assessment and resource surveys are used in planning which is undertaken in essentially two stages. The role of socio-economic analysis, in the first stage, is limited to the examination of the relevance of the types of potential land uses. This stage ends with its output being presented in form of a map and reports. The two-stage analysis is used in resource inventories for broad planning purposes and in biological studies intended to assess production potential (*ibid*). The results obtained during the first stage are used as inputs in the second stage of socio-economic analysis. Socio-economic analysis is followed by land capability classification. Land capability classification can be defined as a grouping of kinds of soil into special units, subclasses and classes according to their capability for intensive use and the treatments required for sustained use (Schwarz, Thor and Elsner 1976). Subclasses and classes refer to units with the same kind of dominant limitations for agricultural use as a result of soil and climate (*ibid*).

Land capability classification establishes the relationship between land and land use. The types of land use to which the evaluation refers are usually modified in the course of planning. For instance, in case of arable land such a modification may include the selection of crops and rotations, estimates of the inputs required and determination of the optimum size of farm. The main utility of the two stage approach is that it is straightforward, and presents a clear cut sequence of activities.

Having evaluated the land in terms of socio-economic assessment and land capability classification, the next step is to allocate the land to various alternative uses. The allocation process can be effected in a number of ways; intuitively, preference principle and use modelling techniques. In this paper we will confine ourselves to the use of modelling techniques in land use allocation. To the extent that land use embody the concept of multiple use (Mgeni 1992), it is considered relevant to review some aspects related to multiresource planning which is presented in Section 3.3.4.

3.3.4 Multiresource approach in land use planning

Land-based resources are diverse. Forestry, wildlife, fisheries and agriculture are some of the land-based resources. There are varied perceptions regarding the interaction of these resources. One school of thought is that they are competing. That is the production of one resource excludes the production of another. A typical example is the competition between agriculture and forestry. Farmers view forestry as a less appealing economic activity basically due to the long rotation period involved in the production process. Foresters view agriculture as being detrimental to the extent that farmers encroach forest in search for virgin arable land.

The second perception is that land-based natural resources are viewed in an integrated manner. That is, production of one resource affects the production of another resource. For instance the maintenance of forest cover, especially on steep slopes that serve as stream sources, enhances the production of adequate and clean water needed for fish production, irrigation agriculture and human consumption. In agroforestry systems trees are mixed with farm crops in an attempt to optimize returns or output.

Ideally natural resources should be viewed as complementary more so than competing basically because each resource contributes towards the survival of mankind and human society (Covington *et al.* 1988; Wood, Fox and Covington 1989). Hence the emergence of the concept of multiresource management. In fact it does not seem wise to talk of land use planning in isolation from other aspects of multiresource management. Thus land use planning must aim at optimizing multiresource outputs which can be classified into physical, economic, social and institutional (Weintraub *et al.* 1982). The goals identified by Weintraub *et al* (1982) are outlined in following sections albeit with some modifications that are relevant to Tanzania's environment.

3.3.4.1 Physical goals of multiresource management

The physical goals that may be optimized through land use planning include:

(a) Develop proper pattern of use of natural resources.
(b) Maintain soil quality, avoid soil erosion.
(c) Maintain water quality, minimize run off.
(d) Protect endangered species.
(e) Protect wildlife, wilderness.
(f) Protect fish habitat.
(g) Protect cultural, historical and archeological sites.
(i) Beware of created hazards such as fire.

3.3.4.2 Economic goals of multiresource management

Some economic goals which land use planners may aim to optimize include:

(a) Increase value of outputs and services most desired by the society.
(b) Enhance opportunities for economic development in regions and especially in rural communities.
(c) Develop economically and environmentally consistent timber production in both short

and long run.
(d) Maintain sound forest habitat for wildlife and range lands.

3.3.4.3 Social goals of multiresource management

Social goals which may influence land use planning orientation are:
(a) Ensure equal opportunity for people to use land-based resources.
(b) Enhance social wellbeing:
   (i) promote a good distribution of income;
   (ii) have acceptable patterns and distribution of employment and other welfare benefits;
   (iii) do not harm social structure of communities;
   (iv) have acceptable system to internalize the externalities of a land use plan;
   (v) avoid overcrowding of community services and other social facilities such as transport means.

3.3.4.4 Institutional goals multiresource management

The institutional goals of multiresource management include:
(a) Maintain or improve land ownership and land tenure system that efficiently advances public programmes.
(b) Plan land uses in recognition of other government and local interests.

Land use planning is a process which require adequate and reliable data base as well as proper analytical tools (Allen 1986). Experience from industrialized countries and elsewhere (for example Bell 1976; Betters 1987 and 1988; Covington *et al.* 1988; van der Zel and Walker 1988; Wood, Fox and Covington 1989; Pukkala and Pohjonen 1991) have shown that quantitative models can provide an important analytical tool for the policy decision makers to develop and establish more sustaining land use plans that can be used to improve the contribution of land-based natural resources to the welfare of the society. In Tanzania, however, the application of quantitative models is still at its infancy (Allen 1986; TFAP 1989).

One of the widely applied approach in quantitative land use planning is the use of modelling techniques. A class of models known as mathematical programming in particular the constrained optimization models may be useful. A detailed review of land use planning models with relevance to Tanzania will be given in Report Number 3 of this study. However it may be appropriate to review some mathematical programming techniques as a way of adding clarity. Therefore in the next section a brief review will be given of some mathematical programming techniques that are considered to be relevant for land allocation problems and general multiresource planning issues.

3.3.5 Mathematical programming in land use planning

Mathematical programming represents a class of models known as symbolic models as they are built using mathematical symbols and relationships (Dykstra 1984). Mathematical programming is applied to a group of optimization techniques which include linear programming, goal programming, integer and mixed integer programming, quadratic programming, geometric programming and dynamic programming (Mgeni 1986). All these are techniques designed to select an optimal solution for a set of variables, often called activities (Joyce, Mckinnon and Hoekstra 1983; Dykstra 1984). Most often the optimal solution is in the form of numerical maximum or minimum of some specified performance criterion or objective function such as maximum net present value (NPV) or minimum total production cost (TC) (*ibid*).

The coverage of each of these techniques in great detail is not necessary here because modelling or quantitative approaches in land use planning will be the main topics of reports number 3 and 4 of this study. However, for illustrative purposes, only two techiques, linear and goal programming, will be briefly reviewed.

3.3.5.1 Linear Programming (LP)

Linear models are characterized by the fact that each and every component of the model exhibit a linear relationship (Dykstra 1984; Mgeni 1986). Linear programming can be used to solve a wide ranging problems related to the management of natural resources, including allocation of land to various uses (Coutu and Ellertsen 1960; Betters 1988; Shakhya and Leuschner 1990; Pukkala and Pohjonen 1990; Sankhayan and Cheema 1991), maximization of net present value (Jackson 1958; Jackson and Smith 1961; Kidd, Thompson and Hoepner, 1966; Kowero 1983; Mgeni 1986) and more general planning problems (Bell 1977; Betters 1977; Kent 1980; Joyce, Mckinnon and Hoekstra 1983). The simplicity or complexity of an LP model is very much dictated by the nature and scope of the problem under analysis.

A simplified mathematical presentation of a linear programming model based on Joyce, Mckinnon and Hoekstra (1983) and Dykstra (1984) can be formulated as follows:

Maximize:

$$Z = \Sigma C_j X_j \qquad [2.1]$$

Subject to:

$$\Sigma A_{ij} X_j \leq B_i \qquad i = 1,..........., m \qquad [2.2]$$

$$X_j \geq 0 \quad \text{(non-negative condition)}$$

$$j = 1,...........,n$$

where,

Z	=	objective function
C_{ij}	=	objective function coefficients, also referred to as technical coefficients
X_j	=	decision variables or activities
j	=	set of activities
i	=	constraints or resources
A_{ij}	=	amount of resource i used in activity j
B_i	=	total resource available for any row (constraint)

Notice that the term C_j which is the objective function coefficient indicates the marginal contribution of each X_j to Z. It is often convenient to summarize an LP model in form of a "detached coefficient matrix" (Dykstra 1984) as shown in Table 3.2.

The linearity condition in a linear programming model is assured by proportionality and additivity. Each activity's contribution to the objective function and its rate of resource use is proportional to that activity, that is, coefficients in both the objective (C_{ij}) and constraints

Table 3.2 A conceptual detached coefficient matrix of an LP problem

Row identity	Activity (decision variable)				Type	RHS[1]
	X_1	X_2	X_3	X_4		
	C_1	C_2	C_3	C_4	Max./Min.	Z
1	A_{11}	A_{12}	A_{13}	A_{14}	$\leq$	B_1
2	A_{21}	A_{22}	A_{23}	A_{24}	$\leq$	B_2
3	A_{31}	A_{32}	A_{33}	A_{34}	$\leq$	B_3

Note: [1]RHS = right hand side

(A_{ij}) are constant for all levels of activity X_j (Dykstra 1984). The total contribution to the total resource use of two or more activities engaged at the same time must equal the sum of the individual contribution, or resource use of each activity engaged separately. A second assumption of a linear programming model is that decision variables must be divisible by taking fractional values. Fourth, all coefficients of the decision variables and activities must be determined (deterministic condition) before the model is formulated and run. Also all variables may not assume negative values. Finally, only one objective function may be specified (for either maximization or minimization) at any one time.

Normally a linear programming model is static. However, discrete time periods may be incorporated by adding extra rows and columns for each time period (Bell 1977; Betters 1977).

3.3.5.2 Goal Programming (GP)

Goal programming is an optimization programming technique which tries to achieve simultaneously unattainable goals by minimizing the difference between the solution and the goals as opposed to linear programming approach of maximizing or minimizing a single goal (Bell 1976; Schuler *et al.* 1977; Van der Zel and Walker 1988). A general structure of goal programming based on Bell (1976) and Van der Zel and Walker (1988) may be cited as follows:

1. Formulation without goal preference

Minimize $Z = d^{+n} + d^{-n}$ [23]

Subject to:

$X_n - d^{+n} = M_n$ [24]

$X_n + d^{-n} = M_n$ [25]

$X_n, d^{+n}, d^{-n} \geq 0$ Non-negative restriction

where

d^{+n}	=	positive deviation associated with goal n (i.e. overachievement)
d^{-n}	=	negative deviation associated with goal n (i.e. underachievement)
X_n	=	decision variable associated with goal n
M_n	=	value of goal n
d^{+n}, d^{-n}	=	0 for all goals (in this case goal n) Also known as non-linear restriction.

2. Formulation with goal preferences

$$\text{Minimize } Z = \Sigma\ (W_1.d^+ + W_2.d^-) \qquad [2.6]$$

Subject to:

$$A.X + Id^- + Id^+ = G \qquad [2.7]$$

$$B.X \leq C \qquad [2.8]$$

$$B.X \geq C$$

$$X_j \geq 0;\ j = 1,\dots m$$

$$d^+, d^-, \geq 0;\ i = 1,\dots n, \text{viz.}$$

where

d^+, d^-	=	the vectors (n x 1) of the negative and positive deviational variables. They represent the solution's deviation from the goal vector G (n x 1).
W_1, W_2	=	the weights and/or priorities for the deviation variables.
A	=	the matrix (n x m) representing the relation between the decision variables vector X(m x 1).
I	=	the identity matrix.
B	=	the matrix (c x m) of coefficients which relate the decision variables to constraint vector, C(c x 1).
n	=	the number of goals.
m	=	the number of decision variables.
c	=	the number of constraints.

The conceptualization of goal programming find roots in the "conflicts between wood yield (timber), erosion control, water yield, wildlife habitat, conservation and recreation in many parts of the world" (Allen 1986). The major aim being to assure the simultaneous attainment of the conflicting goals.

4.0 MAIN FEATURES IN THE TANZANIA'S ECONOMY

4.1 Overview of the Economy

4.1.1 Linkage between the economy and natural resources

Tanzania's economy can be conceptualized using a simple model depicting the interaction between the economic system and an ecological system. Constantly these two systems interact to produce goods and services for the welfare of society. The ecological system is a source of environmental goods and the economic system produces private and public goods other than environmental goods.

Public goods have two essential features as outlined by Stiglitz (1988). That is it is neither feasible nor desirable to ration their use. An example where rationing is not feasible is the case of catchment forests which are managed by the government. It is not feasible to ration the use of water as result of protecting water streams. The fact that such goods cannot be rationed by the price system implies that the competitive market will not generate a Pareto-efficient amount of the public good (*ibid*). The second feature of a public good is that it is not desirable to ration its use. That is, one individual's consumption does not reduce the amount that is available for others to consume. In economic sense it implies that the marginal cost of supplying a public good to an additional individual is zero (*ibid*). Thus the marginal cost of public goods are inherently low to the extent that once produced they are available to all citizens.

Private goods on the other hand constitute of those goods where it is not only possible to ration their use but also exclude an individual from using them. Private goods are associated with relatively high marginal costs of producing them (*ibid*).

The social welfare of the country is a function of products from the economic system (i.e. human capital) and products from the ecological system (i.e. natural capital) both interacting in the socio-cultural and socio-political environment. In an attempt to maximize social welfare of society production efforts in the economy have always aimed at maximizing total economic value of resources comprising of use value and non-use value (Munasinghe 1992).

Use value is composed of direct use value, indirect use value and option value (also referred to as potential use value) (Munasinghe 1992). Direct value comprises those goods which are directly consumed by the society. Thus an individual is willing to pay in order to obtain a good for immediate consumption. Option value is based on how much an individual is willing to pay today for the option of preserving the asset for future direct or indirect use. Conversely, non-use value is made up of existence value and bequest value (*ibid*). Existence value is the perceived value of the environmental asset unrelated either to current or optional use, i.e. simply because it exits. Bequest value is the value that people derive from knowing that others (perhaps their own offsprings) will be able to benefit from the resource in future (*ibid*).

Figure 4.1 shows, in a simplified schematic form, the disaggregation of the total economic value which is expected from an economy such as Tanzania's. Each of the categories of economic value shown are attributed to the environmental assets upon which economic activity emanates. A variety of valuation techniques are available in the economy to quantify

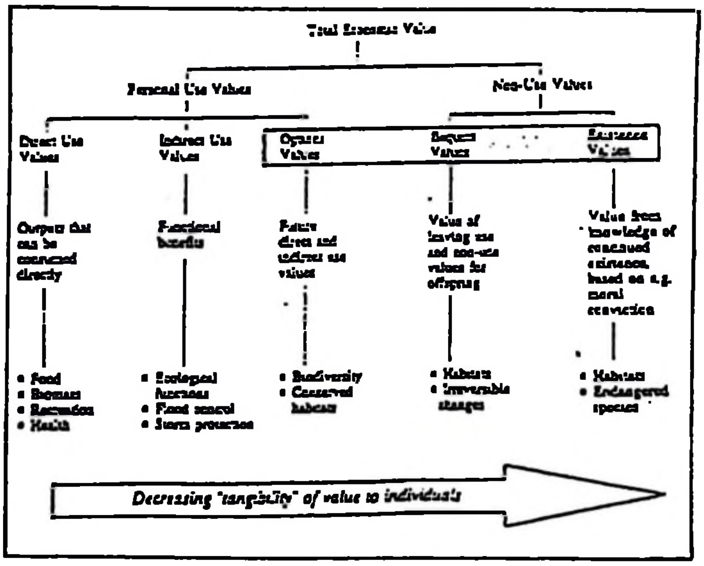


Figure 4.1 Categories of economic values attributed to enviromental assets (adopted from Munasinghe 1992)

each of the shown concepts of value. In case of non-market goods, the willingness to pay (WTP) technique of individuals is used (Munasinghe 1992). The technique involves asking individuals of how much they are willing to pay for a particular good. This is used as a proxy of the individual's preference frontier. The taxonomy of relevant valuation techniques is shown in Table 4.1. Some apply to a purely competitive market (i.e. market valuation) and some are more useful when the market is not fully competitive (i.e. shadow pricing).

Table 4.1 Taxonomy of valuation techniques

	Conventional market	Implicit market	Constructed market
Based on actual behaviour	*Change of productivity *Loss of Earni-ngs *Defensive expenditure	*Travel cost *Wage diffe-rences *Property values	*Artificial market
Based on pote-ntial Behaviour	*Replacement cost *Shadow project	*Contingent valuation	

Source: Munasinghe (1992).

4.1.2 The economy and role of agriculture

In the Tanzanian context, the contribution of the agricultural sector to the total economic value and hence to welfare of society is the greatest of all sectors in the economy. Consequently, Tanzania's economy is agro-based and thus agricultural activities such as crop farming and livestock keeping occupy the prominent role (Economic Survey 1991).

The agricultural sector accounts for about 62% to the gross domestic product (GDP) and generates about 90% of the foreign exchange earnings (EIU 1992). Over 80% of the economically active population is employed in agriculture (URT 1991). Traditional agricultural exports such as coffee, cotton, tea, tobacco, cashewnuts, sisal and pyrethrum remain the main foreign exchange earners of the economy (Bureau of Statistics 1991). Agriculture is also the main source for the bulk of the industrial raw materials hence makes a major contribution to the government revenue.

Despite this significant contribution of the agricultural sector in Tanzania's economy, the agricultural potential of the country is not yet fully utilized. The country still has a high potential for agricultural growth because at present only a mere quarter of the country's estimated 39.5 million hectares of arable land are under cultivation (Prazmowiski 1987; TFAP 1989). Agriculture will therefore continue to be the dominant sector in the country's economy for several years to come.

4.1.3 Some economic trends

The economic growth of Tanzania has not dispayed a smooth trend. It is more or less charaterized by fluctuating pattern. Tanzania achieved and average annual real GDP growth rate of 5.2% between 1973 and 1978. After the second oil price shock real GDP stagnated over four years between 1980 and 1983 when the economy contracted by 2.4% (EIU 1992). There were some output recovery in 1984 after good rains and the implementation of adjustment measures, but economic setbacks in 1985 forced the government to turn to the International Monetary Fund (IMF). Since 1986 recorded GDP has grown steadily, and ahead of population growth rate (*ibid*). Real expansion was 3.8% in 1991 implying an annual average growth rate of 3.9% over six years 1986-1991 (EIU 1992).

The positive GDP growth between 1985-1991 years due to the implementation of the Economic Recovery Program (ERP) and structural adjustment program (SAP) is a positive sign towards self-sustenance of the economy. However, caution is needed when using GDP as a measure of economic growth. According to Munasinghe (1992), among others, the use of GDP in assessing the economy performance is based on the premise that it is the most commonly used measure among the standard income accounting techniques. Performance of the economy is currently measured by the growth in GDP and policy reforms are justified routinely on the basis of their contributions to such growth.

Nevertheless, GDP embodies a number of shortcomings: First, while GDP measures market activity reasonably well, it neglects the non-market value added. This is caused by inefficiency related to the organization of the economy and to weaknesses of the official statistics (Solberg 1988). In connection to this, GDP does not account for personal or household consumption.

Second, GDP does not consider depreciation of man-made capital and also leaves out the degradation of natural capital such as stock of water, soil, air, forests, non-renewable resources and wilderness areas which are essential for human existence, hence is an inaccurate measure of true sustainable income (Munasinghe 1992). Third, GDP does not include environmental damages. The tendency in balance sheets is to include only clean-up costs such as expenditures incurred to restore environmental assets. This implies that undesirable outputs such as pollution are overlooked while beneficial environmental related inputs related to environmental needs are often implicitly valued at zero (Dasgupta and Maler 1990)

Fourth, the yearly fluctuation in GDP, valued at current prices, can be misleading compared with GDP at constant prices. For instance in year 1986 the GDP valued at current prices declined whereas the GDP valued at constant prices showed an increase over the GDP in 1985 (Table 4.2(a) and 4.2(b)). This view is shared by Solberg (1988), who noted that "the year to year fluctuation of the GDP estimates are so sharp that any grouping of years can give a misleading picture". Despite the signs of the economy picking up as shown by the rather promising growth in the GDP, for quite sometime Tanzania's economy has experienced an increasing deficit in the balance of payment (Solberg 1988; Somogyi 1989).

Table 4.2(a). Tanzania's GDP trends: growth rates at 1976 factor costs (% p.a.)

	Agriculture[1]	Manufacturing	Public Administration	Total
1977	1.2	-6.1	6.6	0.4
1978	-1.7	3.4	20.0	2.1
1979	-0.8	3.3	8.6	2.9
1980	3.9	-4.9	-2.1	2.5
1981	1.0	-11.2	11.4	-0.5
1982	1.4	-3.3	-0.1	0.6
1983	2.9	-8.7	-0.4	2.4
1984	4.0	2.7	0.2	3.4
1985	6.0	-3.9	1.9	2.6
1986	5.7	-4.1	-10.8	3.3
1987	4.4	4.5	0.6	5.1
1988	4.5	7.1	3.1	4.2
1989	4.6	3.0	4.0	3.3
1990	2.9	7.8	2.2	3.6

Source: Bureau of statistics (1991).
Note: [1] Agriculture includes also forestry, livestock, fisheries and wildlife
p.a. = per annum

Often the deficit has been covered by foreign borrowing, foreign grants and by depleting reserves of foreign currency (Solberg 1988). Most of the foreign borrowing was in form of long-term debts. However from 1977 the government began to borrow on the short term markets as well. This shift was detrimental because short term loans tended to be very expensive (Somogyi 1989). On the other hand increasing long term debts was not a cure to an ailing economy especially because Tanzania's capacity to export was limited. The inability of Tanzania to increase exports caused an acute shortage of foreign exchange which is needed in the various sectors of the economy (Mbelle 1988).

Table 4.2(b). Tanzania's GDP trends: Growth rates at current factor costs (% p.a.).

Year	Agriculture[1]	Manufacturing	Public Administration	Total
1976	-	-	-	-
1977	23.1	16.9	10.9	18.7
1978	12.4	17.4	10.7	11.2
1979	17.8	-4.9	16.3	13.1
1980	13.0	11.7	18.5	15.9
1981	22.3	9.9	19.5	17.2
1982	30.1	-3.1	15.1	19.7
1983	23.8	11.7	35.4	19.1
1984	26.1	21.8	16.8	24.8
1985	48.3	12.4	24.6	38.3
1986	37.4	28.3	-4.9	30.3
1987	40.2	73.0	30.1	42.3
1988	51.5	2.7	27.6	42.3
1989	15.8	0.0	30.8	17.7
1990	12.9	34.5	44.2	19.4

Source: Bureau of Statistics (1991).
Note: [1] Agriculture includes Livestock, Forestry, Fisheries and Wildlife.
p.a. = per annum

4.1.4 The emergence of economic crisis

During the period 1976 through 1981 there were some external factors which caused some macroeconomic disequilibrium. These were: the 1978-1979 war against Uganda which caused an estimated cost of U.S.$ 500 million, the collapse of East African Community in 1977, the drought of 1980-1981 and the end of boom in coffee prices which caused the terms of trade index to drop from 140.3 in 1977 to 115.1 in 1978 and later this continued to decline to 85.2 in 1982 the lowest since the late 1960's (Somogyi 1989). All these external shocks affected the national income as well as foreign trade. Other factors attributed to this situation include escalation of world oil prices in the early 1970's; collapse of the export commodity prices in the world market; high interest rates on external loans; a series of droughts; the country's dependence on few export crops; inappropriate domestic government policies; the "ujamaa" villagization policy; poor infrastructure and limited implementation capacity among others (Economic Survey 1991). Some of these economic shocks are not unique to Tanzania. However, in my opinion, Tanzania was worst affected by them because the internal economic structure was not made robust enough to absorb these shocks. For example in case of a fall in price the only way to keep constant trade flows is to increase production a challenge Tanzania could not meet albeit in the short run.

An overview of Tanzania's foreign trade is shown in Table 3.3. Government statistics show that by the end of year 1989 gross external liabilities stood at U.S.$ 3.23 billion of which U.S.$ 2.65 billion was long-term debt (*ibid*). It can be observed from Table 4.3 that Tanzania's deficit in the balance of payment is considerable and symbolizes an ailing and unbalanced economy. The trade deficit reached a level of U.S.$ 1 bn in 1991 (EIU 1992).

Table 4.3. Tanzania's foreign trade (mill. TAS, current prices)

Year	Domestic exports	Reexports	Total exports (1)	Direct imports (2)	Volume of trade	Balance of trade (1)-(2)
1976	4055	54	4109	5421	9530	-1312
1977	4448	70	4518	6160	10678	-1642
1978	3632	39	3671	8798	12469	-5127
1979	4343	91	4434	8941	13375	-4507
1980	4700	76	4776	10210	14986	-5434
1981	4706	82	4788	9740	14528	-4952
1982	4119	112	4231	10520	14751	-6289
1983	4187	135	4232	8997	13319	-4675
1984	6028	107	6135	13373	19508	-7238
1985	6048	125	6173	16966	23139	-10793
1986	1090	162	11067	29880	40947	-18813
1987	19091	610	19701	62130	81831	-42429
1988	32758	147	34236	152108	186344	-117872
1989	50758	1772	52530	146709	199239	-94179

Source: Bureau of Statistics (1991).

Somogyi (1989) sums up the mulfunctioning of the Tanzania's economy as follows "in the production sectors we find the decline of the real GDP per capita, falling volumes of export crop production, falling efficiency in the manufacturing sector, falling incomes and insufficient food production. In the monetary sector we identify open inflation, growing budget deficit, a widening gap between the official and real exchange rates: all these accentuated by shortage of basic commodities and under-utilized capacities in most industries".

4.1.5 Some changes in the economic policy

Over time, however, the government has been taking some measures aimed at reversing the dismal economic trends. The turning point in the economy came in 1984 when the government decided to partially liberalize the external trade. This was followed by the adoption of a new investment code in 1990 (National Investment, Promotion and Protection Act, published in Business times 1990) which provides the legal framework for a greatly improved investment climate (EIU 1992). The new code seeks to promote and protect private investment, attract foreign investment and stimulate the economy to follow market principles. For instance the new investment policy offers new investors a five year tax holiday and allows up to 50% of retained foreign exchange to be used to pay overseas obligations (EIU 1992).

Also in 1992 the government decided to free monetary institutions. As a starting point the government opened money shops (*Bureaux de Change*) (EIU 1992). Both public and private bureaux de change were opened. Furthermore the government has reduced subsidy to parastatal enterprises and urged them to have self-financing system by opening up revolving-fund accounts. In fact in the beginning of 1993 the government put some parastatal organizations on sale to private investors. The government has also decentralized some, hitherto, centrally planning functions. All these measures are taken in a bid to revamp the otherwise erratically growing economy. Obviously, it will take a while for tangible effects to be noticed, but the measures themselves may be considered to be positive.

Although the economy has depended mostly on agricultural production, it is envisaged that with proper management the contribution of other sectors such as, forestry, wildlife, fisheries and mining may be increased. In fact, in the absence of strong economic base for industrialization, Tanzania can boost her economy by efficient utilization of natural resources.

4.2 Main sectors of the economy

The economy of Tanzania is made up of several sectors which consists of agriculture and livestock, forestry and fisheries, wildlife, mining and manufacturing industry. These sectors are briefly reviewed in Section 4.2.1 through 4.2.5.

4.2.1 Agriculture and livestock

Agriculture, in the Tanzanian context often implies crop and livestock farming. However in this paper the two are discussed under different sub-headings for the sake of convenience. Even in the present organization structure of the government, agriculture embraces livestock development. In practise however, these two land use systems tend to conflict in interests under certain situations. Hence enhancing the need for land use planning in dealing with such land use concerns.

4.2.1.1 Agriculture

Agriculture is the mainstay of Tanzania's economy. It contributes about 62% of the GDP (EIU 1992) and accounts for about 90% of the total exports (URT 1991). National accounts statistics show that about 90% of the population in Tanzania is directly engaged in agriculture (Bureau of Statistics 1991). Practically, it is dominated by small holders or characteristically peasant farming. There is however, large scale farming in state owned estates. The agricultural potential is enhanced by the relatively favourable man/arable land ratio and diverse agro-climates which permit the production of a wide range of food and cash crops (O'kting'ati 1984; Minde and Mlay 1989). The growth trends in agriculture are shown in Table 4.4

The major food crops produced in Tanzania are maize, paddy, wheat, cassava, sorghum, millet, beans, banana, potatoes, tropical fruits and wide range of vegetables. Cash crops consist of coffee, cotton, sisal, tobacco, tea, cardamon, cashewnut, pyrethrum and variety of oil seeds such as groundnut, simsim, sunflower, castor seeds and soya bean (MDB 1989).

Table 4.4. Growth trends in agriculture for the period 1986/91 (in real terms)

Year	Growth rate (%)
1986	5.7
1987	4.4
1988	4.5
1989	4.6
1990	6.6
1991	4.6

Source: EIU (1992)

Tanzania has arable land estimated at 39.5 million hectares which can be cultivated under rain-fed agricultural system. Nevertheless, the area presently utilized is about 6 million hectares only representing a proportion of 6% of the total land area (Minde and Mlay 1989). Most of the agriculture production is from the small holder farmers who live in about 8,000 registered villages (Mgeni 1992). The size of the small holder farms average 2.5 ha. The means of production are largely manual labour and hand implements (*ibid*).

The development of agriculture has been rather slow and it has been largely through the expansion of farm land rather than increase of productivity per unit area (Minde and Mlay 1989). For instance, between 1972 and 1980 there has been an expansion in farm area of about 6% per annum while productivity declined by 1% per annum during the same period. Perhaps the major reason to account for the slow expansion is the poor extension services and inadequate financial support from the central government. There is, also, a disparity in fund allocation from year to year. In 1983, for example, the agricultural sector received only 12.5% of Tanzania's total development investment compared to 15% in the previous years, of which 80% of the total funds were given to large scale farming projects which are state-owned and only 20% was allocated to small holder farmers (TFAP 1989). The implication of the disparity of fund allocation is that the small holder farmers who account for about 90% of the total area farmed or cultivated receive only a marginal funding assistance from the central government (*ibid*). From economic point of view, one may argue that large-scale farming has high economies of scale although this may not reflect the general objective of the government agriculture policy. However it is desirable that, there is an equitable allocation of funds to agriculture in order to increase the contribution of agriculture towards national socio-economic development.

The perfomance of state-owned farms has been very poor. Therefore, it may be pointed out that the government can be held responsible for the poor agriculture performance (TFAP 1989). These observations point to the need for the transformation of the agricultural sector in order to create conducive environment or conditions for the adoption of improved farming technology.

4.2.1.2 Livestock

Livestock is another form of agricultural related land use that has significant socio-economic contribution in Tanzania. In 1988, the country had an estimated livestock population of 22.6

million animals comprising of 12.8 million cattle and 9.8 million sheep and goats (TFAP 1989) with an offtake of locally consumed and marketed stock in the margin of 10.7% (EIU 1992). The average annual growth rates in the number of cattle and goats plus sheep are 0.7% and 1.0% respectively (TFAP 1989).

Although the carrying capacity of potential grazing land is conservatively estimated to be 20 million stock units, the animals are concentrated in areas that are free from tse-tse flies thereby causing considerable overstocking i.e. the carrying capacity in those areas is exceeded (Mwalyosi 1990). Numerically, 60% of the livestock is concentrated in only 10% of the grazeable land area (LRDC 1987). The consequence has been severe land degradation due to trampling and overgrazing. Most herders have a nomadic form of living habits espeacially the Maasai tribe. The adverse effect of this form of life is considerable. Typical examples of serious land degradation and declining productivity due to overstocking can be seen in the Sukumaland and the Masai steppe where the problem is aggravated further by traditional values (TFAP 1989; Mascarehnas 1991; Mgeni 1992). Among the pastoralist societies which inhabit these areas large livestock herds are considered to be a symbol of wealth and status (LRDC 1987).

It is important to note here that the concern of peasants is the quantity of animals one owns and not their quality. Therefore the drive by the government to reduce the size of herds has been met with some resentment and there are little signs of success (Mwalyosi 1990). Furthermore herders do not take a concerted effort toward the improvement of the grazing lands or pastures (*ibid*). The quest for a high tribal esteem based on large livestock size is so deep-seated that the pressure on common grazing land has had no significant impact on the behaviour of individuals (Mascarehnas 1991).

4.2.2. Forestry and fisheries

In this context, forestry resources are discussed together with fisheries resources basically because there is a direct relationship between forestry and water resources. The Indian ocean and fresh water lakes from which fish are obtained all derive their water from rivers that originate in catchment forests situated on mountain ranges. Furthermore, the fish smoking industry in Tanzania is heavily dependent on fuelwood. Consequently, forests and fish resources are closely linked.

4.2.2.1 Forestry

Forests and woodlands are estimated to cover about 42 million hectares or 68% of Tanzania's land area (Sharma 1992). However, these figures should be taken with caution, basically because they are not based on a countrywide survey in the recent past and there has been very little, if any, monitoring. In fact the figure may be an overestimation since there is unrecorded loss due to deforestation (Kaoneka 1990; Kowero 1990; Mgeni and Malimbwi 1990; Mascarehnas 1991). The distribution of the forests by type and legal status is shown in Table 4.5.

Forests and woodlands include some 98,000 ha of plantation mainly softwood tree species (Sharma 1992). Most forest reserves have been gazetted for production purposes and the rest are for protection, including catchment functions. The true moist tropical forests are generally found on the tops of the old mountains and hills. The miombo woodlands cover the largest section of the country (TFAP 1989) whereas mangroves are site specific and distinct for the coastal areas (Semesi 1991).

Table 4.5. Distribution of Tanzania's forests by types and legal status

Type of Forest	Area covered ('000 ha)
Forests (other than mangrove)	1,400
Mangrove forests	80
Woodlands	42,891
Legal Status	
Forest reserves	13,029
Forest-Woodlands within National parks etc.	2,000
Public forest lands	29,347

Source: TFAP (1989)

The average growing stock is estimated at 41 m^3 per hectare, representing a total wood volume of about 1.8 billion m^3 (TFAP 1989). The potential sustained yield is estimated at 24.3 million m^3yr^{-1} or 0.7 m^3/ha-yr (TFAP 1989). The rate of deforestation is estimated at 130,000 ha per annum representing 0.3% of the total forested area (Sharma 1992). Some of the causes of deforestation are clearing for agriculture, overgrazing, charcoal production, firewood harvesting, bush fires, illegal pitsawing and settlement expansion (Pocs 1988; Kaoneka 1990). Deforestation causes changes in vegetation types and species composition. Forests change to bushland (Figure 4.2) then grassland (Figure 4.3). At the same time the afforestation effort is estimated at 9,000 ha per annum in the 1980s (Sharma 1992). These figures portray a remarkable gap between the rate of tree planting and the rate at which forests are being depleted.

The contribution of forests towards socio-economic development is modest compared to the size they cover. Some studies showed that forestry contributes about 13.9% (Sharma 1992) of the total GDP and employs a little over 2% of the total paid labour force (Ole-Meiludie 1986). Large portion of the forest resource ends up in being used for domestic energy needs which is not valued at neither market nor social prices. Over 80% of the total population in Tanzania live in rural areas and depends largely on fuelwood and charcoal as source of energy for cooking, heating and even lighting. The wood contributes about 60% of the total energy consumption and over 95% of the domestic energy used in Tanzania. Hydroelectricity is a viable option but the initial cost of electrical cookers is prohibitively expensive to the poor rural majority. Therefore, for the foreseeable future wood will continue to serve as the main source of energy to rural people and suburban dwellers.

The forest sector also produces a variety of products with high economic value and export potential (see Table 4.6). For example, in 1987 the export of primary forest products earned Tanzania a total of U.S.$ 11.7 million (Kowero and O'kting'ati 1990). Furthermore, the natural forests are estimated to have nectar yielding plants with a capacity of five million bee colonies that are capable of producing over 50,000 t yr^{-1} of honey and over 5,000 tyr^{-1} of beeswax representing an amount of TAS 1.5 billion and TAS 250 million (valued at the 1986 price) respectively (*ibid*).

Table 4.6. Amount of forest wood and other forest-related products

Type of product	Unit	Amount by year							
		1980	1981	1982	1983	1984	1985	1986	1987
Wood products:									
Plywood	'000m^3	985	722	763	280	345	397	499	393
Hardwood sawn timber	'000m^3	11.7	8.5	7.2	9.0	8.3	9.6	13.3	12.1
Forest related products:									
Hunting Licenses	#	2105	2267	2500	1818	1680	1485	3160	-
Mammals	#	4412	5530	6844	459	3860	3053	15718	17244
Birds	#	-	-	2440	5425	4500	8337	6673	-

Source: Kowero and O'kting'ati (1990)

The benefits of forests are not, however, limited to wood-based products only. Forests are also important in soil and ecological conservation such as gene pool conservation (Pocs 1988). In fact the current drive in most developing countries, Tanzania included, is to integrate tree planting with crop farming under agroforestry systems (O'kting'ati 1984; Kaoneka 1990). Under agroforestry, trees provide a host of functions/benefits such as provision of fuelwood and building materials, soil binding by tree roots, soil moisture conservation, minimization of soil erosion, prevention of environmental degradation and amelioration of climatic conditions (Young 1989).

4.2.2.2 Fisheries

Fisheries resources in Tanzania constitute a considerable proportion of a natural resource base (Bureau of statistics 1991). They include marine products as well as products from lakes and rivers. Tanzania has a long coastline on the Indian Ocean. It also controls a big area of inland waters comprising of big lakes and rivers. Lakes Victoria, Tanganyika, Nyasa, Rukwa, Eyasi and Natron are large lakes whereas the rivers such as the Rufiji, Pangani, Ruaha, Ruvu and Malagarasi are long rivers in Tanzania. The lakes and rivers are a source of fresh-water fish

Figure 4.2 Conversion of forest vegetation into bushland

Figure 4.3 Conversion of forest vegetation into grassland

such as tilapia, Nile perch and sardines whereas the Indian Ocean waters are a source of many marine products particularly prawns, sea-shells and a variety of marine fish.

Despite the presence of these resources, Tanzania is yet to fully utilize this potential (Prazmowiski 1987). The Board of external trade (1987) observes that, although Tanzania controls a long coastline, the export of marine products especially prawns which have a ready market abroad is about 150 tones per annum. The export of fish is low compared to the resource base in the country. A large proportion of fishing industry has been to satisfy the domestic market with very little exports.

Since the country's exports are largely agricultural which are often supplemented by natural resource products, there is need to invest more in the fisheries sector to raise the contribution of this sector in socio-economic development. This would be a positive step towards the country's programme to diversify exports by encouraging export of even non-traditional exports.

4.2.3 Wildlife

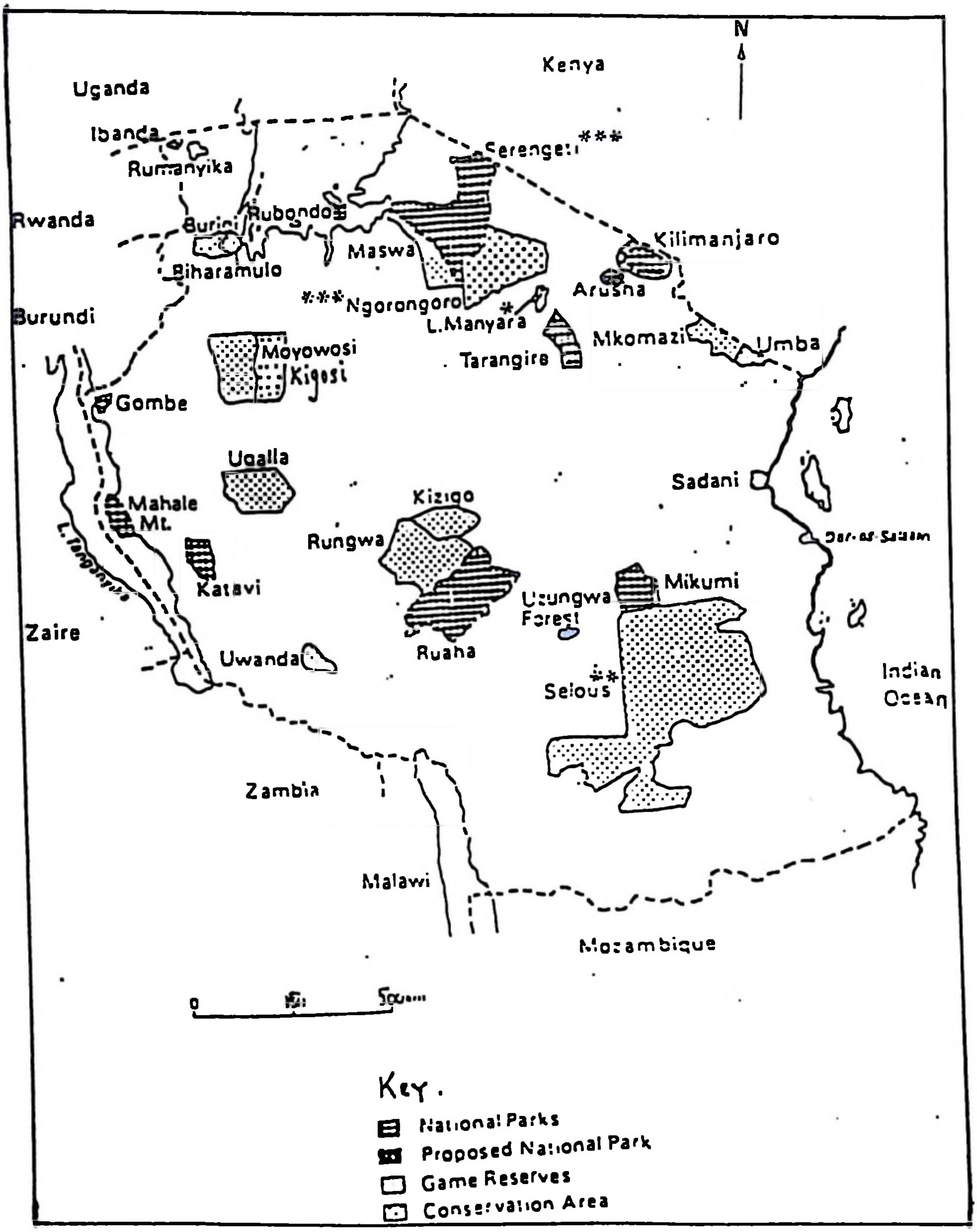
Tanzania is one of the few countries in the world endowed with large populations of wildlife composed of high density of animal species which is "probably unequalled anywhere in the world" (Dykstra 1983). Although wildlife conservation is one of the important forms of land use in the country its potential is yet to be fully tapped (TFAP 1989). Tanzania occupies only 3% of the total land area of Africa and yet it is the home for 24% of the remaining populations of African elephants (Douglas-Hamilton 1980) and supports some of the largest remaining populations of lion, leopard, rhinoceros, buffalo, hippopotamus and crocodile (Matthiessen 1981; Dykstra 1983; TFAP 1989).

There are, currently, 92 wildlife conservation areas which cover about 328,600 km^2 of the total land area (Table 4.7). The wildlife conservation areas are widely distributed over the country (Map 2). The majority of National Parks and Game reserves are situated in tse-tse fly infested areas to the southern and western regions, and dry lands to the northern regions of Tanzania (TFAP 1989).

Table 4.7 Wildlife conservation areas of Tanzania

Legal status	Number	Total area, km^2	Proportion,%
National Parks	11	38,131	16.4
Ngorongoro Conserv. Area	1	8,288	3.6
Game Reserves	18	95,750	41.2
Game Controlled areas	56	90,000	38.8
Biosphere Reserves	3	23,376	10.2
World Heritage Site	3	73,051	31.5

Source: TFAP (1989)



Map 2 Distribution of National Parks and Game Reserves in Tanzania (adopted from TFAP-Technical annexes vol. II 1989)

The widely held view is that the contribution of wildlife industry to socio-economic development is significant (TFAP-Technical annexes vol II 1989). The major contribution to the national economy accrue from tourism and hunting. The gross value of wildlife in 1988 was estimated to be about U.S.$ 108 million, of which U.S.$ 48 million accrue from legal activities and U.S.$ 60 million from ivory and meat poaching (TFAP 1989). Certainly poaching is an illegal activity which the government strives to eradicate.

However, lack of adequate funds and the possession of automatic fire arms by the poachers has made this task especially difficult. In the wake of increased poaching the government clamped a ban on all types of hunting for the 1989/90 season, when members of the armed forces were deployed in various areas on a national wide campaign to crackdown poachers.

Hunting is carried out in two forms, the safari hunting and resident hunting. The overall animal population killed through hunting is 45,000 animals per year (TFAP 1989). Safari hunting fetches about $ 3.3 million which accounts for 50% of the wildlife reserve which enters the government treasury, whereas resident hunting which accounts for about 82% of the total animal kill contributes only U.S.$ 0.7 million which is 11% of the total hunting income (TFAP 1989).

Tourism is another wildlife activity of significant economic contribution. In 1987 a total of 94,000 tourists visited Tanzania. In the same year tourism generated about U.S.$ 33 million of which U.S.$ 2 million entered the government treasury (TFAP, 1989). The revenues generated from tourism in 1990 was U.S.$ 65 million and it is projected that by 1995 the earnings will increase to an estimated amount of U.S.$ 500 million (MTN E 1991). The tourism industry is affected by poor infrastructure and accommodation in National Parks, absence of competitive prices, poor services, inadequate tourist market promotion abroad, and lack of tourism priority in national development prog·ams (EIU 1992). These problems have to be tackled by the government and its agencies if the projected targets are to be realized.

4.2.4. Mining

Tanzania is fairly rich in a variety of minerals which are yet to be fully exploited contributing just 1.2% of GDP (EIU 1992). The mining sector has, nevertheless, shown significant recovery and attracted new foreign interest as a result of the improved investment climate of recent years (*ibid*). Considerable achievement in the short run has been attributed to "simply by the redirection of existing exploitation of the country's mineral resources through official, and hence regulated, recorded and taxed, channels" (*ibid*). Mineral earnings as of 1991 amounted to U.S.$ 35 million representing 11% of total exports (*ibid*). Examples of exploited minerals are diamonds, gold and coloured gemstones, the popular one being tanzanite.

There has been, for quite sometime, oil exploration efforts in the Southern Indian Ocean Coast of Tanzania since 1986. Preliminary reports indicated the presence of some deposits of gas in the Songo Songo field off the coast of Lindi Region, with 32.77 bn m^3 of proven methane gas reserves and 130 bn m^3 have been found onshore at Kimbiji, 40 km south of Dar es Salaam (EIU 1992). The exploitation of the gas is still minimal due to inadequate capital supply required to install the exploitation capacity.

Diamond mining has been a leading mining industry for several decades. Exports of diamonds have earned the country substantial amounts of badly needed foreign exchange for several decades since the opening of the Mwadui Diamond Mines in the 1940's (MEM 1991). However, in recent years production has progressively declined (see Table 4.8) due to exhaustion of the deposits and reached a low figure of just 11,577 ct in 1990 (EIU 1992).

Most gold mines in Tanzania were closed for large scale mining several decades ago. The reason for closure was that most of the gold deposits were only present in small quantities not economical for large scale mining. However, small scale exploitation by private miners continued at Mpanda, Geita, Nyarugusu and Chunya deposits. Most of the gold obtained in these areas was smuggled out to neighbouring countries where more lucrative terms of trade could be obtained (Board of External Trade 1991).

Following the inception of trade liberalization, the government has taken some steps to protect and motivate prospective private small scale gold miners. These steps include offering official gold prices equal to prices in the parallel market and permitting individuals to directly sell gold to state-owned banks without the need to explain how the gold was obtained. Also licensing procedures for small-scale, private gold miners have been easened. In response to these policy changes the volume of gold passing through official channels rose by a factor of 58 to 1,631 kg in 1990 from just 28 kg in 1989 (EIU 1992). Production of coloured gemstones reached a level of 144 tons in 1990 and public auction sales system was introduced in 1992 (*ibid*). A summary of the recovery of mineral as a result of policy changes is presented in Table 4.8

Table 4.8 Some recovery trends as a result of policy changes for the period 1986/90

Mineral	Year				
	1986	1987	1988	1989	1990
Gold (kg)	45	48	55	28	1,631
Diamond (ct)[(1)]	120	120	44	34	12
Colured gemstones (kg)	13	702	514	85369	144094

Note: [(1)]The figures were truncated to the nearest tenth number
Source: EIU (1992)

Substantial coal deposits have also been discovered in the South-western part of Tanzania particularly in Mbeya region. Exploitation started at Songwe-Kiwira in 1988 with the help of the Chinese experts. The mine has a production capacity of 100,000 t yr^{-1} and in 1989 it was producing at a rate of 40,000 t yr^{-1} (EIU 1992). Unfortunately the industrial and domestic consumption as well as export potential for coal is very low due to its high ash content (MEM 1988; EIU 1992). At the end of 1990 about 20,000 t of coal was stockpiled at the mine awaiting buyers (EIU 1992).

Prospecting is still continuing for other valuable minerals such as iron ore, phosphate, salt, tanzanite, ruby, and green tourmaline. Iron ore is mined at Chunya where the deposits can produce 250,000 t yr^{-1} and Liganga in Njombe district with a production potential of 500,000 t yr^{-1} (EIU 1992). Iron ore deposits are often associated with titanium and vanadium.

Phosphate deposits at Minjingu in the Arusha Region whose exploitation begun in 1983 have a production capacity of 100,000 t yr^{-1} mainly used in the production of mineral fertilizers (*ibid*). Deposits of uranium, niobium, copper and nickel have been confirmed but nickel is most likely "to attract one of the largest new investments in the sector" (*ibid*).

3.2.5 Manufacturing industry

Tanzania is a developing country and her economy is characterized by low industrialization and high degree of external dependency on developed countries for capital, entrepreneurship, technology, market for exports and imported goods. The manufacturing industry was initially concentrated more on primary production especially processing agricultural products, cigarette manufacture, meat canning, brewing, pyrethrum processing and cashewnut shelling and provided agricultural inputs such as fertlizer, improved seeds and implements. Later on import substitution industries were established. These included textile mills mainly under the National Textiles Corporation (TEXCO), steel mill in Tanga region and Aluminium Africa with the National Development Corporation (NDC) owning 61% and 28% shares respectively and the Sao Hill Pulp and Paper Mills Ltd. (EIU 1992).

Consequently, the contribution of manufacturing industry to the GDP has been very low and fluctuating from time to time. At independence in 1961, the contribution of the manufacturing industry to the GDP was 2.8%. This rose to 12.2% in 1978, dropped to 11.0% in 1982 and to 5.2% in 1983 (Bureau of Statistics 1991). The growth rate of this sector has also been very low. During the period 1970 through 1981 it averaged 2.2% and the target for 1981/82 to 1985/86 was 8.8% (*ibid*). After the inception of the Economic Recovery Program in 1986, the aim was to increase industrial production capacity from 20-30% to 60-70% by the end of the program in 1991 (Ministry of Finance 1984; Prazmowiski 1987).

According to Somogyi (1989), production efficiency in the manufacturing sector particularly in the parastatal sector began to fall after 1967. For example, between 1967 and 1968 value added per employee fell by 21% and in 1981 it was slightly more than a third of its peak value in 1967 (*ibid*). In recent times between 1986 and 1991 the manufacuring industry has shown signs of recovery in which the value added grew in real terms by an average of 4.1% annually (EIU 1992).

In this sector, over the entire period, real value added per employee deviated from the average by 25% (*ibid*). Incremental Capital-Output ratio (ICOR) for the entire sector also consistently rose beyond 4.0 which is the highest limit for developing countries (Mbelle 1988; Somogyi 1989). Later these ratios became negative. Mbelle (1988) found also that many manufacturing firms in the country were underutilizing their capacity.

Many reasons have been advanced to describe this poor performance in the manufacturing industry. These include external shocks such as increased oil prices "combined with domestic mismanagement to create a vicious circle of chronic balance of payments deficit, capacity underutilization and production shortfalls" (EIU 1992). Some donors in this sector delayed disbursement of promised funds, loans were not forthcoming, some public corporations failed to raise enough local cash to buy the little foreign currency allocated to them by the government for importing raw materials, spares and experts. Also some local industries were affected by frequent water shortages, power cuts and high operational costs. In some extreme cases production has to be suspended while salaries still had to be paid. Furthermore, losses and overdrafts is a common practise (Ministry of Finance 1987).

However, Mbelle (1988) observed that the acute shortage of foreign exchange was the main cause of the excessively poor performance of the manufacturing sector. Under such a situation it was not possible for the firms to invest in the purchase of new capital equipment because with negative incremental-capital output ratios, total output would decline when new investments are made (Somogyi 1989).

Following the trade liberalization policy which came into effect in 1984, the Economic Recovery Program of 1986, the drive to privatize public enterprises and the removal of foreign exchange restrictions early 1992, the manufacturing industry is picking up (EIU 1992). Furthermore stiff competition from imported foreign products has been a catalyst to increase efficiency in the manufacturing sector (*ibid*).

5.0 REVIEW OF SOME POLICY ISSUES INFLUENCING LAND MANAGEMENT IN TANZANIA

5.1 General overview

Although there are many sectors in the economy which deal with issues related to land use and nature conservation, agriculture is still a leading sector in Tanzania, hence it is a major land use in the country. Any attempt to resolve environmentally related problems must in one way or another first address agricultural related issues. This reflects the need for a holistic approach in tackling nature conservation problems. Policy actions and enforcement of legislation which are some of the effective means used to address such problems must embrace this point of view.

Nevertheless, some policies and legislation have promoted extensive and inefficient use of land-based resources and consequently leading to environmental degradation (Mnzava and Riihinen 1989). Inconsistent and incomprehensive policies and legislation are a typical case in point. In addition failure of some policies to accommodate local specificities such as physical environment and land use in different agro-ecological zones and hence resulting in implementation failures.

Also some policies inculcate lack of responsibility due to absence of property rights over some land based resources. Another critical aspect has been the tendency of many sectors and organizations to try to act alone in resolving environmental degradation problems. Many policies formulated are sectoral oriented in contradiction with the current drive to promote multi-sectoral cooperation. The resolve of many sectors has been to boost their own role in the government structural setup on the belief that this would enhance their pursuit on handling environmental problems more effectively.

Unfortunately, none of the sectoral policies can be successfully implemented on its own. Neither can any legislation be enforced in isolation. Coordination and cooperation among sectors is inevitable to facilitate integrated management. Nevertheless, in the current setup, none of the sectors or organizations, even if it has the will to cooperate, has the legal mandate to facilitate integration, cooperation and coordination with other users of land-based resources. Only the government has this mandate through establishment of a multi-sectoral institution adopting an integrated approach. What has been accomplished to this effect is the subject of our discussion.

5.2 Political factors

The ultimate objective of political actions is to promote socio-economic development. One of the goals of the government of Tanzania as stipulated in the national policy on productivity, incomes and prices is to raise efficiency in the allocation and utilization of national resources among which land-based resources are extremely important (Mnzava and Riihinen 1989).

Thus in the pursuit for society interests, the government has from time to time taken some political actions many of which had some bearing on the use and management of land-based resources as well as nature conservation. The need for such political actions has often been enhanced by the view that resources are increasingly becoming scarce. Land itself for example is being increasingly claimed for agricultural crop production, pastures and infrastructural development due to population increase. In the absence of proper policies more problems can be expected in the future. Deforestation is not merely a forestry problem but is related to other sectors as well. Hence the measures to be taken to curb deforestation must be extended also to other sectors. This is the dimension political actions have been trying to address (LRDC 1987).

However, among the many political actions so far taken in Tanzania the widely recognized political bench-mark was the promulgation of the Arusha Declaration in 1967. This was a blueprint which spelled out Tanzania's political, social, cultural and economic aspirations. It critically shaped the path which Tanzania was to take to address her problems. This socio-economic and socio-political pronunciation spelled the new pattern of resource ownership and hence critically affected agriculture, livestock and other land uses and to a great extent influenced the future environmental degradation (LRDC 1987).

The main clauses in the Declaration emphasized work for every able person, public ownership of the major means of production which include the land, public participation and the ideology of socialism. The implications of each of these clauses can be interpreted in terms of the after-effects of the declaration.

Work for every able person and state ownership of the major means of production abolished capitalistic tendencies of land use and land ownership in the country and consequently some big portion of the land was left as public land or open access resource for which no one took direct responsibility. The land which was formerly protected was turned into an open-access resource for which there was no proper control structure for its management. Thus the tragedy of the commons for land degradation, deforestation and environmental degradation in general came into effect. According to Hardin (1968) common property resources such as public land are the ones that lead to the tragedy of the commons with the main contention that "freedom of the commons to pursue their own interests brings ruin to all". Coase (1960) also observed that clear definition of property rights enhances efficient utilization of resources.

The establishment of the state controlled financial institutions, cooperatives, crop authorities, rural credit facilities and new distribution methods for agricultural goods to foster public ownership of major means of production culminated into gross inefficiency and corruption. Both of which frustrated the peasants leading into misuse of resources and environmental degradation (Minde and Mlay 1989).

Finally the ideology of socialism in itself had shortcomings. For example, among what it spelled out as the major prerequisites for the country's socio-economic development, it ignored the role of some crucial aspects such as funds, infrastructure and vital resources such as water. The importance of such resources came to be realized later after the economy and the environment had already suffered. In most cases these vital resources influenced to a great extent human settlement patterns and consequently land use.

Following the Arusha Declaration a number of other pronouncements were made from time to time including, Socialism and Rural Development in 1967, Operation "Vijiji" in 1966 ("Vijiji" is a Swahili word for Villages), "Mwongozo wa TANU" (TANU Guidelines) in 1971, the Decentralization Policy in 1972, "Siasa ni Kilimo" (Politics is Agriculture) in 1972 (TANU 1972) and Operation Vijiji in 1976. Each of these pronouncements was designed to achieve specific political objectives ranging from introduction of new settlement patterns, rational use of land resources, modernization of agriculture, improvement in planning and promoting public participation in decision making. Unfortunately most of these political actions never succeeded as expected.

There is one more important political-cum-economic action which also affected land use programs in Tanzania before the Arusha Declaration. This was the decision to change the Tanzania currency 1966 which was hitherto pegged to the British Pound (£). This action prompted many donors to withhold aid and even loans promised to the country. Hence it had negative effects in terms of implementation of development programs many of which had direct impact on land use.

5.3 Villagization programme

Since independence in 1961, Tanzania's development effort focused on rural development. This is due to the fact that the majority of people are rural based peasants. Thus it looked rational for the government to aim its development strategy in areas where most people live. It was upon this background that way back in 1966 the government decided to establish village settlement schemes in the country (Agricultural policy report 1982). These to a great extent influenced natural resource use and nature conservation because they brought people together in one location hence subjecting resources to intense pressure. The idea was to use these settlement schemes as models of economic development to be imitated by other villages around.

After the establishment of only 22 settlements throughout the country the idea collapsed and hence was abolished. Many reasons engineered the collapse of these settlements: The settlements were capital intensive relative to their capacity to generate economic returns; they were viewed as government projects because of excessive dependency on government subsidy and they sharpened intra-rural income disparities (LRDC 1987).

Upon failure of settlement schemes, and on the basis of lessons learnt, a different villagization program was initiated in 1974-76 through the "Ujamaa" Villagization Act of 1975 which provided for establishment of Ujamaa villages throughout the country. The villages were granted legal recognition with all powers to democratically run their affairs while ownership of property was communal. However, this programme also faced some shortcomings. For instance, the settlement areas were not selected prior to resources assessment, boundary demarcation and land use planning. Hence some villages were established on marginal lands where they could not last. Thus to some extent lack of village land use plans curtailed the successful implementation of the villagization programme.

In some cases coercion rather than conviction means were applied in the villagization process. The consequences were environmental degradation due to overuse, conflict between sector interests or lack of control over the use of resources (Jerve 1990). An example of a case where coercion was used is in the dissection of the "mbuga" and closure of traditional herding routes as a result of villagization (*ibid*). The effect of such actions increased pressure on grazing land keeping herders in constant search for pasture and water (TFAP 1989). This made some pastoralists to migrate to distant regions in the country hence subjecting even wider areas to overgrazing impacts.

5.4 Land use planning policies

The main purpose of land use planning policies is to foster proper land use and to harmonize the conflicting interests of various sectors in the economy (Van Lier 1988). However, experience shows that most of these policies are pursued along sectoral lines than on multi-disciplinary basis hence promoting more conflicts than compatibility of various landuses (Riihinen and Mnzava 1989).

Ideas on land use planning policy can be traced back in 1952 when the then Agricultural Department established a Land-use and Soil Conservation Unit at Tengeru near Arusha (Agricultural Policy Report 1982). This was a capital intensive unit established especially to serve the white settler farms in constructing terraces for cash crops. The local people did not adopt the services of this unit because it alienated them. Thus the unit was closed. After independence the Ministry of Agriculture decided to continue with the idea by establishing a Land use Planning Unit. The same idea was cherished in the Arusha Declaration which emphasized the need for resettling people to coordinate land use activities.

Despite the establishment of a land use planning unit, todate there is no comprehensive land use planning policy save for the Land use planning commission (Riihinen and Mnzava 1989). However, on and off, various institutions have practised some form of land use planning. The plans formulated under such circumstances have been more sectoral thus failing to address the land use conflicts in society. Contemporary approaches to land use planning require that plans should be multi-sectoral and should include all factors which influence land use such as infrastructure, social and public amenities, employment opportunities , water, funds and so forth. Such factors cannot be handled under the full mandate of one sector. Cooperation and coordination among sectors is inevitable hence the birth of the National Land-use Planning commission by Act number 3 of 1984 to address land use planning issues more comprehensively. Todate the positive outcomes of this commission have never become a reality (*ibid*).

One of the main shortcomings that have constrained formulation and successful implementation of land use plans relates to some legal aspects of land use. Whereas the power to issue land title deeds are vested in one Ministry, the implementation of many land use policies is vested in other Ministries. This has been a source of conflicts. Thus major restructuring of government organization to address this situation is needed if land use planing is to be successfully done (LRDC 1987).

5.5 Agricultural development policy

An agricultural policy is the main guideline on all agricultural related issues in the country. Therefore it has direct impact on land use and nature conservation. However, despite formulation of the agricultural policy, agricultural practises in the country are still in many cases, not sound. In extreme cases the agricultural policy itself has encouraged some land use mal-practises. For example, it encourages peasant farmers to raise production by increasing the area under cultivation (TFAP-Technical annexes vol II 1989). This in itself promotes deforestation. Consequently, only in very few localized areas are intensive agricultural systems put into practise. Furthermore, the agricultural policy has not been able to raise agricultural production. At present less than 16% of arable land is cultivated (IFAD 1986; UNSO 1986; Prazmowiski 1987).

Consequently agricultural activities are concentrated in few areas which are in turn subjected to overuse due to population pressure. Population growth has made it necessary to cultivate even on marginal lands thus causing environmental degradation. For future agricultural expansion, nucleated settlement patterns have to be avoided if the incidence of land degradation due to human concentration in one area is to be mitigated. Unfortunately, the current agricultural policy does not address itself to this issue just like it does not address the use of natural resources on public lands.

There are other questions which need to be resolved to facilitate farming systems compatible with nature conservation. These relate to land tenure systems and government organization structure. The present land tenure system encourages small-holder pattern of land use. Ultimately this may prevent introduction of large scale farms such as block farms which require large adjacent units. Hence, this also may negate the use of mechanized farming techniques which are more compatible with better land use patterns. The organization of government structure in which the Ministry of Agriculture is the implementor of the agricultural policy while it has no control over issuance of land title deeds and marketing issues can cause contradictions when resolving intersectoral conflicts on land use.

Therefore apart from preparing the agricultural policy, institutional mechanisms have also to be restructured in order to facilitate the implementation of the policy. The establishment of a legally mandated multi-sectoral and multi-disciplinary institution able to adopt an integrated approach in its activities could be a positive step towards that direction. The National Environment Management Council and the National Land-use Planning Commission were established to assume that role.

5.6 Forest policy

The present Forest policy in Tanzania was first proclaimed in 1953 (LEGICO 1953). The Forest Policy connotes a policy document and less to the legal provisions to achieve the policy objectives. The legal provisions are contained in a different document referred to as the Forest Ordinance (Government Notice No. 399 1990). Basically the forest policy document is a statement of general objectives rather than detailed guidelines on policy implementation. It emphasizes on the demarcation, management and preservation of forests in perpetuity for the benefit of present and future generations (LEGICO 1953). The role of government in taking care of interests of society as a whole is stressed hence calls for efforts on reforestation, research, education and promotion of financial returns from forest related activities (Mgeni 1992). Proper use of public lands and practise of private forestry is also stressed.

Enforcement of this policy has been through the 1957 Forest Ordinance. Experience shows that many of the Forest Policy aims are only enforceable in about 79,000 hectares of forest which constitute mainly plantations and in the legally reserved or controlled natural forests which account for only about 30% of the land area classified as forested land (Mnzava and Riihinen 1989; Kowero 1990). These are the only lands directly affected by the Forest Ordinance. Thus about 31 million hectares of natural forest and woodlands are left without legal protection. Hence these are subjected to heavy utilization in order to meet society needs for fuelwood, charcoal, sawntimber, poles and other uses of wood. The estimated annual allowable-cut from natural forests is about 25 million m^3 (r) whereas rural households alone require some 42 million m^3 (r) of wood per annum (TFAP 1989; Mascarehnas 1991).

In light of the prevailing situation, the government and its various services have little chance to halting deforestation on the public lands as long as it remains uncontrolled. Neither has preservation of reserved or controlled forests been very successful due to the big weak link existing between public and reserved forests. The reserved forests are subject to considerable encroachment (Kaoneka 1990).

Attempts to minimize the confusion were made in 1986 by drafting a new forest policy proposal which extends the objective of preservation, development and management also to public lands especially natural forests. Public lands within the village boundaries would be managed taking into account the provisions of the villages and "Ujamaa" villages Act of 1975. All other important forested public lands would be included in controlled areas governed by appropriate legislation.

Apart from outlining desirable government activities in primary forestry activities, the 1986 draft forest policy, like its predecessor, contains provisions for other public bodies and for private and collective sectors in forestry activities so that interests of society can be fulfilled more efficiently. These provisions however, are hardly effective due to lack of instruments to implement them. Lack of an explicit land use policy coupled with weak and ineffective local government authorities which by legislation are empowered to make use of public lands (Local Government District Authorities Act 1982 Section 114) are some of the deficiencies. For the same reason even the Forest Ordinance limits its jurisdiction on government forest estates only.

Proper utilization of natural resources on public lands is one area of emphasis for which can enhance a successful implementation of the Forest Policy. However, the Forest Policy itself does not provide the means and legislation to encourage efficient utilization of natural forests. One of the means could be to apply for an integrated management approach which entails cooperation and coordination of various users of natural resources on public lands in order to stimulate efficient exploitation and minimize environmental degradation. Furthermore, cooperation among users will prevent the occurence of destructive events such as wildfires and if they do occur there would be willingness and coordinated effort to combat them.

5.7 Wildlife policy

The objectives of the Tanzania wildlife policy are stipulated in the 1984 Wildlife policy document. However, the main focus is on conservation, sustenance, development, cropping and wise utilization of game animals for the benefit of society and also to monitor and protect the environment in which animals live (Wildlife Policy 1984). The role of wildlife in

Tanzania's economy is already outlined in section 4.2.3.

Wildlife, like forestry, is a land-based resource. Therefore any pressure on the land near game areas have some impact on wildlife and its environment. Human population growth near some game protected areas have given rise to a growing demand for arable land, forest products and other natural resources (TFAP-Technical annexes vol.II 1989). However the wildlife policy cannot be implemented in isolation because wildlife conservation is closely linked to other land use systems such as forestry and agriculture. Thus, it could be important for the state policy maker to encourage the participation of rural communities in management decision. Such an approach may stimulate people's willingness to participate in conservation efforts. These measures could enhance a successful pursuit of wildlife concerns.

The Wildlife Policy also fails to address the issue of natural resource use in public lands where some of the problems seem to originate. For example, forestry and wildlife experience same problems emanating from public lands such as poaching, bushfires and encroachment. The shrinkage of the buffer zones around the wildlife conservation areas as a result of expansion of human settlements is a clear signal of the bleak future to be expected if proper policies are not put into effect (Mwalyosi 1990).

5.8 Livestock policy

Tanzania is endowed with a sizeable number of livestock resources as detailed in section 4.2.1.2. Out of the 88.6 million ha of available land in the country, 60.0 million ha can be grazed by livestock. Unfortunately 60% of the country is tse-tse infested and coupled with poor availability of veterinary facilities, about 60% of the livestock is concentrated in only about 10% of the land area (TFAP-Technical annexes vol.II 1989).

This concentration of livestock on a small area is a cause of environmental conservation problems. It is estimated that the available pastures have the potential to support up to 20 million livestock units (*ibid*). However unbalanced stocking causes considerable problems related to land degradation. Thus overstocking is in general discouraged (Mwalyosi 1990). The problem is not easy to deal with because it originates from the behavioral pattern of pastoralists, ignorant of their nomadic habits (Mascarehnas 1991).

Pastoralists often keep large herds of cattle because pastures are free, as a risk averting strategy and as a symbol of wealth and status. Furthermore, their seasonal migratory tendencies, when kept to a minimum, is considered to be a suitable technique of exploiting the environmental resources under semi-arid conditions (Mwalyosi 1990).

The main objective of policy makers has been to encourage destocking which so far has been ineffective due to rigid behaviour of individuals (*ibid*). Like in forestry and wildlife land uses, land degradation caused by livestock originates from the use of grazing areas on public lands. These are areas with uncontrolled grazing which causes soil erosion and general land degradation. This situation is a symptom of the failures associated with the present livestock policy.

The present policy stipulates the need for proper land use planning to provide suitable areas for livestock keeping in relation to recommended carrying capacities. These plans have never been prepared and therefore livestock continues to be concentrated in limited areas. Furthermore conventional pastoral activities such as establishment of water points, dams, veterinary services and improved market facilities have not been able to stimulate dispersion and low stocking of livestock.

Moreover under the current government organization structure the functions of land use planning and issuance of land title deeds are in the Ministry of Lands, Housing and Urban Development whereas livestock development is the responsibility of the Ministry of Agriculture and Livestock Development. This causes some contradictions during the implementation of policy issues.

5.9 Nature conservation legislation

In the bid to foster proper land use and environmental conservation, a number of legislation with direct and indirect influence on land use and nature conservation have been enacted in Tanzania. Enforcement of these legislation has been the way to promote adoption of land practises that enhance nature conservation (Mnzava and Riihinen 1989). The various legislations relevant to land use and nature conservation that have been enacted in Tanganyika and later Tanzania are summarized in Table 5.1. The intended objectives of each legislation are also explained.

Table 5.1 Summary of legislation relevant to land use and nature conservation in Tanzania

Legislation	Intended purpose
1. Wildlife Conservation Act 1914	For protection conservation of wildlife.
2. Game Preservation Ordinance of 1921 Cap. 86	Established game reserves
3. Game Preservation Ordinance of 1940 Cap. 159	Effected birth of National Parks
4. National Parks Ordinance of 1948 Cap. 253	Established National Parks
5. Fauna Flora Conservation Ordinance of 1954 Cap. 259	Prohibited cultivation in National Parks. Established Ngorongoro multiple land use conservation area
6. Natural Resources Ordinance of 1954 Cap. 259	Formed a natural Resources Board to conserve natural resources.
7. Ngorongoro Conserv. Area Cap. 413	For management control of the Ngorongoro as a unique area.
8. National Parks Ordinance Cap. 412	For creation, management control of National Parks
9. Grass Fire Ordinance	Prohibits burning grass without authority.
10. Forest Ordinance Cap 289 of 1957	For creation, management conservation of forests.
11. Land Tenure Reforms of 1962	Urged peasants to develop and expand land occupied under native law custom.
12. Wildlife Conservation Act No. 12 of 1974	For conservation of wildlife
13. Rural Settlement Commission Act	Aimed at establishing a legal framework body to coordinate early settlement schemes.
14. Right of Occupancy (development condition) Act	Paved the way for the conversion of freeholds into government leaseholds.

Source: LRDC 1987.

6.0 LAND USE PROBLEMS IN TANZANIA

6.1 Types of land use in Tanzania

6.1.1 General land uses

The main types of land use in Tanzania include small scale farming (cultivators, peasants), plantation and large scale farming, grazing (pastures), forests and woodlands, and urban (others). Their distribution by area and percentage is shown in Table 6.1.

Table 6.1. Land use types and their distribution in Tanzania

Type of land use	Area, ('000 ha)	Percentage (%)
Small scale farming	3,880	4.1
Plantation Large scale farming	585	0.6
Grazing (pastures)	44,245	46.9
Forests Woodlands	38,050	40.4
Urban development (others)	1,600	1.7
Inland water	5,900	6.3
Total land area	88,360	100.0
Total area	94,260	-

Source: Mascarehnas (1991)

The striking feature of the figures in Table 6.1 is that, despite its fairly significant contribution to the national economic development, agriculture occupies barely 5% of the total land area. One argument may be that the land needed for various uses is limited in supply relative to the demand for it. Large scale farming accounts for a fraction of less than 1% of the total land use. Although large scale farming is capital intensive it has relatively high economies of scale. Thus, there is a trade off between capital intensity and high economies of scale.

The land use pattern in Tanzania varies widely over the entire country with a close relationship between the distribution of population and the distribution of natural and agricultural resources. The higher the population pressure, the more intense the pressure on forest lands. Other factors that exert some influence on the regional agriculture activities are topography, soil type, a permanent water supply, the presence or absence of tsetse fly and climatic conditions. There are also traditional methods, that were practised in such a way as to conserve soil fertility. Over time, however, these traditional techniques changed due to some socio-economic factors such population increases and poverty.

6.1.2 Types of agriculture

The major agricultural systems in Tanzania includes shifting cultivation, rain-fed permanent cultivation and pastoralism which include both agropastorists and nomadic pastoralists especially the Maasai tribe.

6.1.2.1 Shifting cultivation

Shifting cultivation is the name given to agricultural systems that involve an alternation between cropping for a few years on selected and cleared plots and a lengthy period when the soil is allowed to rest (Ruthenberg 1980). The system involves systematic shifts within an area usually covered by forests or other natural vegetation. When shifting cultivation involves a larger area relative to the total area and the fallow period becomes shorter, the system becomes more stationary (*ibid*). That is long-fallow is replaced by short-fallow. In the words of Ruthenberg (1980), "if the characteristic R is more than 33, i.e. if 33% of the arable and temporarily used land is cultivated annually, we no longer speak of shifting system but of fallow systems".

Shifting cultivation is the traditional method of farming system practised in most parts of Tanzania. The system is characterized by two stages, bush fallow and commercial fallow. The commercial fallow system is widely used in semi arid and tsetse fly infested areas of Tanzania. The system requires the abundance of land to allow for a cultivation cycle of between 2 to 8 years followed by a fallow period of 40 to 50 years. The fallow land is used for grazing livestock to supplement crop residue feeding. Bush fallow is practised in lesser drier and marginal areas particularly in mechanized agriculture (TFAP 1989).

The carrying capacity of shifting cultivation systems is variable but Bishop (1984) observes that "shifting cultivation in the tropics is a sustainable system for population up to about ten people per square kilometre". That means with a population density averaging 25.5 persons per km^2 (URT 1991), Tanzania cannot maintain a sustainable shifting cultivation system. However, the carrying capacity is not limited to population density only, it depends also on, *inter alia*, factors like soil type, rainfall (amount and distribution), temperature and kind of crops grown; and tree characteristics such as density per ha, the proportion of suitable woodland in an area and the length of fallow period (Allan 1966; Hofstad 1990).

The rapidly increasing population coupled with the introduction of cash crops have exerted tremendous pressure on landuse such that the fallow periods are, at present, too short to allow the land to recover its full productivity. Shortened fallow period causes accelerated soil degradation, weed invasion, infestation by pests and diseases with the resulting effect of a decline in crop yields (Hofstad 1990). Land scarcity compels the farmers continue to use the same parcel of land over an extended period despite the decline in productivity. In some cases farmers are forced to clear marginal areas for agriculture which could otherwise be used for ranching or forestry (Rwechungura 1985; Minde and Mlay 1989). In extreme conditions, such as the situation in Kondoa and part of Shinyanga, the farmers are forced to abandon the land altogether, due to considerable decline in productivity accompanied by drastic soil erosion (TFAP-Technical annexes vol.II 1989).

6.1.2.2 Rain-fed permanent cultivation

The rain-fed permanent cultivation is practised in the humid highlands and in the fertile flood plains of Tanzania. Livestock keeping is more intensive, and in some cases cattle is raised using cultivated grass such as "guatemala" (*Tripsacum laxum*). Generally, the system is less prone to land degradation, although a minimal decline in soil productivity is not unusual (TFAP-Technical annexes vol. II 1989).

6.1.2.3 Pastoralism

Pastoralism is a system that is carried out in essentially three ways. The first one is the nomadic pastoralism a system practised largely by the Maasai people. The second one is the semi-nomadic pastoralism which is practised by the Sukuma people. The nomadic pastoralism is characterized by free movement of livestock influenced by seasonal variation viz. rainfall seasons. The present trend is to minimize the free movement of livestock in the wake of agricultural expansion in semi-arid areas. Consequently the system is changed into semi-nomadic pastoralism. The move is no better because the result of semi-pastoralism is concentration of livestock which thus accelerates overgrazing and overall land degradation through increased soil erosion (Minde and Mlay 1989). The third one, practised mainly by the Wachagga, is the "indoor technique" where animals are kept in paddocks and stall-fed.

6.2 Diagnostic view of land use problems in Tanzania

6.2.1 Symptoms of land use conflicts

Generally, land use conflicts in Tanzania stem from the competition for different land uses (Table 6.2). It can be seen from Table 6.2 that the total area claimed by the various land uses is 2,106,750 km^2 more than twice the total land available which is 886,000 km^2. Therefore, the demand for land to be used by the various interest groups is 238% more than the actual supply for it. Such unbalanced claims may be a symptom of deficiencies in land use planning at the national level.

Due to the inequality between the demand and the supply of arable land, conflicts arise among the various interest groups. Even if some of the different land uses overlap, it is apparent that the same parcel of land may fall under the claim of two or more sectors. Such conflicts call for the government to evolve an overall system for planning and monitoring land uses in order to harmonize the demands of the various interest groups.

Table 6.2 Land area claims under various uses

Type of land use	Area covered, km²
Arable land	
- under agriculture	487,100
Forest reserves	44,650
Game reserves	130,000
Forests Woodlands	314,000
Pastures	600,000
Others(tsetse fly infested)	531,600
Total	2,106,750

Source: TFAP-Technical annexes vol.II (1989)

For the purpose of coordinating and harmonizing one way or the other the interests of various sectors, the government set up a National Land Use Planning Commission (NLUPC) in 1984 (by Act No.3). The NLUPC has, *inter alia*, the mandate to:

(a) Formulate policy on land use planning;

(b) Coordinate the activities of all bodies concerned with land use planning;

(c) Examine existing laws, and when appropriate formulate proposals for legislation in the area of land use planning;

(d) Recommend measures to ensure that the government policies including those for the development and conservation of land take adequate account of its effects on land use;

(e) Prepare national physical plan and ensure its implementation by the regions;

(f) Issue orders, directives, notices and other documents to the Districts and Regional Land Advisory Committees and all such orders, directives and notices shall be binding.

The set-up and *modus operandi* used by the Land use planning commission followed the pattern of top-down system of administration. The vastness of the country and varied socio-economic settings has made it difficult for the NLUPC to function effectively. For instance, Mnzava and Riihinen (1989) point out the following drawbacks:

(a) Land use planning and subsequent implementation at the district and village levels has to go concomitantly with land ownership and tenure. Land titles are issued by MLNR and T, but land surveys and demarcations made by personnel other than those from Lands Department are not recognized. The effect was a confusion when it came to the implementation of a land use plan.

(b) There is, at present, no education curriculum on land use planning *per se*.

(c) The current practise is based on a "piece-meal" approach which is neither elaborate nor systematic. The planning horizon assumed of 20 years is too long to take care of the land use dynamics and pattern.

As a final comment, it may be said that, the NLUPC has not fulfilled all the practical objectives intended. This means, measures are still needed to redress the land use problem. TFAP-Technical annexes II (1989) proposes a classification of land use in Tanzania by problem areas as a way of identifying area of serious land use problems and as a basis for designing specific remedial action. The classification is outlined in section 6.3.

6.2.2 Classification of land use by problem areas

Tanzania is a large country with a relatively high diversity of physical conditions. Also there is significant variation in terms of climate and socio-economic development between bordering regions and even within regions. There are differences in vegetation cover especially forest. These factors coupled with political factors make a territorial land use planning very difficult. Consequently the TFAP-Technical annexes vol. II (1989) proposes the division of the country into zones on the basis of problem areas (Map 3). Such division is envisaged to enhance the design of specific actions geared toward checking the rapid environmental degradation and fast dwindling of land-based resources. The zones proposed are described in the following sections:

6.2.2.1 Zone I

An area of high population pressure on land for farming and on woodfuel with subsequent deforestation. High risk for erosion due to steep sloping terrain and high precipitation. The areas that fall under this category are West and East Usambara, Kilimanjaro and Meru Mountain slopes, Kagera, Rungwe, Ukerewe, Tarime and Mbulu districts.

6.2.2.2 Zone II

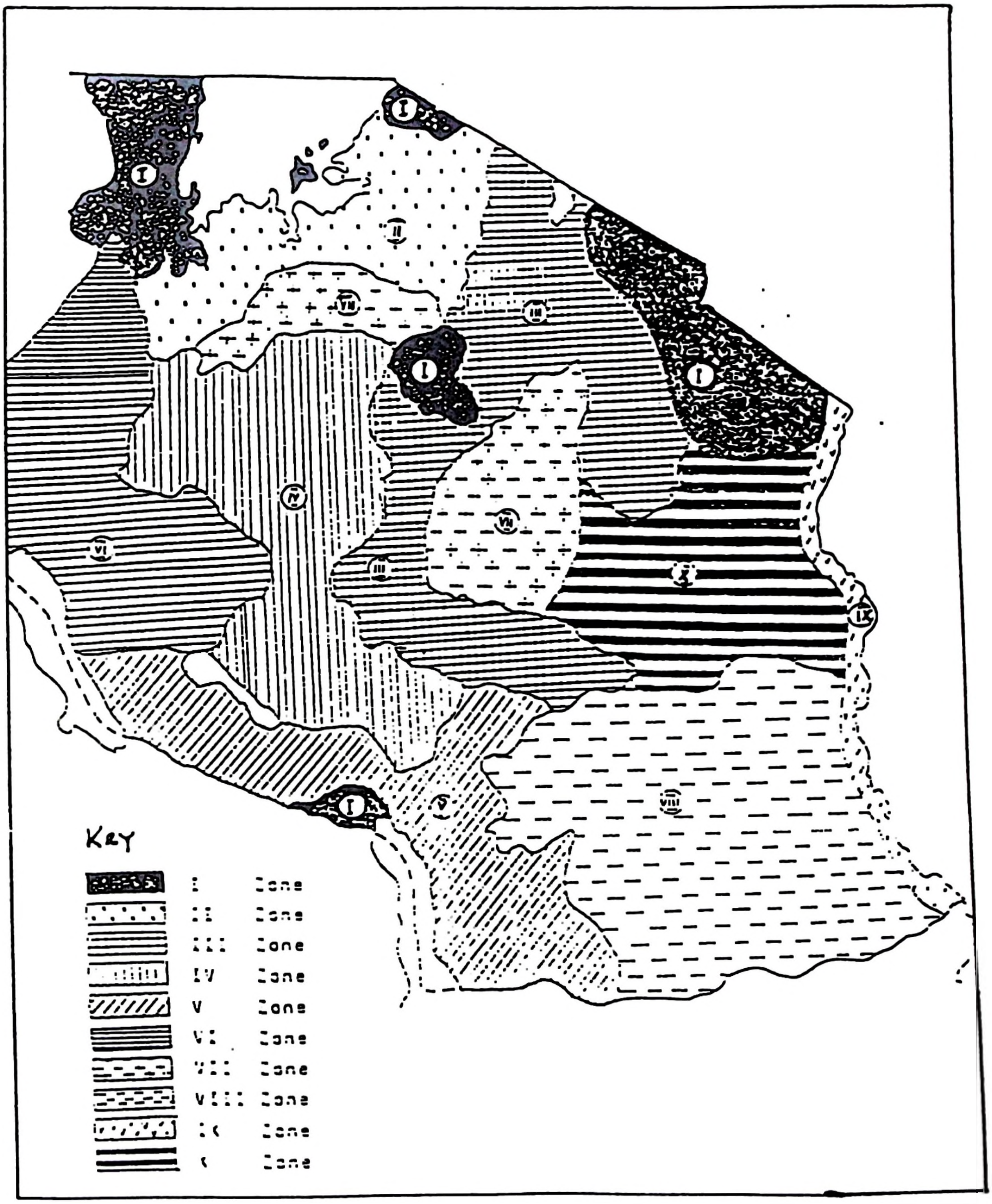
An area of high population with extensive agriculture for cotton accompanied by overgrazing due to concentration of large livestock herds. The areas that fall under this zone are Mwanza, Mara and some parts of Shinyanga.

6.2.2.3 Zone III

An area characterized by overgrazing and migratory pastoralism. The areas representing this zone are Masai steppe, parts of Dodoma and Singida regions.

6.2.2.4 Zone IV

This zone has features more or less like those in zone II except that it is also characterized by extensive agriculture for tobacco production. The zone covers Tabora region, Chunya and Northern Iringa districts.



Map 3 Division based on problem areas in Tanzania (adopted from TFAP-Technical annexes vol.II 1989).

6.2.2.5 Zone V

The zone represents what is referred to as the "grain basket" of Tanzania. The area is reputable for the production of maize for commercial purposes. The zone covers Iringa, Mbeya, Southern Rukwa, North and West Ruvuma regions. Also known in the political arena as "the Big Four" of Tanzania.

6.2.2.6 Zone VI

An area characterized by high population pressure due to immigrants and refugees from

Burundi and Rwanda with a high demand for farming land. Areas falling under this category are Kigoma-Mpanda and Northern Rukwa Region.

6.2.2.7 Zone VII

This zone is characterized by degraded lands. Largely Dodoma under "Hifadhi Ardhi Dodoma "(HADO) literally meaning "Conserve Land in Dodoma" and Shinyanga under "Hifadhi Ardhi Shinyanga" (HASHI) meaning "Conserve Land in Shinyanga". The two projects are designed basically to rehabilitate the severely degraded lands in these areas.

6.2.2.8 Zone VIII

The zone represents relatively sparsely populated areas of the country with a fair abundance of wood supplies. The zone covers Lindi, Mtwara, Eastern Ruvuma viz: Tunduru; Southern Morogoro viz: Mahenge district and South Coast region viz: Utete district.

6.2.2.9. Zone IX

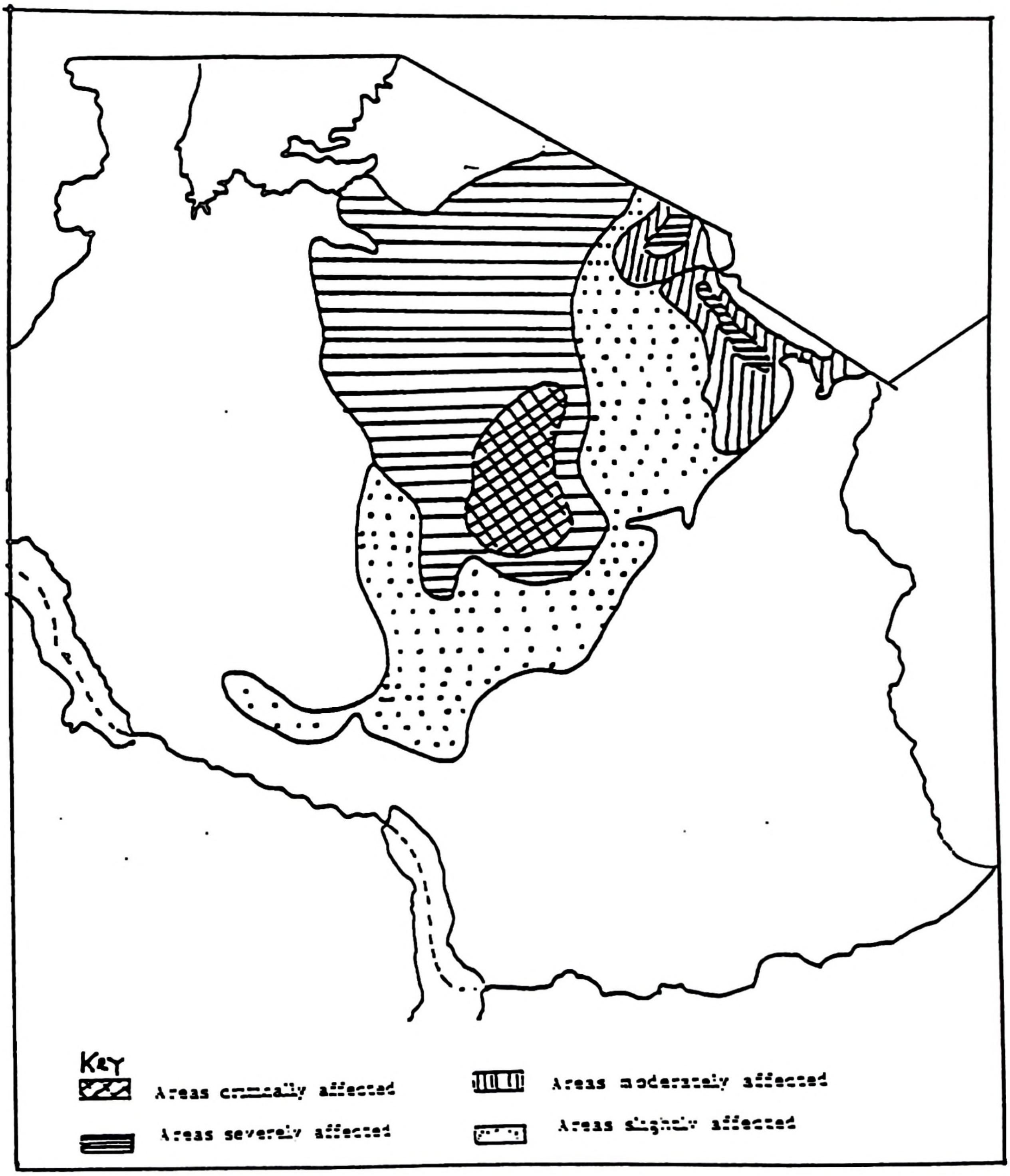
The zone covers the whole coastal belt and Mafia Island. Deforestation in these areas is caused by salt production and fish smoking consequently there is considerable degradation of mangrove forests.

6.2.2.10 Zone X

This zone is termed commercial fuelwood deforestation belt. It is characterized by charcoal burning, firewood cutting and shifting cultivation. The areas covered by the zone are Eastern Morogoro, Coast region with the exception of Rufiji, West of Tanga and South-Eastern Dodoma region.

6.3 Extent of Land Degradation

The rapid rate of deforestation has caused a great deal of land degradation. The proportion of degraded land has been estimated at between 33% and 45% of the total land area (Kowero 1990). These proportions and the extent of degradation are shown in Map 4. The extent of degradation is classified into four levels; critically affected, severely affected, moderately affected and slightly affected areas. One of the causes of soil or land degradation is overgrazing because animals destroy regeneration, causes soil compaction and deprive the soil



Map 4 The state of land degradation in Tanzania (adopted from TFAP-Technical annexes vol. II 1989)

of vegetation and grass cover (Kaoneka 1990). The loss of vegetation coupled with animal trampling exposes the topsoil to serious erosion. The effect of overgrazing is more evident in arid and semi-arid areas such as Northern Maasailand, and areas around Kondoa, Mkomazi and Same and parts of Shinyanga Region. In those areas the vegetation cover is completely destroyed leaving "the areas either semi-desert or bare ground" (Lundgren 1975).

6.4 Factors contributing to land use problems

6.4.1 Land tenure and land use policy

The land tenure system in Tanzania finds roots in the legislation composed of the Land Ordinance Cap.113, The Village and Ujamaa Villages Act No.21 of 1972 which was revised in 1975, the Forest Ordinance Cap.389, the National Resource Ordinance Cap.259, the Rural Lands (Planning and Utilization) Act No.14 of 1973 and the Local Government (District Authorities) Act of 1982. The legislation classifies the land tenure system in Tanzania into four categories (see Mnzava and Riihinen 1989) outlined as follows:

(a) The public sector or state leasehold: under this system the state leases land to individuals and communities for a specified period of time, say, 33, 66 or even 99 years.

(b) Private or rights of occupancy: this arrangement concerns the parcels of land owned by individuals for the purpose developing them into agriculture, livestock keeping or for the purpose of service industry.

(c) Traditional or customary land tenure: under this system the ownership of land is gained through inheritance or customary rules among tribes, clans or kinships.

(d) Collective or village land ownership: the land ownership by a village is based on law. The land must be surveyed and demarcated before a certificate of ownership is issued. Villages are then entitled to use the granted parcel of land according to their own best interests.

Land use policy encourages individuals or villages to acquire lease title deeds for their land from the central government in recognition to their right of occupancy (TFAP-Technical annexes vol. II 1989). Basically the legal contentions of land tenure, as stipulated in the Landuse Act of 1973 pursuant to the Limitation Act of 1971, are clear and embody the principle of proper land use. That is individuals hold only use rights on land. Hence they are entitled to exclude other potential users from a parcel of land as long as the that parcel is used in someways or put under long-term crop.

In practise, however, there have been disputes associated with improper interpretation of the Act itself. Disputes occur between villages and between households, and between individual land owners. Some village leaders allocate land to outsiders without the consent of the villagers, who under customary arrangements are the custodians of the land in their respective areas (Mwalyosi 1990). Perhaps one of the reasons for the increased disputes on land is the abolition of chiefs who were responsible for land administration within their respective chiefdoms (*ibid*). The chiefs were more capable of resolving local land disputes. Experiences elsewhere point to the same argument. For instance, Bromley (1992) observed that local rulers exercised control over the political and economic life of villages and that their effectiveness was based on the fact that they could control the actions of individual members of the community.

In Tanzania, at present, those powers are vested on local government related organs such as Divisional and Ward Secretaries and Councillors in the district. Such remotely and centrally located authorities lack adequate local information and thus are not sufficiently competent in dealing with land use planning issues (TFAP-Technical annexes vol. II 1989; Kowero 1990). The consequence has been the emergence of insecurity of land tenure which is fragmentary and incomplete (TFAP-Technical annexes vol. II 1989).

Land allocation and insecurity of tenure is especially an important issue due to fast population growth and disputes between private and village or collective interest (Gibbon, Havnevik Hermele 1992). Furthermore, temporal limit on a farmer's tenure affects his decisions regarding soil conservation measures such as erosion control. In practical terms the benefits of soil conservation, which comprise enhanced land productivity in the future, can only be gained through some sacrifice in the near term (Southgate 1988). Therefore if the farmer does not own a parcel of land in perpetuity but rather possesses only a leasehold, the tendency is the unwillingness to incur these short term costs for the sake of benefits realized after the terminal date of that leasehold (*ibid*). One more argument can be raised here. Some farmers are averse to long term investments because of the risks involved. Whenever a farmer realizes the risk of future loss of the title deed on a parcel of land, the tendency is to disregard the benefits of conservation realized only after the passage of many years. Thus TFAP (1989) proposes that the current land tenure be revised such that title deeds are more permanent than the current 99 years maximum lease period.

The problem of land tenure and land use policy is not limited to administrative and political shortfalls, but to other socio-economic factors. The socio-economic factors include the changing of patterns of land use, ownership and control; and the emergence of commercial markets (Kowero 1990). In traditional communities land was considered to be a common property. Common properties are owned and can be used by members of a well-defined group such as those living in a particular village or those belonging to a particular family, clan or tribe guided by certain resource use rules in order to enhance continued productivity of land (Southgate 1988). In fact the principle of common property has been used by various cultures throughout history to manage natural resources on a sustainable basis (Ciriacy-Wantrup Bishop 1975). Recent literature also confirms the existence of reasonably successful common property regimes (Berkes 1989; Berkes *et al.* 1989; Bromley Cernea 1989; McCay and Acheson 1987; National Academy of Sciences 1986). The essence of common property regimes hinges on the fact that "property rights is a structure of duty that will give any particular benefit stream protection against adverse claims" (Bromley 1992). However individual pursuits such as profit maximization could weaken commmon property rights.

For instance, the emergency of commercial markets introduced a kind of market-oriented economic competition (*ibid*). This situation led, in certain cases, to the sale of land holdings to individuals, who could produce enough to meet market demands, hence the emergence of commercial production which put more emphasis on producing cash crops. The privatization of better village lands lead peasants to increase their dependence on the market and on the money-lender (*ibid*). Also commercial markets caused an increase of the disparity between wealth and income of the local people (at the village) making self-governing system ineffective due to the emergence of classes with contradicting strategies (Bromley 1992). The consequence of these events generated pressure that weakened the traditional land tenure arrangements and customary practises which defined land use rights and ownership (*ibid*).

Furthermore, where farmers were uncertain about long term ownership of land, they felt no incentive for long term investment on the land such as tree planting (TFAP-Technical annexes vol.II 1989). This resulted into some shortcomings such as lack of full participation of the local people in afforestation programmes. Thus adverse effects such as decreased productivity due to increased land degradation and severe soil erosion continued to persist. The fall in crop farming productivity gave rise to induced dependence on livestock keeping to supplement farm produce. Large herds of livestock increased pressure on common pastures. In some cases more forage has to be obtained by grazing animals in the forest reserves. Extensive grazing depleted the forest understorey cover resulting into land degradation.

The land tenure system currently in practise in Tanzania is inadequate to ensure sustainable land use practises. The revision and development of a new land tenure system or policy is important (TFAP 1989). It is envisaged that a stable and amicable land tenure system "creates incentives for producers to make long-term investments and use production techniques that permit sustained production" (Lutz and Daly 1990).

Furthermore, the socio-economic and political climate in Tanzania has changed over time. Thus, it may be necessary to review some of the contents of the land use legislation (Kowero 1990). For instance the provision for "Ujamaa Villages" is no longer a component of emphasis since the current drive is to promote private production save for situation where community forestry programmes are in effect. Therefore, it is imporatnt that the legislation be "updated, revised and compiled into a comprehensive Land Tenure Act" (Mnzava and Riihinen 1989).

In the quest to reform the land use situation the National Five-Year Development Plan covering 1988/89 to 1992/93 puts an emphasis on essentially four aspects related to land use planning (TFAP 1989). First, land use plans at village and zonal level should be prepared and implemented. Second, village boundaries and residential-commercial areas for individuals and the public should be surveyed and demarcated. Third farmlands should be surveyed and clearly demarcated. Fourth, land title deeds for village cooperatives, companies, registered trustees and individuals (subtitles) should be prepared and registered. At the same time there must exist legal and administrative processes to ensure the implementation of these provisions. However, little action appears to have been taken so far. Only 1450 out of about 8,200 registered villages have been issued with title deeds to their land and village land use plans have so far been approved by the respective authorities (*ibid*).

6.4.2 Extension service

Adequate extension service is needed in order to assure proper land use. The overall function of extension service is to promote new technical practises which are deemed beneficial, such as use of chemical fertilizers, improved seeds and agroforestry practise. The main extension work in relation to land husbandry is carried out by the Forestry and Beekeeping Division in the Ministry of Tourism, Natural Resources, and Environment; and the Department of Agriculture in the Ministry of Agriculture and Livestock Development.

The forestry extension service offers advice to farmers regarding the consequences of deforestation such as fuelwood shortage and soil erosion and educate them about the use of agroforestry system, proper farming practises which minimizes land degradation and encourage them to participate in tree planting. There are are some problems which affect such service. Lack of adequate staff and transport. Hence the extension staff reach only about 27% of the rural majority (TFAP-Technical annexes vol. II 1989). Also the extension staff rarely meet with village women who are the main land users because women are less represented in village governments.

The livestock extension service provides to a large extent curative service, that is dipping and vaccination campaigns and related advice to farmers. The service is affected by lack of adequate transport, staff and equipment. Overall the agriculture service reaches about 42% of the villages (*ibid*) The general conclusion is that the extension service as it is offered at present covers only a small portion of the rural area.

6.4.3 Infrastructure

Success in any land use system is partly dependent on the prevailing infrastructural set up. In Asia for example, the Green Revolution flourished because of having elaborate irrigation system among other factors. Also there were efficient transportation systems together with other infrastructural requirements. Farmers who have access to commercial markets and research centres increased food yields tremendously through the absorption of improved technology (O'kting'ati 1984).

In Tanzania the role of the transportation network, markets, storage facilities, crop handling systems and other infrastructural demands in facilitating the increased returns from a land use system is stressed. However there has been limited effort towards the improvement of important components of the infrastructure system.

It is not uncommon to hear that food crops are plentiful in one part of the country whereas in others there is food shortage. The same situation is common with cash crops such as cotton. Sometimes farmers obtain a bumper harvest but handling, storage and transportation become a serious problem resulting into a substantial amount of the crop yield getting destroyed in the field (Mascarehnas 1991). Such events defeat the whole idea of efficient utilization of land. This emphasizes the need for developing efficient marketing institutions.

6.4.4 Socio-economic factors

Land use patterns are not only based on the ecological and geographical factors of altitude and climate particularly rainfall with soil playing a big role but also on some socio-economic factors and the kind of crops grown whether cash or food crops (Mascarehnas 1991). All these factors have a bearing on people's income. In these areas where climate allows cash crop production, people have a high standard of living as compared to those areas where there are no cash crops (O'kting'ati 1984; Minde and Mlay 1989).

Another socio-economic factor which is likely to influence land use practises is the opportunity cost of labour. In least industrialized countries (LDCs) labour endowment is a very important factor of production to smallholder or peasant farmers (Southgate 1988). Sometimes it is assumed that peasant farmer's labour has no opportunity cost (its shadow price is zero or even negative) due to widespread underemplyment (*ibid*). However this may be true in to some extent only because the value of labour scarcity is not constant throughout the year. For instance, during the peak season labour demand is so high that time and effort carry a considerable opportunity cost. An increase in wages and provision of employment opportunities on non-farm activities is likely to reduce the time and effort devoted to erosion control and land clearing (Southgate 1988). However, it may also have the reverse effect because as more people are employed in non-farm activies the pressure of tillage is reduced hence stimulaiting the adoption of conservation measures that reduce the labour-intensity of farming (*ibid*).

The infrastructural set up and socio-economic factors have also tended to enhance development in cash crop growing areas than in food crop growing areas. Therefore even population growth rate have followed similar trends. The most densely populated areas are, those where cash crops are grown. These areas also enjoy high literacy level and hence people can harness the environment in a more efficient manner to generate cash income.

The national income also is heavily dependent on cash crops such as sisal, coffee, cotton, cashewnuts and tobacco. For this reason the government pays more attention to areas producing cash crops than food crops. However, at the national level, international terms of trade which are unfavourable in most cases to developing countries, dictate the levels of income realized.

Poor socio-economic situation coupled with the growing human demand for food, fuelwood, and fodder has overtaxed many of the ecosystems thus leading to poor land use practises. The overall result is deforestation, soil erosion, poor crop yields and declining balance of natural ecosystems. Also the injudicious land use is a consequence of poverty which find roots in the Tanzania's poor economic base. Therefore, the role of socio-economic factors in promoting proper land use practises cannot be ignored. In much of the Third World, Tanzania included, social and economic pressures have compelled people to continue with the same land practises and social values which are no longer appropriate under present land use systems. For example some tribes in Tanzania such as the Wamaasai, Wagogo, Wasukuma continue to measure their status in terms of the size of cattle herds they own. The belief which encourages to keep large herds of livestock beyond the carrying capacity of pasture or grazing lands (Mwalyosi 1990). In the highlands of Kilimanjaro and Usambara, the Wachagga and Wasambaa farmers, respectively, place great value on private (family) land ownership. It is prestigious and respectful for a parent if his sons and grandsons can inherit land (O'kting'ati 1984). However, the system has some shortfalls especially where it led to the fragmentation of land into small plots that have very low economic value.

Furthermore socio-economic factors are very much influenced by some government policies. Thus in the next section an attempt will be made to examine some of the government failures that may have contributed to land use planning problems in Tanzania.

6.4.5 Government failures in relation to land use problems

6.4.5.1 The Arusha Declaration and public policy

In 1967 Tanzania adopted the Arusha Declaration, a blue-print of Tanzania's aspirations towards becoming a socialist state. The adoption of the declaration emphasized that land is a public property, decreed public ownership of the means of production and discouraged private ownership of property. In other words private property rights were not only discouraged but in some cases denied. This decree had a negative impact on the production sector.

The Ujamaa (socialist) policy of state controlled production discriminated private initiative with the consequence of stagnation in production. Because it curtailed the improvement of the existing land use systems as well as the absorption of new technologies. Also individuals feared to invest more in economic ventures due to possibility of confiscation by the "socialist" government.

6.4.2.5.2 Pricing policy

Market prices are normally the ones used to valuate economic performance to the extent that they reflect the willingness of consumers and producers to pay for the goods they actually buy except where rationing is in effect and the availability public goods is fairly adequate (Somogyi 1989). The main utility of market pricing is that, prices send correct signals to both producers and the consumers (Sarris 1990).

In Tanzania, like in most developing countries, there is tendency of high degree of rationing and price controls (*ibid*). Thus there exist strong parallel markets, which are conventionally referred to as "black markets" but not necessarily illegal, with their prices different from the official or controlled ones that reflect more accurately the supply and the demand conditions (Sarris 1990; Gibbon, Havnevik and Hermele 1992). The parallel market approximates the real market situation characterized by competitive market forces (*ibid*).

Most often controlled or official prices are significantly lower than the prices offered by the parallel market while at the same time the government tries to control both the producer (farmer) and the consumers. By offering low prices to cash crops, however, the government takes away an economic incentive for the farmers. The effect is that the farmer diverts family labour from producing tradeable (cash) crops to non-tradeable (food) crops. The second, overall effect is that in the absence of economic incentive the peasant continues to produce at the subsistence level using less productive cultivation practises causes land degradation (Lutz and Daly 1990).

6.4.5.3 Foreign exchange policy

Tanzania's policy on foreign exchange has been that of rationing and overvaluation of the domestic currency, the Tanzanian Shilling, which "grossly distort the border prices expressed in domestic currency" (Somogyi 1989). The relationship between price levels and exchange rates can be explained using the purchasing power parity (PPP) doctrine (Mbelle 1988). There are two propositions in the theory. The first one known as the absolute version of PPP states

that "the exchange rate between two currencies will be determined by the ratio of the price levels of the two countries" (*ibid*).
That is,

$$r = P/P^{*} \qquad [5.1]$$

where

r	=	exchange rate
P	=	domestic price level
P^{*}	=	price level of foreign country

The second proposition is the relative version of PPP which states that a percentage change in the exchange rate will be equal to the difference between the percentage changes in the two price levels (*ibid*).

Thus,

$$\frac{\delta r}{r} = \frac{\delta P}{P} - \frac{\delta P^{*}}{P^{*}} \qquad [5.2]$$

where

δr	=	change in exchange rate
δP	=	change in domestic price
δP^{*}	=	change in foreign price

r, P and P^{*} remain as previously defined.

Most often governments set an exchange rate arbitrarily not tied to international market situation (Sarris 1990). Reverting to equation [5.1], overvaluation means setting lower exchange rate relative to real or effective exchange rate. Therefore, if equation [5.1] is to hold true, at an assumed international or foreign currency, setting low exchange rate means low domestic price. Thus the price of tradeable crops a farmer (peasant) receives when valued at the border price will be lower (Sarris 1990).

The operating mechanism is that, with low border prices there is no incentive for the farmer to produce tradeable crops. And if the farmer does produce tradeable crops, two scenarios are possible. The peasant may sell the crops to the parallel market which will eventually be smuggled (an ancient economic activity) out of the country. The extent of this activity depends on *inter alia* the risk of being caught and the magnitude of purchasing power parity. The second scenario is that the peasant may decide to limit production to non-tradeable crops whose prices are formed freely by interaction of supply and demand (*ibid*). The two scenarios are possible in the Tanzanian context.

Also low prices for crops discourages smallholder or peasant farmers from investing in natural resource inputs to agriculture such as conservation measures to existing farms (Southgate 1988). This may be ascribed to the fact that low crop prices decrease the economic profitability of soil-conserving land uses (*ibid*).

Further the over-valuation of domestic currency (i.e. setting lower than market exchange rates) discourages farmers from producing export crops. "This in turn diminishes derived demand for agricultural land, which discourages individuals both from managing existing farmland well and from pushing out of agriculture's extensive margin" (Southgate 1988). However, the effect of inappropriate foreign exchange rate very much depends on the magnitude of the portion of the farm produce which is traded internationally.

Moreover, the effect of overvaluation of the domestic currency is not only limited to crop prices but also it does affect the prices of imported agricultural inputs such as chemicals and mineral fertilizers (*ibid*). These inputs are traded internationally and thus their domestic prices are tied to the international ones. In Tanzania the importation and domestic prices of the tradeable inputs is controlled by the government. Until in the middle of 1980s tradeable inputs were bought by the peasants at government subsidized prices. The argument here is that if, for instance, fertilizer is sold at a low price due to combined effect of overvaluation and subsidization, the effect would be (not necessarily so) excessive use of fertilizer which may result into land degradation.

Also due to cheaper prices the farmers substitute mineral fertilizers to soil conservation measures because mineral fertilizers compensate for soil nutrients lost through erosion (Southgate 1988). However, the effect depends primarily on whether or not the peasant is accustomed to the use of fertilizers. In essence therefore, there are mixed schools of thought regarding the extent to which overvaluation affect the use of traded inputs in the absence of free market forces (Sarris 1990).

6.4.5.4 Fiscal policies

In analysing the fiscal policies, the aspects to be considered are allocation of resources, inflation, interest rate and various taxes which are envisaged to be more relevant in the Tanzania's situation. Despite its being the mainstay of the Tanzania's economy, the government allocates a disproportionate amount of resources to agriculture. For instance during the 1988/89 season the allocation of resources to agriculture and livestock was 20% compared to 31% in the 1986/87 season (Gibbon, Havnevik and Hermele 1991).

Another item falling under the fiscal policy is the rate of inflation. The rate of inflation in Tanzania has averaged between 20-30% during the period 1985 through 1991 (Bureau of Statistics 1991). The effect of inflation is that as the rate increases it pushes high consumer prices. The worst hit group constitute the peasants and the low income earners in the employed sector of the civil service, who struggle to meet basic necessities (Somogyi 1989; Gibbon, Havnevik and Hermele 1992). Increased cost of living occasioned by rise of consumer prices compel the peasants to cultivate in marginal areas.

Interest rates have no direct bearing on land use pattern and subsequent land degradation, at least in the Tanzanian context, because seldom do peasants apply for loans. But for the purpose of this analysis, it was assumed that peasant farmers have access to loans. In Tanzania, credits to peasants are extended by the Cooperative and Rural Development Bank (CRDB), which levies an interest rate of 28% per annum, embodying the inflation rate which averaged 20% in the middle of 1992 (EIU 1992). This is too high an interest rate to be recouped by a one year turnover. That is, it is not easy to invest on an economic venture that has an annual turnover of at least 28%. In essence, therefore, the high interest rate in itself deters the would be loan seekers, in this case the peasants. Furthermore financial institutions are reluctant to extend loans to peasant farmers because "small farmers are costly to serve and are risky clients since they possess little collateral and since their marginal socio-economic status renders uncertain the returns they gain from farming" (Southgate 1988). In the absence of a credit facility peasants cannot transform the subsistence agriculture into improved farm practises. Thus they are compelled to continue with traditional farm practises which, in most cases, have damaging effect to the land (TFAP-Technical annexes vol.II 1989).

The effect of taxes on land degradation is rather diffuse especially in the Tanzanian context where the agriculture sector is dominated by smallholder farmers or peasants. The reason is that "the income of the sector is almost never taxed at the source" (Sarris 1990). The only payment peasants bear, which is not tax *per se*, is a portion of the sales taken to partially compensate for subsidized farm inputs. And this applies largely to tradeable crops only. On the other hand cuts in subsidies and transfers to agriculture affect both the incomes of peasants and cooperative unions (Tibaijuka 1990). However, the elasticity for agricultural poducts is less than 1 (i.e. < 1.0), hence the impact of cuts on public spending is rather low compared to non-agricultural sectors (Sarris 1990). The overall effect of cuts in public spending is the reduction of aggregate demand (*ibid*).

6.4.5.5 Public investment policy

Tanzania's public investment policy has been questionable for quite sometime (Gibbon, Havnevik and Hermele 1991). The main criticism is that public funds are spread over a lot of projects with less contribution to the welfare of the common or ordinary citizen, and economically less viable (Somogyi 1989; Gibbon, Havnevik and Hermele 1992). Public investment allocates disproportionate funds to agriculture development, forest protection and general land use management activities (Kiondo 1989).

Further, the government committed itself to ambitious social obligations such as provision of free education and medical services (*ibid*). These commitments increased government spending substantially. Even when it faced huge budget deficits, the government was reluctant to change course (Somogyi 1989).

Finally the government protected public enterprises through the provision of heavy subsidies and centrally planned production strategies. This situation led to inefficiency and low turnover.

6.4.6 Demographic factors

Tropical countries of which Tanzania is one are characterized by fast growing populations, low per capita incomes, and agrarian economics (Kyrklund 1986). Thus food production in developing countries needs to increase substantially on annual basis in order to meet the demand of the ever increasing population. The need for food increase may be even higher for Tanzania whose population growth averages 2.8% per year (URT 1991) and has no population policy (TFAP-Technical annexes vol. II 1989).

Population structure in the tropical countries is dominated by young people (*ibid*). The young age structure implies that population growth in most developing countries, including Tanzania, has a built-in momentum that will prevent stabilization of population until well into the next century. The growing population calls for needed gains in agricultural production and these gains could be achieved through improved irrigation, crop breeding and technical inputs. Besides creating food problems, population growth is a source of other socio-economic problems such as unemployment, deforestation, land degradation, poverty, degradation of the environment and improper land use practises such as extensive cultivation, particularly shifting cultivation, coupled with overgrazing, in the quest to satisfy food demand (Biswas *et al.* 1987).

6.4.5.6 Overall impact of government failures

The converging effect of government failure was that, over time, people could not improve their living standards. They continued to live at the subsistence level based on peasantry economy because the government could not deliver the expected goods and services (Tibaijuka 1990). Such low economic situation provided an impetus for the overexploitation of land-based natural resources (Gibbon, Havnevik and Hermele 1991).

7.0 CONCLUSIONS

Based on the discussion presented in this paper the following main conclusions can be gleaned:

(a) Land use problems in Tanzania are considerable and need to be redressed in order to improve the use of natural resources.

(b) Land use planning process is an important aspect to the extent that it can promote sustainable use of land-based resources.

(c) The economy of Tanzania is heavily dependent on land-based resources. Thus proper management of these resources is important in order to increase their contribution to the economic development of the country.

(d) Sectoral policies are not adequate enough to accommodate the ever changing soci-economic environment. Therefore, it is important to review the existing sectoral policies and explore the possibilities of developing comprehensive multisectoral policy that can integrate and mitigate the needs and conflicts of various interest groups.

(e) Land use problems in Tanzania are caused by several factors either directly or indirectly. Therefore efforts to redress the issue of land use problems must take into account these causative factors. In light of the vastness of Tanzania's land area and limited resources, case- and more site-specific studies can be relevant and a baseline in land use planning.

(f) The exposure presented in this report may not be an end by itself. However, it can serve as a point of departure for more intensive studies which can be integrated into the national land use planning framework.

Therefore the present study proposed to confine research efforts in one area, the West Usambara mountains. A review of land use in the area is presented in report 2 of this study (Kaoneka 1993b).

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LAND USE IN THE WEST USAMBARA MOUNTAINS: ANALYSIS OF ECOLOGICAL AND SOCIO-ECONOMIC ASPECTS WITH SPECIAL REFERENCE TO FORESTRY

Report Number 2

SUMMARY

Land use problems in the Usambaras have been viewed with great concern because they threaten the existence of the remaining tropical rain forests which have high ecological and socio-economic value. This paper attempts to analyze the relationship between the ecological and socio-economic aspects related to land use in the Usambaras. The more specific objectives are: examine ecological and socio-economic aspects in relation to land use problems, account the historical background which has a bearing on land use problems, examine and discuss factors which cause land use problems and identify research aspects which should be given high priority in the Usambaras.

As a starting point the paper presents a description of ecological and socio-economic aspects characterizing the Usambaras. The description covers aspects related to location, soils, geology, climate, biodiversity, population, agroecological zones and major land uses. These aspects are considered to be relevant basic data for subsequent analysis.

The paper also reviews the historical perspectives of land use in the Usambaras. The perspectives reviewed are the pre-colonial period, the colonial period *viz* under German rule and British rule, and post independence era. It is envisaged that these historical perspectives have had an influence on land use trends in the Usambaras. The paper elucidates the contradictions in each historical period or era and the implications to land use at present.

The major land uses in the Usambaras are examined. These include, agriculture, pastoralism, forestry and others which include human settlements. The general development and present status of agriculture and forestry, which constitute the main land uses, is presented in more detail. These two sectors are seen to contribute substantially to the existing land use conflicts in the Usambaras.

The paper discusses the existing land use problems in the Usambaras. The main land use problems discussed are fast population growth which have led to increased derived demand of land for agriculture, human settlements and expanded cash crop production; extensive uncontrolled mechanized logging and pitsawing. Additional factors are poverty, inefficient farming practises and the effect of macro-policy issues *viz* structural adjustment programmes (SAPs) and overall weakness in government fiscal policies. These factors have a bearing on land use problems either direct or indirect. A further analysis of the land use problems is carried out using the general framework of peasant household economic theory.

Finally the paper presents a review of SECAP approach which is a major attempt, in the recent times, to redress and improve land use practises in the West Usambaras. Also a set of proposals based on an evaluation of SECAP approach is outlined.

Generally, the seriousness of land use problems in the West Usambaras and the need for efforts to redress the situation is appreciated. It is, therefore, recommended that detailed case studies could form a baseline for developing a comprehensive, embracing and more acceptable land use plan for the West Usambaras. It is envisaged that such an effort will enhance and promote sustainable use of land-based resources in the Usambaras.

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LIST OF ABBREVIATIONS

TAS	=	Tanzanian shilling
URT	=	United Republic of Tanzania
MALD	=	Ministry of Agriculture and Livestock Development
MDB	=	Marketing Development Bureau
IUCN	=	International Union for Conservation of Nature
FINNIDA	=	Finnish International Development Agency
SECAP	=	Soil Erosion Control and Agroforestry Project
TIRDEP	=	Tanga Integrated Rural Development Project
GTZ	=	Germany Assistance for International Development
SUA	=	Sokoine University of Agriculture
CRDB	=	Cooperative Rural Development Bank
AUN	=	Agricultural University of Norway
TAF	=	Tanzania Association of Foresters
LEGICO	=	Legislative Council (of Tanganyika Territory)
TFAP	=	Tanzania Forestry Action Plan
ERP	=	Economic Recovery Programme
SAREC	=	Swedish Agency for Research Cooperation with developing countries
TRDP	=	Tanga Regional Development Plan

SI UNITS

mm	=	millimetre
cm	=	centimetre
m	=	metre
km	=	kilometre
ha	=	hectare
ppm	=	parts per million
me	=	milligram-equivalent
g	=	gramme

UNIT CONVERSIONS

1 cm	=	10 mm
100 cm	=	1 m
1000 m	=	1 km
$10000 m^2$	=	1 ha
1000 ha	=	$1 km^2$
1 ha	=	2.471 acres

1.0 INTRODUCTION

Tanzania is a country lying just South of the Equator on the East coast of East Africa. It occupies a total of 939, 700 km^2. About 68% of the country is covered by different types of forests and woodland, whereupon some 18,000 km^2 have been reserved as watershed and catchment forests (Mbwana 1990; Mascarehnas 1991; Sharma 1992).

Tanzania has a population of 23,174,336 people, with an average annual growth rate of 2.8% (URT 1991). The population density is 25.5 persons/km^2 which is lower than the world average of 36 persons/km^2 (*ibid*). About 80% of the total population live in rural areas and the remaining 20% live in urban areas.

The mainstay of the Tanzania's economy is agriculture. The agricultural sector contributes about 52% of the total Gross Domestic Product (GDP) and over 85% of the total exports hence a major source of government revenues. Also agriculture provides employment to about 90% of the country's labour force (ERP 1988). The main producers of the agricultural crops are the small holders or peasants. About 85% of the cultivated land is tilled by using hand hoes, 10% by ox-drawn ploughs and 5% by tractors (MALD 1989). These statistics show that large part of agriculture is carried out using inefficient means of production. The very fact that causes land degradation.

Tanzania is a relatively dry country, where only a little over 1% of the country receives sufficient and reliable rainfall to support high closed forests (FINNIDA 1988; Iversen 1989). The same reports show that some 8% of the mountain rain forests in Tanzania are growing in the Usambara mountains. Such a proportion is fairly high relative to the vastness of Tanzania's land cover. These mountain rain forests, besides production of commercial timber, have a special role as water catchment reserves, in soil erosion control and provision of biological diversity. A concern has been raised to the effect that the destruction of these mountain rain forests is an irreversible process and that rain forests are "mines" because of the relative difficulty in regenerating them (Bjørndallen 1992). The fact that mountain rain forests are difficult to regenerate amplifies the need to wisely exploit and conserve them for the benefit of the present and future generations.

Peasants have a high dependence on natural forests as a source of fuelwood, poles, wild fruits and medicinal plants. Over time, however, there has been a tendency towards the over-exploitation of the natural forests. Such a situation has occurred on the mountain forests of the West Usambaras. Hence the natural forests are no longer sustainable.

Despite the many benefits accruing from mountain rain forests, a dismal trend has been observed in the Usambara mountains, and indeed in most parts of Tanzania. Large parts of the naturally occurring high, closed rain forests have been destroyed to pave way for settlement and agriculture (Hofstad 1990, pers. comm.; Bjørndalen 1992). Reversal of such a trend is necessary if the mountain rain forests are to be saved from total extinction.

The resource and land use problems in the Usambara mountains is a socio-economic issue that is both complex and long-term oriented. Therefore for any remedial measure to take a noticeable effect there has to be case specific studies and research on socio-economic situation of the problem areas. At present there are only few, if any, studies which have attempted to analyse the problem in the Usambaras from enviromental/ecological and socio-economic points of view. It seems appropriate therefore to present this paper with the intent of contributing to a better understanding of the land use problems in the West Usambara mountains. Such understanding can be the basis for developing strategies to improve the utilization of land-based resources. The more specific objectives of this paper are to::

(a) examine ecological and socio-economic aspects in relation to land use problems in the West Usambaras;

(b) account the historical background which has a bearing on land use problems in the West Usambaras;

(c) examine and discuss factors which cause land use problems the West Usambaras;

(d) identify research aspects which should be given high priority in the West Usambaras.

This study is based on both secondary and primary sources, *viz*, own field data.

2. ECOLOGICAL AND SOCIO-ECONOMIC DESCRIPTION OF THE WEST USAMBARA MOUNTAINS[1]

2.1 Location

The Usambaras covering about 2,000-3,000 km^2 in Tanga region, North-East of Tanzania, form a part of the geologically ancient crystalline gneiss complex of East Africa (SAREC 1987). They are part of montane forests of the Eastern Arc Mountains in NE Tanzania which are relics of earlier, widespread moist forests of East Africa (Map 1). Tectonic movement and the drying of the climate separated them approximately 80-100 million years ago from the main rain forest area of Congo and Zaire (Hamilton and Bensted-Smith 1989).

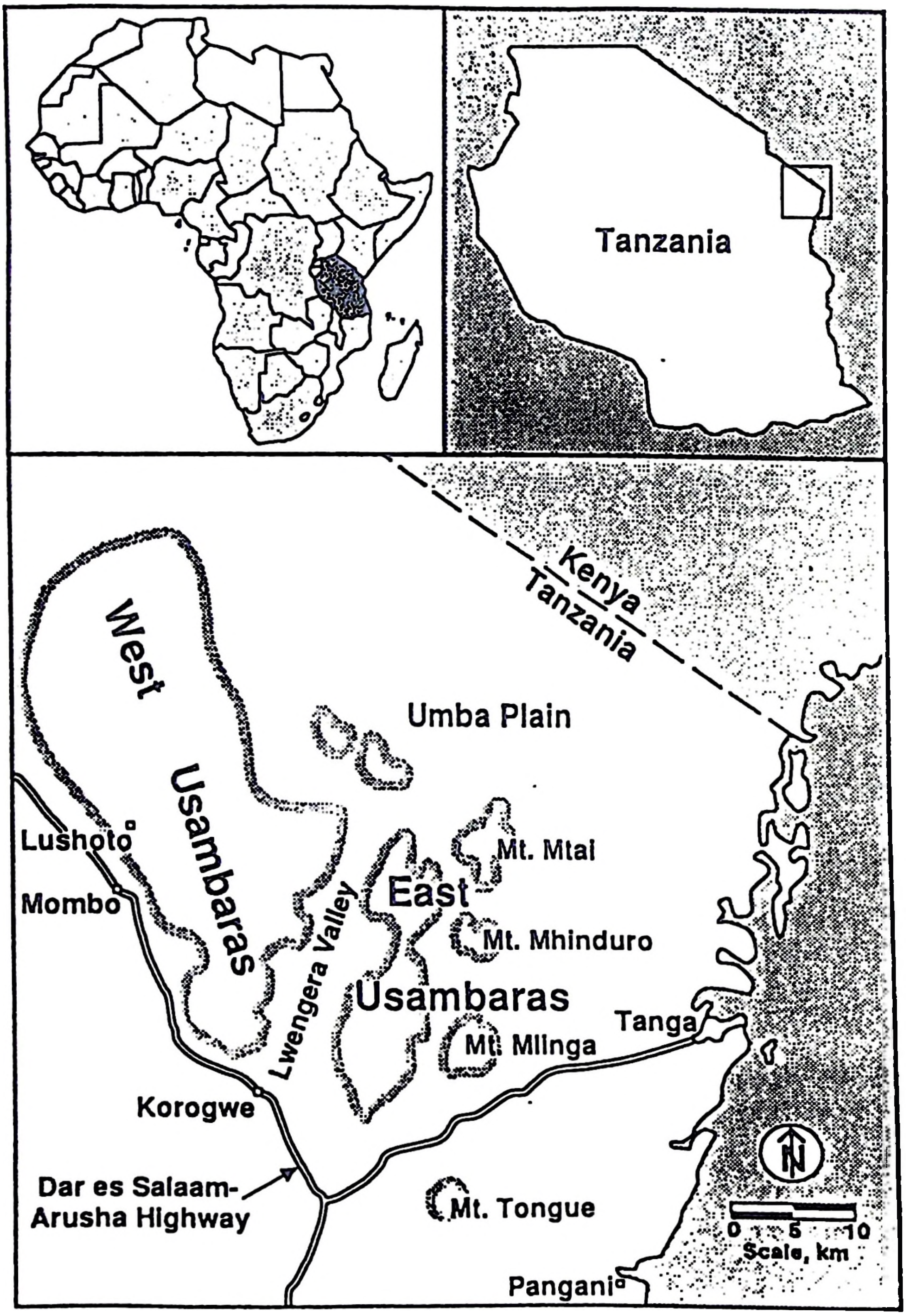
The Usambaras contain a great amount of unique fauna and flora species which are endemic and not found elsewhere in the world (FINNIDA 1988). Fluctuations in climate during the Ice-Ages, about 100 million years ago (Griffiths 1990), were probably never sufficiently pronounced to cause very extensive contacts between the higher altitude plants and animals of the Eastern Arc Mountains, each of which is to some extent biologically distinctive (*ibid*).

2.2 Soil

The soils in the Usambaras are predominantly acidic, with a pH range of 3.5-5.5, and poor in nutrients. Characteristically soil variation parallels forest variation, with two main types, corresponding approximately to the original occurrences of lowland and montane forests. The soils are clay or clay loams, red or otherwise brightly coloured, usually deep, very freely draining and have their nutrients concentrated in the top soil which is no more than 30 cm deep (IUCN 1987). They are exceptionally well leached and are very impoverished in nutrients below the upper organic-rich stratum. They have low cation exchange capacity (c.e.c) (Table 2.1). Therefore, the basic nutrient elements calcium, potassium and magnesium are not readily available. Nutrient circulation under undisturbed natural forests is clearly very tight and hence streams originating from such forests are not polluted. Since these soils have inherently very low cation exchange capacities, unless a high content of organic matter is retained in the top soil, cannot be efficiently enriched through the application of artificial fertilizers (Ndakidemi, pers. comm.)

The high altitude soils are practically unsuitable for long-term agriculture, except for crops which actually prefer acidic soils such as tea. At the same time, it is on these soil types that extensive peasantry farming takes place year after year. The lowland soils are richer in cations and much less acidic with a pH range of 6.0-7.0 (*ibid*).

Note: [1] The word "Usambaras" will be used in this paper to mean West Usambara Mountains.



Map 1 Geographical location of the Usambara Mountains

Table 2.1 Soil cation exchange capacity for selected villages in the Usambaras, Lushoto District.

Village	Cation exchange capacity (me/100gm)						Avail P (ppm)
	Ca^+	Mg^+	K^+	Na^+	H^+	c.e.c.	
Magamba	3.19	0.50	0.11	0.23	0.40	4.9	4.20
Lukozi	15.57	2.70	0.50	0.30	0.20	19.3	5.94
Viti	5.19	1.07	0.36	0.16	0.25	7.0	4.55
Manolo	16.77	3.00	0.20	0.23	0.19	20.4	3.16
Kwemakame	3.59	1.20	0.19	0.30	0.20	5.4	4.20
Mkuzi	4.79	1.20	0.21	0.24	0.25	6.7	4.2
Migambo	7.58	2.40	0.12	0.25	0.20	10.6	7.70
Kwai	7.98	2.13	0.31	0.26	0.20	10.9	4.20
Milungui	7.58	2.00	0.36	0.26	0.25	10.5	4.20

Source: Own field data

2.3 Geology and climate

Geologically and climatically the basement blocks of the Usambaras are believed to have been comparatively stable for more than 20 million years (Iversen 1989). The altitude of the area varies between 1650 and 1750 m above sea level, the steepest slopes with tree vegetation being 55%. The main mineral found on the Usambaras is mica which is yet to be exploited.

The Usambaras receive bimodal pattern of rainfall. The long rains fall between March and May whereas the short rains fall between October and December. The annual rainfall averages a little over 1000 mm per year. The months of June to early September is the coldest period of the year with temperature in the region of 15 to 20 °C. The atmosphere at this time of the year is mainly misty with occasional rainfall. The average annual temperature of the area is 25 °C (see also Table 2.2).

Table 2.2 Average climatic data in the Usambaras for the period 1931-1988.

	Average Rainfall		Temperature °C			Relative humidity %	
	Amount (mm)	Rain days	Max	Min	Range	0600GMT	1200GMT
	1753	183					
SD	40	22	24.9	16.3	8.6	8.7	75

Note: SD = standard deviation
Source: G.M.S. (1992).

In some areas of the Usambaras temperatures vary considerably within short distances. Generally Usambara mountains are not a windy area. Winds are virtually cool to moderate all the year round. Therefore the wind drying effect is relatively small.

2.4 Biodiversity

2.4.1 Vegetative diversity

The pioneer vegetation of the Usambara mountains belongs to the camphor-podo mountainous rain forest. About 25% of the area is completely covered by forest. The forest vegetation is composed of a diversity of species of both economic and ecological value (table 2.3). Despite it being relatively unbroken and stable for millions of years, the Usambara mountains have experienced severe disruption during the past 50 years. Some 60% of the West Usambara rain forests have been destroyed since 1956 (Kalaghe *et al.* 1988). About 90% of the remaining forest patches are today gazetted as forest reserves under the control of the Central Government or District Council. A few (approx. 5%) are privately owned and about 5% of the forest is still left on the public land without any legal protection (FINNIDA 1986; Iversen 1989).

The Usambaras have high species diversity (see Table 2.3) compared to other Eastern Arc Mountain forests. More than 100 years of research have shown the Usambaras to represent an outstanding but fragile ecosystem (Fleuret and Fleuret 1978; SAREC 1987; Iversen 1989 and 1991) which need to be conserved and wisely exploited for the benefit of the present and future generations (TFAP 1989). There is quite a wide range of functions which the vegetation provides to the inhabitants of the Usambaras such as water catchment, gene pool conservation, soil rehabilitation, amelioration of local climate, a variety of wood-based products and medicinal plants. Also the area has several endemic tree species that are commercially important including *Allanblackia stuhlmanii, Beilschmedia kweo, Cephalosphaera usambarensis and Isoberlinia scheffleri.*

Table 2.3 Summary of tree species diversity on the Usambaras, Lushoto District, by end uses

End-use	Number of Species
Timber and plywood	40
Poles	33
Long burning fuel	30
Wild fruits	15
Dyes	21
Medicine[(1)]	63
Total	202

Source: TFAP (1989)

[(1)] Rather conservative figure i.e. an underestimation (see Fleuret and Fleuret 1978; Fleuret 1980). There are as many as 150 medicinal tree spp.

The wild species of coffee that occurs in the Usambaras is a genetic resource of great importance to the development of the country. About 40% of the world's wild species of coffee occur in Tanzania, of which approximately 25% are endemic to the Usambaras (Lovett 1985). These endemic species are of great importance in future coffee breeding programmes. It is because of these multiple functions that the sustainable use of the Usambaras is desirable.

2.4.2 Classification of vegetation on the basis of elevation

The natural vegetation can be classified according to the elevation as follows:

2.4.2.1 Lowland evergreen forest < 750 m a.s.l. (above sea level)

The dominant species are *Afzelia quanzensis, Anisophyllea obtusifolia, Anthocleista grandifolia, Antiaris toxicaria, Milicia excelsa, Scarodophlocus fischeri.*

2.4.2.2 Intermediate forest 750-1400 m a.s.l.

The dominant species are *Isoberlinia scheffleri, Macaranga usambarensis, Myrianthus arboreus, Newtonia buchananii and Parinari excelsa.*

2.4.2.3 Highland evergreen forest > 1500 m a.s.l.

The dominant species are *Albizzia spp., Cassipaurea spp., Chrysophyllum spp., Entandrophragma spp., Ficalhoa laurifolia, Macaranga kilimandisharica, Ocotea usambarensis, Olea spp., Parinari excelsa, Podocarpus spp., Pygeum africanum and Syzygium guinense.*

The dry montane forest is dominated, largely, by *Juniperus procera*. Generally, *Ocotes*, *Ficalhoa*, *Podocarpus* and *Syzygium* occur on hillsides, making them particularly important for catchment and erosion control functions. *Chrysophyllum*, *Newtonia*, *Parinari* and *Albizzia* commonly occur in valleys and alongside rivers hence important for protecting water courses.

2.4.3 Vegetative diversity on the basis of end uses

The vegetative diversity can also be seen in the context of end uses namely medicinal, fuelwood, building poles and timber trees as shown in Tables 2.4(a), 2.4(b), 2.4(c) and 2.4(d). The rather high diversity of tree species has made the Usambaras of immediate importance as a catchment area to assure adequate and consistent supply of water for the industrially expanding port city of Tanga and its immediate environs.

Table 2.4(a). Medicinal trees and plants in the Usambaras, Lushoto District

Species name	Local name (Kishambaa)
Piper umbellatum L.	*Ugufa, Gugufa*
Berberis holstii Engl.	*Kilasho*
Cassia abbreriata Oliv.	*Msangazi*
Myrica salicifolia Hochst. ex. A.Rich.	*Mshegheshe*
Clutia abyssinia Jamb. Spach.	*Mhende*
Ensete edule Horan.	*Tambwe*
Chrysanthemoides morilifera	*Kabugha*
Culcasia scadens P.beauv.	*Kiandama*
Landolphia buchananii	*Ugototo*

Source: Own field data and identification by Silviculture Station, Lushoto.

Table 2.4(b). Fuelwood and firewood tree species in the Usambaras, Lushoto District

Species name	Local name (Kishambaa)
Deinbollia adusta Radlk	*Mkunguma*
Aphloia theaeformis Benth	*Mdananda*
Macaranga kilimandscharica	*Mkumba*
Macaranga conglomerata Brenan	*Mkumba*
Macaranga capensis Sim.	*Mkumba*
Teclea amaniensis Engl.	*Nkwati*
Heinsenia diervilleoides	*Mkunguma*

Source: (*ibid*)

Table 2.4(c). Building poles and timber in the Usambaras, Lushoto District

Species name	Local name (Kishambaa)
Ocotea usambarensis	*Mkulo*
Newtonia buchananii	*Mnyasa*
Podocarpus usambarensis	*Podo*
Ficalhoa laurifolia	*Mkuka*

Source: (*ibid*)

Table 2.4(d). Timber trees (pitsawn on public land)

Species name	Local name (Kishambaa)
Milicia excelsa	*Mvule*
Pterocarpus holtzii	*Mkula or Mkurungu*
Pterocarpus usambarensis	*Mkula or Mkurungu*

Source: (*ibid*)

2.4.4 Faunal diversity

The Usambaras consist of a diverse variety of faunal species. The species include soil mites, caddy flies, fungus gnats, wasps, butterflies, spiders, millipeds and carnival snails (Bjorndalen 1992). Endemic mammals are less abundant, but there are numerous endemic taxa of frogs, tree-frogs, toads, geckoes, chameleons, lizards and snakes (*ibid*).

2.4.5 Impact of deforestation

2.4.5.1 General decline in forest cover

The catchment function is, however, threatened by the rather rapid decline of forest cover (Table 2.5; also Msangi, pers. comm.). The figures in Table 2.5 show a decline of 43% in 27 years (i.e. 1965 - 1991), a rather too high rate of deforestation. The decline in the forest cover has caused a decrease of water retention capacity of the soil, decline in timber production, drying up of water sources in catchment areas and the disappearance of some valuable tree and plant species hence a general degradation of both biodiversity and soil. A typical case showing the adverse effect of deforestation is the drying up of water sources in Kwaboli area (Lubango pers. comm. 1992).

Table 2.5. Trends of decline of forests in the Usambaras

Year	Area, ha
1965	53,000
1981	48,000
1991	30,000

Source: Division of Forestry and Beekeeping, Catchment Section (1992).

The main causes of deforestation are clearing of natural forest for agriculture, charcoal burning, fuelwood, overgrazing and illegal pitsawing (Massawe and Kajiru 1991).

2.5.5.2 Land use/cover change in the Usambaras

This case analysis was carried out to illustrate the extent of decline in natural forest reserve as a result of conversion to other uses. The analysis was based on aerial photographs for a period of 20 years from 1957 to 1976 covering Shume village one of the areas in the Usambaras which in the past was virtually covered by natural forest reserves. The results of the analysis are presented in Tables 2.6 and 2.7. It can be inferred from Table 2.6 that natural forest reserves declined at a fairly high rate of 75% in 20 years. The area under plantation increased by 190% over the same period. This indicates that there has been some efforts to reafforest the clearcut areas. In fact in the early 1960's the British administration initiated a forest project intended to reafforest the degraded lands which were initially under natural forest reserves. This project is nowadays called Shume-Magamba Forest Project.

Table 2.6 Land use/cover change in the Shume area (1957-1976)

Land use	Estimated area, ha		% Change
	1957	1976	
Natural forest	16.7	4.2	-74.8
Forest plantation	3.0	8.8	+193.3
Farmlands and village settlements	0.4	7.0	+1650.0
Bare lands	0.1	0.2	+100.0

Source: Own field data

The area under farmlands and village settlements increased dramatically by 1650% over the 20-year period. These results indicate that the main cause of deforestation was the expansion of farmlands and settlements as the population increased (c.f. section 2.6). This observation supports the widely held view that population growth is the main agent of deforestation.

Table 2.7 Conversion of natural forest to other land uses (1957-1976)

Land use	Area, ha	% of natural forest conversion
Forest plantation	5.6	33.5
Farmlands and village settlements	3.4	20.4
Agriculture land	3.3	19.7

Source: Own field data

2.6 Population

The Usambaras have a population of about 400,000 people which grows at a rate of 3.2-4.0% annually, much higher than the national average of 2.8% (URT 1991). The population density stands at 200 to 400 persons per km^2. The predominant tribe is the Shambaa, 78%, whereas the Pare, 14% and Mbugu, 8% are the minority. The Shambaa are largely farmers, the Pare are agropastoralists and the Mbugu are pastoralits.

2.7 Agro-ecological zones of the Usambaras

The Usambaras are divided into four agro-ecological zones (SECAP 1991). These are outlined in the following sections.

2.7.1 Soni/Lushoto zone

This zone is warm and humid. Rainfall ranges from 800-1700 mm per annum. The altitude is 1000-1300m above sea level. Crops grown in this zone are potatoes, beans, maize, coffee, tea, cardamon and a variety of vegetables.

2.7.2 Shume zone

The zone is cold and dry. Rainfall ranges from 500-800 mm with a dry period of four months. The altitude is 1700-2100 m above sea level. Crops grown in this zone are maize, beans, cassava, potatoes, coffee, vegetables mainly cabbages and tomatoes and fruits such as peaches, plums and pears.

2.7.3 Mlola zone

The zone is warm and dry. Rainfall ranges between 500-750 mm. The elevation is 500-1000 m above sea level. Crops grown in this zone are pineapples, maize, beans, mangoes, cardamon, tea, a limited amount of coffee and sweet potatoes. The crop varieties grown in this area are limited due to prolonged periods of drought every year.

2.7.4 Mlalo zone

The zone is warm and dry/semi humid. Rainfall ranges from 500-800mm with four months dry period. The altitude is 1200-1800 m above sea level. Crops grown in this zone are maize, paddy, mangoes, sweet potatoes, coffee, cassava and small amounts of wheat.

2.7.5 Concluding remarks

The agro-ecological zones determine, to a great extent the type of crops to be grown as well as the nature of traditional customs in terms of staple food and cultural rituals. The zonation pattern is also used for agriculture planning. In terms of livestock, there are no reliable estimates available but it is understood that people keep goats, sheep, dairy cattle and an assortment of birds including ducks, guinea fowl and poultry. Piggery is a rare activity although it is not completely absent (Mngulwi pers. comm. 1992).

3.0 HISTORICAL PERSPECTIVES OF LAND USE IN THE USAMBARAS

The material used to write this chapter were obtained from various sources. Besides the cited references, other sources include tales from elders and personal experiences of the study area.

3.1 Pre-colonial period

"Man has been living on the Usambaras for at least 2000 years. It is surprising that extensive forest still existed at the end of the 19th century, the time of the earliest written accounts. Probably, virtually all forests on the mountains have been influenced by man to some extent" (Hamilton 1989). This statement underscores the importance of tracing and understanding the historical social organization of the Shambaa tribe which in one way or the other has influenced resource utilization on the Usambaras. This section examines some of the historical trends which led to the continued long existence of the forests on the Usambaras.

The presence of Early Iron Age settlements in both West and East Usambaras[(2)] as early as about 2000 years, indicates that the natural forests were to some extent disturbed by human activities (Hamilton 1989). It is presumed that some forests were destroyed in order to increase farmlands as the population grew and obtain fuelwood for domestic use and iron smelting.

Unfortunately the extent of the Early Iron Age forest utilization is not known (or it is yet to be documented). However, recent studies in the East Usambaras showed that during soil excavations, scientists found remains of charcoal and pottery (Hamilton and Bensted 1989). This revelation indicates that the forests were exploited by way of making charcoal, drying and seasoning of pots.

The early inhabitants of the Usambaras belonged to the Shambaa tribe (Feierman 1974). The Shambaa tribe is still predominant on the Usambaras, with the Pare and Mbugu tribes as the minority. Some historians contend that, even during those early times, the Washambaa were "organized under a loose political system dominated by iron smiths in order to enhance the continuity of iron-smelting business" (Kimambo and Temu 1969). However, at a later time the Wapare from north-west part of the West Usambaras dominated the iron production and working (Feierman 1974).

The Kilindi family from Nguu Mountains in Handeni District migrated to the Usambaras in the 18th century, mainly to escape the notorious raids of the Wakwavi (a clan of the Maasai tribe). The Kilindi family under King Kimweri, who succeeded his father Kinyashi, formed a "centralized political power base" (Hamilton 1989). The capital of the Shambaa Kingdom was Vugha located in the southern parts of the Usambaras called Soni. The Kimweri dynasty lasted well into the latter part of the 20th century.

The emergence of a powerful Kingdom enhanced the customary land tenure system and

Note: [(2)] The demarcation of West and East Usambaras was done so arbitrarily that the distinction is rather diffuse.

regulated the use of forests. For instance King Kimweri declared some of the forests as "traditional forest reserves" to be used for ritual and cultural ceremonies (Feierman 1974). In fact even to-date there are patches of the natural forests that have not been exploited because the people consider them sacred places. A myth abounds that those areas were used by the rain-makers. This is one of the reasons why some of the forests in the Usambaras survived for fairly long time.

Another plausible reason is the pattern of settlement. The Washambaa preferred to settle on the western rim of the escarpment facing their main base on the Usambaras (Feierman 1974). Despite, the settlements being mainly situated on steep-sloping land escarpment, soil erosion was minimal due to banana gardens, whose dry leaves formed a porous litter that prevented rapid water run-off. This view is shared by Scheinman and Mchome (1986) who observed that "farming systems on the Usambaras were in a state of ecological equilibrium with the environment: agriculture was practised in such a way as not to endanger the long term viability of the community". These arguments show that the Washambaa people were not ignorant of the merits of keeping a sound environment. That is, "the Washambaa had, and still to a degree, have a vast store of knowledge about their biological world and the survival of forests could be due partly to an appreciation of the limitation of the land" (Feierman 1974). Such understanding possibly reduced the quest for over-exploiting the forests.

The final reason could be attributed to some external factors. For instance, the slave trade which entered the Usambaras during the 19th century (Kimambo and Temu 1969) resulted into "massive local depopulation" (Feierman 1974).

3.2 Colonial period

3.2.1 Under German rule

"The Germans expropriated most of the land on the Usambaras as estates planting coffee at higher altitudes. The coffee soon failed, due to failure to appreciate the severe limitations of the strongly leached soils at higher altitudes" (Hamilton and Mwasha 1989). The era of the German rule is dated back to 1891 when the Germans took over the administration of German East Africa from the infamous Karl Peters. It lasted until 1919 after the 1st World War. A treaty signed by Karl Peters and Chief Kibanga of the now East Usambara changed significantly the pattern of land tenure system (Farler 1879; Feierman 1974). Under the treaty the Germans were given legal ownership of almost all the land of the Usambaras for an undefined period of tenure (Hamilton and Mwasha 1989). Later on the Germans established the headquarters of the German East Africa at *Wilhemstal* (now called Lushoto). Most German settlers then settled in various parts of the Usambaras notably the Mkuzi area (see also Schabel 1990).

The coming of the Germans coupled with an upsurge in slave trade led to the disruption of the Shambaa Kingdom causing a series of warfare and social upheavals in subsequent years (Hamilton and Mwasha 1989). Also the German administration changed both the pattern of agriculture and types of crops grown on the Usambaras.

The government of the German East Africa engaged mainly in the production of cash crops. Therefore large portion of the land in the Usambaras was split into parcels which were allocated to the German settlers. However the Germans also were interested in forest conservation. Forest reserves were surveyed and demarcated with the forest rules enforced with "vigour and some brutality" (Grant 1924; Schabel 1990). The tale of the Shambaa elders attest to the excessive use of force by the Germans earning them a nickname of "Bwana Kiboko" (a swahili phrase for "whip man").

The major crops tried on the Usambaras were arabica coffee, sisal and rubber on the south-west side close to Mombo. Of the three crops only sisal estates faired well (Hamilton and Mwasha 1989). Other "exotic" trees and crops introduced on the Usambaras were tea, cinnamon, cardamon, cinchona, camphor and robusta coffee. All these are still grown widely on the Usambaras.

A point of controversy surrounds the extent of logging on the Usambaras by the Germans. Despite the controversy, there were harvesting and export of *Ocotea usambarensis* and *Beischmeidia kweo* to Germany by a company called Sigi Export Gesellschaft (Hamilton and Mwasha 1989; Schabel 1990).

During the German era some problems in relation to fuelwood shortage begun to emerge in the Usambaras (*ibid*). It is a bit hard to attest to this observation because as late as the 1960s fuelwood was still plentiful in the Usambaras (pers. exp.) and the natural forest was having a closed canopy, although some exploitation, mainly pitsawing, was going on in the area.

The German rulers passed various rules in an attempt to regulate burning , grazing, cutting and other practises deemed destructive to the forests. The rules were vigorously enforced coupled with severe penalties for the violators (Schabel 1990). It was also during the German rule that the first Usambara Forest Ordinance was passed in 1895 with the view of conserving the Usambaras (*ibid*).

Schabel (1990) sums up the German era by observing that, "The tenure of the Germany rule was simply too short to have left a lasting forestry legacy for British Tanganyika and independent Tanzania".

3.2.2 Under British rule

The British arrived in the Usambaras during the 1st World War in 1916. However, it was until the end of the First World War in 1919 that the British actually ruled Tanganyika territory (mainland Tanzania) under the protectorate agreement with the United Nations Organization (UNO). The agreement allowed the British to rule Tanganyika Territory by way of preparing it for self-rule. The very fact that gave the British rulers little incentive for long-term investment in the country. The British forced out the German settlers and deported them to camps in Rhodesia (now Zimbabwe) and South Africa (Hamilton and Mwasha 1989).

Initially the British rulers continued with the land ownership system designed by the Germans. Under this land tenure arrangement estate companies were granted renewed ownership of land and the forest reserves remained intact. The decision to retain the German land tenure system was a mistake because "it was a lost opportunity to revise the legal basis for managing the land" (*ibid*). In 1925 the German settlers were given an "amnesty" to return to Tanganyika, but only about half of the deported ones returned.

The British rulers formed a Forest Department in Tanganyika in 1921 with the aim of boosting up timber production but was less successful (*ibid*). The second mistake that was done by the British rulers was to grant one sawmill a 100-year concession to exploit 27,900 ha (about 69,000 acres) of the Shume-Magamba Forest Reserve on the Usambaras in 1924 (Forest Department 1935). The concession caused a considerable destruction to the natural forest reserves (Troup 1936).

Under the British rule, some of the old German estates were converted to forest reserves, mainly because of the concern for environmental degradation following the forest clearance if the estates remained in private hands (Hamilton and Mwasha 1989). As early as 1932, the British rulers began to become increasingly concerned about the problem of soil erosion in Tanganyika, and in particular the mountainous areas which include the Usambaras (*ibid*). Due to this awareness, in the early 1950s, a large scale erosion control scheme was established "for the heavily populated West Usambaras" (*ibid*).

Initially the soil conservation measures were used by a modest majority of the local inhabitants of the Usambaras. Later on, however, in the late 1950s the measures begun to be unpopular (Attems 1968) and they were not entirely well received by the local people (Kimambo and Temu 1969). Furthermore, some politicians used the campaign platform to attack the soil conservation measures as being "alien impositions on the people's fundamental rights" (Hamilton and Mwasha 1989). Therefore just after independence the government of newly independent Tanganyika abolished the regulations to conserve soil only to raise the concern on soil erosion again in the mid 1970s (Forest Division 1975; TRDP 1975) and later on amplified by the Tanzania Forestry Action Plan (TFAP 1989) after considerable damage has been inflicted.

The British rulers, also, emphasized the need to conserve natural forests for the purpose of ameliorating local climates, soil conservation and rehabilitation, and enhance water supplies (Forest Department 1928; Troup 1936). The sawmilling industry was at a low ebb right after the 2nd World War because the montane high forests were considered to contain tree species of little commercial value! (Eggeling 1951). Subsequently, however, it was discovered that the Usambaras contained commercial tree species as well. Therefore pitsawing begun and peaked up in the late 1950s and early 1960s respectively, particularly with the influx of the Kisii people from Kenya who virtually " invaded the West Usambaras " (Hamilton and Mwasha 1989). The nature of the massive licencing for pitsawing is still a misery!.

The British rulers left behind a very important document in the history of forestry in Tanzania: the Forest Policy of Tanganyika of 1953 (LEGICO 1953).

3.3 Post independence era

3.3.1 Historical trends

Tanganyika (now Mainland Tanzania) became independent in 1961. After independence the attitude and perceptions of the local people changed. On the bargaining table short-term rather than long-term exploitation of the forest reserves was favoured most (Hamilton and Mwasha 1989) partly because the young government of the newly independent Tanganyika could not enforce the forest regulations thoroughly well basically due to lack of adequate personnel

(Hamilton and Bensted-Smith 1989). The demand for farmland received more emphasis at the expense of forest reserves. For instance, there was about 50% of forest reduction at Amani to pave way for agriculture between 1954-1976 (Rodgers and Homewood 1982). A similar trend of forest reduction in favour of expanding farmlands was observed in Usambaras where in 1963 about 13,400 ha of Shume-Magamba Forest Reserve were degazetted and given to small-holders or peasants in response to a popular cry for land (Egger *et al.* 1980; TRDP 1975).

In the early 1960s the parliament passed an act stating that all underdeveloped land, including the uncleared forests on the tea estates belonged to the state (Hamilton and Mwasha 1989). Obviously the uncleared forests in the tea estates were kept for the purpose of ameliorating climatic conditions for the tea to grow well. Individuals that were ignorant of this fact invaded these forest patches and cleared them in a process which was both illegal and undesirable (IUCN 1985). The politicians who encouraged peasants to invade estate land were violating constitutional authority. In fact, at times, some politicians seem to have acted that way to solicit for votes during subsequent parliamentary elections (Hamilton and Mwasha 1989).

According to IUCN (1987) clearing of estates for farms began on a large scale in 1967-8. Such a move worried the estate managers due to the prospects of losing a large portion of tea plantations. In 1968, the estates managers approached the government to express the seriousness of the problem and requested for legal action to be taken. Pursuant to a visit by senior officials, the Ministry of Lands and Natural Resources directed the villages to draw up new boundaries with provision for buffer zone of a forest between farmlands and tea estates. The move was perceived as an administrative convenience rather than a legal action.

Consequently the estate managers pressed the government hard for further action. In response the government assigned a team to survey and mark new boundaries. The move reduced the problem but failed to accomplish thorough eradication. Whilst the legal situation remained vague, however, the new areas of public land received *quasi* official recognition in a map showing village boundaries prepared by Tanga Integrated Rural Development Project (IUCN 1987). The map was apparently developed by asking villagers the position of village boundaries (*ibid*). The very fact that provided for cheating and manouvres.

3.3.2 Factors that caused the emergence of conflicting views on land use

3.3.2.1 The Arusha Declaration

The Arusha Declaration in 1967, a blue-print of Tanzania's "Socialist path", with *inter alia* an emphasis on communal ownership of land under the control of village governments, appeared to have only a marginal effect on the reality of individual land ownership in the Usambara mountains. In fact the people of the Usambaras resisted this policy which was seen as a disruption to the customary land tenure system (Fleuret 1980).

Private parcels of land are acquired through purchasing and inheritance. The latter process is by far the main source of land acquisition. Most peasants are too poor to afford the cost (price) of land. The land acquired through inheritance is considered to be a "private" property or cultural heritage that must be passed on from one generation to the next. Thus any land use policy that contravenes such customary arrangements is rarely acceptable to the

Washambaa people.

3.3.2.2 Emergence of commercial markets

The emergence of commercial markets has weakened to some extent the customary land tenure system. Today it is common for the people to sell their land holdings acquired through inheritance for various reasons such as dowry payments. Poverty makes farmers to invest only modestly on farmlands. The result is that highly productive parcels of land become marginal within short cropping horizons. The progressive farmers most often purchase parcels of land for growing cash crops. In effect, therefore, the traditional mixed cropping system is gradually being phased out.

3.3.2.3 Large families

The Shambaa people are traditionally polygamous. Thus, most households tend to have large families such that the existing land is no longer adequate to sustain crop production. An attempt to distribute the land equally to the children results into the fragmentation of the land into economically useless parcels. Therefore to tackle the land use management issue one has to come to face with socio-economic and cultural factors.

4.0 PRESENT LAND USE IN WEST USAMBARAS

4.1 Land tenure system

The main forms of land tenure system in the Usambaras are public estates, customary land system, individual farms and "Ujamaa" (or collective) farms (Massawe and Kajiru 1991). The main system being the customary land tenure arrangement.

4.2 Types of land use

The major land uses in the West Usambaras are shown in Table 4.1 and they are described in subsequent sections. It is evident from the table that the main land cover of the Usambaras falls under forestry followed by land under agriculture. The land use classified as "others" include residential areas, road network and infrastructure.

Table 4.1. Land uses in the Usambaras, Lushoto District

Type of land use	Area, ha	Proportion (% of total area)
Agriculture	78,450	19.7
Pasture	1,483	0.4
Forests	302,086	75.7
Others	16,899	4.2
Total	398,918	100.0

Source: Massawe and Kajiru (1991).

4.2.1 Agriculture

4.2.1.1 Background

The traditional agriculture of the Washambaa was shifting system. Shifting cultivation is the name given to agricultural systems that involve an alternation between cropping for a few years on selected and cleared plots and a lengthy period when the soil is rested (Ruthenberg 1980). The fallow period, for which the land was allowed to recover, was very much determined by the available land opportunities that permit shifting cultivation. However due to population growth land became gradually scarce. Consequently the Washambaa people abandoned the shifting system and adopted the multistorey agroforestry systems or *authochtonous* system more or less like the one found in Kilimanjaro Region which is described by O'kting'ati and Kessy (1991). Basically the system is intended to ensure continuous food supply rather than satisfying markets through maximum production. Thus the peasants planted crop mixtures that in one way or the other replenished soil fertility, such as maize intercropped with beans. However, during the colonial administration, the white settlers introduced monocropping systems. These demanded clean weeding thereby increasing the potential of soil erosion (Scheinmann 1986; Shenkalwa 1989).

The tree species used in the traditional agroforestry were mainly *Albizzia spp.*. Later on *Grevillea robusta* was added. Today the Shambaa system of agroforestry includes an understorey of coffee (and fruits), food crops such as maize and a variety of pulses, middle storey of *Albizzia spp.* and an overstorey of *Grevillea robusta*. The latter tree species is especially preferred by the peasants because it produces multiple products such as timber, fuelwood and building poles. Furthermore it has minimal shading effect on the crops.

4.2.1.2 Farming system in the Usambaras

The major farming systems in the Usambaras are monocropping especially of cash crops and intercropping of food crops. The cash crops cultivated include tea, coffee, cardamon, fruits, sugarcane and vegetables. The food crops grown are maize, beans, sweet potatoes, irish potatoes, cassava and bananas. The major fruits produced in the Usambaras are plums, apples, pears, avocados, peaches and mangoes.

Tea is typically an "estate" cash crop grown in the Usambaras. (Estate is a name given to large scale farming systems mainly carried out by the state or by progressive farmers). The production of the tea in the 1980's has been considerably less than the factory capacity, about as low as 20% only (FINNIDA 1988). The estates have not been able to pay enough to tea-pluckers and are suffering from labour scarcity. The consequence has been improper maintenance of tea fields resulting into a decline in production.

Cardamon is another major cash crop that is cultivated by the Washambaa peasants. About 80 to 90% of all the cardamon production in Tanzania is estimated to come from the Usambaras (FINNIDA 1988). The official figure averages between 200-800 tons annually for the past decade. The figure is not reliable because considerable amounts are also believed to be smuggled to Kenya (FINNIDA 1986). Cardamon needs shade trees and therefore it is planted inside the forests, legally in public lands and illegally in forest reserves. Cardamon has a production life time of about 9 to 12 years (*ibid*). On average the production varies between 70-200 kg/ha per year depending on the climate and tending operations (Mwaimu pers. comm. 1992). Many shade trees die or fall down during the cultivation period. Twelve years under cardamon production degrades the soil and after the cultivation period, the crop is succeeded by a secondary bush that inhibits the regeneration of forest species (Iversen 1989).

Tea and cardamon are exported to earn the country foreign exchange. Tanzania is one of the world's major cardamon exporters. The other countries are India and Sri Lanka. Other crops that are grown in the Usambaras are sugarcane which is largely used for brewing local beer (or locally known as *pombe*), cloves, bananas, sweet potatoes, maize, cassava, paddy and vegetables. A portion of the crop production is sold and the bulk is used for household consumption.

The traditional farming practises in the Usambaras were charaterized by less productive and inefficient subsistence farms and estates. Most of the estates were established during colonial rule and have not been maintained in a proper way. Also due to increasing population people have been compelled to divide the available land into small parcels. On the other hand, the subsistence farms were less productive and thus less sustainable. The capacity to generate cash income was very low thereby making people poor with low living standards.

Poverty prevented the local populace from improving their farming practises. In effect they were compelled to cultivate in marginal areas which resulted into land degradation. Inefficient methods used in agriculture have had long term effects to the environment (Hamilton and Bensted-Smith 1989). For instance the slash and burn technique is still used to clear farmlands. Sometimes the fire runs out of control and guts nearby forests. Furthermore the fire used in land/farm clearing destroys both microflora and microfauna, organisms that are of considerable biological importance (*ibid*).

4.2.2 Forestry

4.2.2.1 Overview of forests in Lushoto District

The distribution of forests by forest types in Lushoto District is shown in Table 4.2. It can be seen from the table that the main forest type is woodlands i.e. miombo and savannah which occupies about 89% of the total forested area. Also in the Usambaras there are both natural high forest and forest plantations.

Table 4.2. Forest distribution by types in Lushoto District (1991)

Forest type	Area, ha	Proportion (% of total area)
Natural high forests	29,685	9.8
Plantations	4,455	1.5
Woodlands (Miombo and Savannah)	267,946	88.7
Total	302,086	100.0

Source: Massawe and Kajiru (1991)

The ownership or legal status of the forested areas is divided into four categories, forest reserves, forest in public lands, village forests and private forests. The area and proportion of each category is shown in Table 4.3. The proportion of the forest under public land is fairly big. The unfortunate situation is that the forest in public land is less protected by forest laws hence more prone to misuse. Also the data show that the afforestation effort has not succeeded very much. This is indicated by the small cover of village (100 ha) and private (200 ha) forests respectively. The mean annual increment for all forest lands is estimated at 294,000 m^3year^{-1} whereas the total demand for wood-based materials is estimated at 610,000 m^3year^{-1} (Massawe and Kajiru 1991). These figures show that the allowable cut does not satisfy the demand for wood. The implication is that if the demand is to be satisfied there

m^3year^{-1} (Massawe and Kajiru 1991). These figures show that the allowable cut does not satisfy the demand for wood. The implication is that if the demand is to be satisfied there must be an overcut unless management improves production through various management prescriptions. The forest reserves with their respective areas found in the Usambaras are shown in Table 4.4.

Table 4.3. Forest area distribution by legal status in Lushoto District (1991).

Legal status	Area, ha	Proportion, %
Forest reserves	34,140	11.3
Forest in Public lands	267,646	88.7
Village forests	100	N.S. < 0.01
Private forests	200	N.S. < 0.01
Total	302,086	100.0

Note: N.S. = not significant
Source: Massawe and Kajiru (1991).

Table 4.4. Forest reserves in the Usambaras, Lushoto District

Name of reserve	Area, ha
Baga I and II	12,276
Balangai	7,830
Mkussu	3,674
Ndelemai	3,059
Shagayu	987
Shume - Magamba	1,421
Total area	24,247

Source: SECAP (1991)

The mean annual growth in the natural forests is estimated to be 0.7 m^3ha^{-1} in the low land areas and 4.1 m^3ha^{-1} in the more moist mountain areas (Massawe and Kajiru 1991).

4.2.2.2 Harvesting

Forest harvesting from the Usambaras can be divided into three categories namely, local wood use, pitsawing and industrial or mechanized logging. The licenced forest harvesting for various uses in Lushoto District is summarized in Table 4.5. It can be observed from the table that a large amount of wood is harvested for use as firewood. There is no data on non-wood uses of the forests such as medicinal collection.

Table 4.5. Licenced forest production in Lushoto District

Type of use	Unit of measure	Quantity
Sawlogs	m^3ha^{-1}	50.0
Poles	$numberha^{-1}$	100.0
Firewood	m^3ha^{-1}	2,560.0
Charcoal	$bagsha^{-1}$	3,890.0

Source: Tanga Regional Forest Office, Annual Report for 1988/89 (1990)

4.2.2.2.1 Local wood use

Villages need wood for fuelwood and construction. Fuelwood and pole gathering has only marginal effect on the forest reserve in the Usambaras. For fuelwood, only dead wood is collected. Since dead wood is abundant, live trees are rarely felled for fuelwood. Charcoal production in the Usambaras is quite limited. The annual per capita consumption of fuelwood in the Usambaras is estimated at 1.5 m^3 (*ibid*). Pole gathering is prohibited in the forest reserves and where permitted, a fee is levied. The demand for construction and other wood consuming areas is estimated at 0.5 m^3 (*ibid*). Preference of poles from the natural forest reserves is attributed to their natural resistance to biodeterioration and rotting. Despite the otherwise low demand, pole cutting has significant influence on the forest reserves particularly in altering species diversity and inhibiting regeneration because some of the poles are cut at an immature stage before flowering. Therefore there is a possibility that seeding mother-trees of some species are taken away. The resulting effect is a decline in species diversity.

4.2.2.2.2 Pitsawing

Pitsawing is managed by businessmen living in the West Usambaras or surrounding towns. The businessmen organize the finance, transport and marketing. The pitsawyers favour the best species, mainly *Milicia excelsa* (Mvule) and *Khaya nyasica* (Mkangazi) in the lower parts and *Ocotea usambarensis* (Mkulo) and *Newtonia buchananii* (Mnyassa) on the highlands. The average recorded volume sold to pitsawyers from the Usambaras is estimated at about 12,500 m^3 per annum (*ibid*). This figure is low because a lot of timber is taken out through illegal pitsawing which is estimated to be 1,800 m^3yr^{-1} (Massawe and Kajiru 1991).

Many illegalities are associated with pitsawing mostly due to poor or non-existing control. Other factors include non-licenced pitsawing, improper measurement i.e. poor sawing accuracy, smuggling of planks to Kenya and even bribing forest officers. Thus it is difficult to compute an accurate and precise log-volume, which in turn, poses some problems in evaluating reliably the monetary benefits accruing from pitsawing. Pitsawing can be a more environmentally sensitive technique than ordinary sawmilling provided it is controlled. Well controlled pitsawing has minimal adverse effect on soil and catchment properties compared to uncontrolled mechanized logging (Pocs 1988). However, at present thorough control is lacking due to lack of adequate logistical support such as reliable transport means. Most pitsawyers search for the best trees of most important species without due regard for regeneration or water catchment aspects. These problems make pitsawing a wasteful venture which jeopardizes the prospects for sustained use of forests.

4.2.2.2.3 Mechanized logging

The Usambara mountains, in particular the Shume-Magamba Forest Project, has been and is still a dependable source of logs for Tembo Chipboard Ltd, a board factory owned by the Tanzania Wood Industry Corporation (TWICO), located several kilometres from Mombo town along the Dar es Salaam-Arusha highway which uses mainly *pines* and *cypress*. It also serves Grewal Sawmills Ltd and Mavongo Sawmill both privately owned enterprises which are located between Magamba and Gologolo (West Usambara) and Sikh Sawmills Ltd located in Tanga municipality. However, due to transportation problems and the closure of Sikh Sawmills Ltd., the main consumers of timber from Shume-Magamba Forest Project are Tembo Chipboards, Mavongo Sawmill Ltd ans Grewal Sawmills Ltd.

The Shume-Magamba Forest Project has the capacity to cut an average of 50,000 m^3 of round wood per year. It plants between 33 and 100 $hayr^{-1}$ depending on the availability of funds (Magamba Forest Project Management Plan 1991-96/7). A fairly large scale logging operation has been going on in the area for the past decades with external financing and consultancy aid. Large tracts of forest have been cleared in the process. Extensive mechanized or industrial logging has been going on in the Usambaras for several decades. The trend has shown a substantial increase of mechanized logging in recent years (IUCN 1987). The major commercially valuable tree species logged from the natural forest are *Cephalosphaera usambarensis* (Mtambara), *Beilschmedia kweo* (Mfimbo), *Newtonia buchananii* (Mnyasa), *Odyndea zimmermannii* (Mbako), *Milicia excelsa* (Mvule) and *Antiaris toxicaria* (Mkuzu) and from the plantations are *Pinus patula and Cupressus lusitanica*. Recently (1985) logging in the natural forest reserves was banned. It is currently concentrated mainly on the forest plantations. The project also has a large plantation of *Acacia mearnsii* (Black wattle) which is supplied to Girraffe Extract Co. Ltd. for extracting tannin, a chemical used in hide tanning. Thus the main product from wattle is bark and the woody part is mainly used as fuelwood. In spite of the closure, however, a considerable scale of pitsawing, both legal and illegal, is still taking place in the natural forest reserves (Lubango pers. comm. and own observ.).

4.2.2.3 Non-timber uses of forests

4.2.2.3.1 Minor forest products

The forests on the Usambara mountains do not only provide logs for sawntimber and plywood, poles and fuelwood, but also other products which are mainly for local uses. Ropes and twines are made from climbers. They are used in building construction and fencing of crop fields. Wood is collected for carving tool-handles, wooden-spoons, cups, pestles and mortars. At least 15 species supply edible fruits. Fat is extracted from the seeds of *Allanblackia stuhlmannii* (Msambu). Latex from several species is used for making bird-lime and the manufacture of rubber balls and many species are used in the preparation of dyes. At least 63 species of forest plants are known to be collected for medicinal purposes. An example is the quinine tree whose bark is used to extract antimalarial drug.

4.2.2.3.2 Watershed function of catchment forests

The catchment forests are important in order to regulate surface runoff, prevent soil erosion and ensure adequate and consistent supply of clean water for human consumption (Bjørndalen 1992). The capacity of the forest to offer the catchment function depends on, *inter alia*, interception, evapotranspiration, through-fall, stem-flow, infiltration, percolation and surface runoff (*ibid*). These aspects are very much influenced by structural elements of the forest canopy and multistorey layers of the vegetation, amount of litter fall and meteorological factors such as frequency and intensity of rainfall, temperature, moisture regime, wind speed and temporary water storage in the vegetation and soil.

The water catchment function is especially important because the rainfall pattern in most tropical areas, the Usambaras included, is seasonal. Thus catchment forest reserves serve to protect water sources and streams in order to sustain the supply of both adequate and clean water, especially in light of the ever increasing population (Bjørndalen 1992). About 99% of the people leaving on the Usambaras obtain water from natural water sources.

A large part of the Usambaras has steep sloping terrain. Thus, the presence of vegetative cover minimizes soil erosion which would otherwise cause soil degradation and siltation of water streams. Water and soil conservation role is considered to be an option value of the catchment forest reserves. In this regard, the key question is, who pays for the management of these catchment forests. Presently all catchment forests are managed by the government. The funds used are largely donated by international donor agencies including Norwegian Agency for Development Cooperation (NORAD), Swedish International Development Agency (SIDA) and Finnish International Development Agency (FINNIDA). In the long-run, however, it is the people who will shoulder the responsibility.

Valuation of non-marketable forestry products is possible by making use of the willingness to pay (WTP) of individuals or society (Munasinghe 1992). Such a valuation serves a couple of purposes. First the proxy calculated allows the management to determine the opportunity cost of managing catchment forests. This will indicate the importance of catchment forests to the welfare of the society. Second it can be used to justify the cost incurred in managing the catchment forest reserves. It has been observed, however, that the technique lacks both scientific appeal and reliability (*ibid*). Whatever controversy surrounds the WTP technique, it is still used in the valuation of non-market forest benefits.

4.2.2.4 The reason for conserving the forests in the Usambaras

The forests in Usambaras consists of a high diversity of flora and fauna (Bjørndalen 1992). There are about 169 endemic and 487 near-endemic taxa of vascular plants in the Usambaras (Iversen 1991). This is by no means a small number by world standards. Example of endemic plants are African violets-Saintpaulia and wild coffee species which can be used in coffee breeding programmes. Also zoological researches in the Usambaras has shown the area to have a relatively high diversity of faunal species. These include 5 endemic or near endemic bird species, 3 endemic snake species, 38% of lizard species, 21 of *Sphaecidae* (*Hymenoptera*), 45% of the *Gastropoda* (Millipedes) are endemic to the Usambaras (*ibid*). It is due to such a high biodiversity that the conservation of forests in the Usambaras is very important.

4.2.2.5 Silviculture

The use of silvicultural methods to maintain a sustainable yield and value from tropical rain forests is a global problem (IUCN 1987; FINNIDA 1988). The problem is ascribed to the ecological diversity of the tropical rain forests which leads to complicated dynamics and lack of basic relevant silvicultural knowledge. Present silvicultural techniques used include poisoning of non-preferred trees, encouraging the natural regeneration, careful selection of trees to be felled, gap and enrichment planting, proper tending of seedlings and saplings and using shadow trees. A detailed account on the techniques that can be used to regenerate some of the most important tree species in Tanzania is given by Kimaryo (1990) who notes, however, that they are still experimental.

4.2.3 Livestock

The main system of livestock keeping in the Usambaras is the free-range method whereupon animals are grazed in the open. This system causes land degradation through overgrazing and accelerated soil erosion. Also when allowed access to the forest reserves they tramp on regenerating trees. Animals such as goats eat both saplings and tree tops thereby impairing regeneration.

The major animals reared in the Usambaras are goats, cattle, sheep, pigs, rabbits and poultry. The size of herds are 2, 2-3, < 1.0 and < 0.5 for cattle, sheep, goat and pigs respectively (SECAP 1991). Another system of livestock keeping, is stall feeding but practised only to a very limited scale.

5.0 NATURE OF LAND USE PROBLEMS IN THE USAMBARAS

5.1 General perspectives of misuse of land-based resources

The present land use practises in the Usambara mountains are not consistent with the ecological balance of the forest ecosystem. The poor land use practises have led to the degradation of both the open or public land under agriculture and the forest resource base. Furthermore, the forest officer attached to District Natural Resource Office lacks adequate logistic support to ensure efficient utilization of the forest resources.

The misuse of resources in the Usambaras demand an immediate action if further degradation is to be avoided. The main problems arise due to the contradictory perceptions of the people interested in the long-term conservation, the government and its agencies; and those interested in the immediate exploitation of resources, a group which constitutes largely of local populace having to survive from year to year on limited resources for investment on improved land use practises.

The present agriculture husbandry in the Usambaras is that of "land mining". That is, the land is used without a proper effort to replenish the soil nutrients in order to enhance sustainable productivity. Thus after only a few cropping seasons the land becomes marginal i.e. deficient of basic plant nutrients. Therefore more land is sought to meet the increase in demand for food. In the following sections an examination of some of the causative factors that have contributed to the land use problems in the Usambaras will be presented.

5.2 Land use problems from forestry view point

5.2.1 Effect of population growth

The Usambaras have rather fast population growth which causes substantial increase in the demand for food. Besides, the normal population growth through reproduction, there is an influx of migrants from neighbouring districts and countries. An example is the influx of Kisii people from Kenya in the late 1950's and the early 1960's who were engaged in pitsawing. Also there were migrants from Kilimanjaro. These were both the Wachagga and the Wapare who were and are still largely engaged in petty business.

The present population density in the Usambaras is more than 200 persons/km^2 compared to an average of about 4 persons/km^2 a hundred years ago (Iversen 1989). Furthermore, the rate of population growth is fairly high. It stands at about 3.2-4% compared to the regional and national averages of 2.1% and 2.8% per annum respectively (URT 1991). The high population density coupled with rather poor capital formation base has caused excessive use of the available forests and other land-based resources for settlement and food production. The rather poor economic base and rigid cultural values has made it difficult to increase production by intensifying agriculture through application of improved technology such as the use of improved seeds and fertilizers.

5.2.2 The pressure for more arable land

The demand for more farmland is inter-linked to the rapid population growth. The pressure for more arable land is a result of increased demand for food production. Such a need is the consequence of rapid population growth, poor farming practises and poverty. The farms are expanded largely through the encroachment of forest reserves (*ibid*). The invasion of forest land is illogical due to the fact that nutrients are depleted after only a few cropping rotations while at the same time causing erosion since most of the reserves are located in steep sloping areas (Pocs 1988). The expansion of farmlands leads to the destruction of natural forests which are otherwise important in ameliorating and mitigating climatic conditions (O'kting'ati 1984).

5.2.3 Cash crop production

The distinction between food and cash crop production is done basically because the two affect the forest resource quite differently. The major cash crops grown on the Usambara mountains are tea, cardamon, coffee and to a less extent sugar cane. The market price for the tea has been falling in the world market, as a result there is no economic incentive for the expansion of its production. Hence the trend for tea production has been on the decline. On the contrary, the market price for cardamon has been rising or stabilizing, hence the expansion of the crop production (MDB 1989).

The expansion of cardamon is achieved at the expense of forest reserves. The optimal growth conditions for cardamon are mainly found in the forest because the crop demands half-shadowy, warm and humid conditions in order to grow satisfactorily (Iversen 1989). In the process of expanding cardamon fields, the canopy inside the forest is opened substantially, while at the same time the undergrowth is cleared. The nutrients in the soil are depleted after a few cropping seasons whence the peasants clear the area completely and convert it to shamba or grazing ground.

5.2.4 Mechanized logging

The destructive aspect of mechanized industrial logging is caused by soil compaction, suppression of regeneration and poor logging practises. There are rules stipulated in the Forest Ordinance to govern the logging operations but loggers tend to evade them. Lack of control has led to a situation where rules concerning the logging along the riverside catchments are not followed. The selection of tree to be felled is based on commercial criteria and subsequent logging cause a lot of damage to the remaining trees. The large openings in the canopy create conditions that are conducive for the invasion of secondary bushes and pioneer plants such as *Maesopsis eminii*. It will take a long time for the harvested forests to regenerate. In fact they may never reach their previous status. Often there are no pre- or post-logging silvicultural efforts that are taken to promote regeneration. The situation is further aggravated by the construction of high density roads even on steep slopes. The consequence is accelerated soil erosion due to the exposure of soil on the logging roads and tracks (FINNIDA 1986; TFAP 1989).

Generally, lack of thorough harvesting control is caused by several reasons including lack of adequate and reliable transport for the forestry staff at the district level, increase of fuelwood demand, offer of higher wages making timber cutting attractive especially as an additional source of income, special preferences for forest products such as fruits and medicinal plants.

5.2.5 Pitsawing

Pitsawing has been a booming business for the past 50 years. There are varied perceptions regarding the effects of pitsawing on natural forests. Proponents of the system contend that "pitsawing is the recommended method of harvesting in catchment forest reserves under controlled conditions" (Pocs 1988), due to the fact that in montane rain forest, as the one found on the Usambaras, hand sawing is ecologically less destructive than mechanized logging (Kijoti and White 1981).

Pitsawing is, however, a problem in the absence of proper control and monitoring. The operation may alter the "under-canopy" ecology by opening up large gaps inside the forest (Iversen 1989; Kaoneka 1990). Also pitsawing can be wasteful because of poor sawing accuracy. Furthermore pitsawing is an activity that is difficult to monitor with the actual resource inventory in the area. Most pitsawyers are operating as syndicates and scattered over a wider area thus making it difficult to keep track of their activities. Consequently, far more timber than the official, legal licence allows is taken out of the forest reserves in the Usambaras. Therefore only a small portion of the financial benefits that accrue from pitsawing are entered into the government treasury because of illegal cutting. Finally pitsawing is an activity which disturbs considerably the natural regeneration by taking out trees with the good phenotypic gene pool qualities (Iversen 1989).

In the Usambaras, pitsawing as it is carried out at present is destructive because it lacks proper control particularly after the banning logging in the natural forest reserves. Today almost no accessible area in the Usambaras, including steep and exposed slopes and ridges and stream banks is free from illegal pitsawing (TFAP 1989; Kaoneka 1990).

5.3 Land use problems from agriculture view point

5.3.1 What is at stake ?

In the preceding discussion, the forestry view is that the farmer is irrational hence causing the degradation of land-based resources. To what extent the forestry view is justified is a question open for discussion. However, at this juncture, we assume that the farmer is rational in thinking and decision making. He is driven to marginal lands only by factors beyond his control. The farmer considers forestry activities as a competitive form of land use to the extent that once afforested, the land is excluded from agricultural uses. This realism is not especially appreciated by the peasant who operates at the subsistence level of production.

Using this framework, in the next sections we shall examine a portfolio of factors which compel the farmer to use farming practises that cause land degradation. The factors may have, either direct or indirect bearing depending on the position assumed in the analysis.

5.3.2 Factors causing land use problems

5.3.2.1 Social and cultural factors

The first social factor is population growth. The factors causing fast population growth have been outlined in section 5.2.1. Fast population growth is used here to mean that the rate at which the population grows is higher than the rate of socio-economic development. The disparity in population growth and economic development threatens social welfare of the people. The peasant is faced with a couple of challenges, the increased demand for food and settlement. Also due to stagnated economic development, the opportunities available for alternative employment of labour is limited.

Furthermore, due to poverty a peasant is unable to increase food production through intensive or modern farming practises. Thus, the peasant finds a cheap way of expanding the farm acreage through encroachment of natural forest reserves. The initial perception is that forest soils are very fertile hence more productive. By acting in this way, the peasant is "rational" to the extent that it would seem illogical to allow starvation in order to conserve forests. How far does such rationality go? Only in the short run because in most cases the forested areas are located on steep sloping terrain conditions therefore prone to severe soil erosion (Pocs 1988). Also peasants have a tendency of land mining. Thus the nutrients of the forest soils become depleted after only a few cropping seasons. In most cases, peasants do not take into account the opportunity cost of clearing the natural forest reserves. Thus they are largely concerned with social pressures. However, forest land is a finite resource relative to the multitude of the demand for it. Therefore the expansion of farmlands through the encroachment of forests can only be continued to limited extent.

The second factor is ascribed to somewhat rigid tastes and preferences which caused reluctance on the local people to adopt new technologies. The local populace considers the indigenous crop varieties as being "perfect". Consequently they resisted the introduction of hybrid maize which otherwise produces high yields. It was considered to be less tasteful compared to indigenous varieties. Therefore the introduction of new seed type is adopted at a slow rate. The same situation occurred in Rukwa region when new farm methods were introduced without a prior feasibility study (Jerve 1990). It is argued that peasants attitude was rational. Monoculture maize plantations demand high level of inputs such as improved seeds and fertilizers both of which are expensive to the peasant. Traditionally, peasants use cropping mixtures such as maize/beans or maize/*marejea (Crotaralia ochroleuca)* in order to enhance sustainable land productivity. The technique was cheap and convenient because the peasant could obtain a variety of crops from the same hectare of land.

5.3.2.2 Institutional factors

5.3.2.2.1 Extension services

There is an absence of adequate extension service which could enhance the improvement of the existing farming practises as well as adopting new technologies. Perhaps one typical example is the improper application of fertilizers which lead to rising soil acidity, thus rendering land less productive. Traditionally the Washambaa people intercrop maize with beans as a means of adding nitrogen to the soil in order to maintain fertility. In instances where intercropping is not possible, a crop rotation system is used. This system is working fairly well. In fact one could enhance increased production by improving on the system.

5.3.2.2.2 Effect of some marketing issues

The emergence of commercial markets has weakened the customary land tenure arrangements. Cash crop production became an incentive to individuals wishing to sell out their land holdings (Kowero 1990). Also Tanzania has had a tendency of rationing foreign exchange in which case the local currency was overvalued. The low exchange rate encouraged the production of subsistence crops because of low producer price of cash or tradeable crops such as coffee when valued at border prices (Munasinghe 1992). A typical case is the switchover from coffee, a perennial crop, to vegetable, a seasonal crop, production by the Wachagga people, who are otherwise the major growers of coffee.

Overvaluation of the shilling also reduced international competitiveness of the tradeable or cash crops. The combined effect of decreased competitiveness and lower farmgate prices pushed farmers to marginal lands in an attempt to absorb the impact of price changes (*ibid*). In order to elucidate the actual and precise effect of these macro policy issues a more detailed analysis is required than can be covered in this study.

5.3.2.2.3 Political factors

The Arusha Declaration of 1967 which decreed land to be a public property encouraged land degradation. The local people perceived that there was no longer an incentive towards long-term investment on the land, such as tree planting and manuring, to the extent that they were not guaranteed an over time land ownership. It reduced responsibility for proper land use management. The Ujamaa policy of state controlled production discriminated private initiative with the consequence of stagnation in production.

The use of top-down approach in the decision-making system, in some cases, had wrong impression on the people. People perceived such *modus operandi* as a kind of moral degradation because the people were considered to be decision-takers rather than active participants in the decision-making process. Sometimes coercive rather than persuasive means were used to introduce new technologies (Jerve 1990). In this case the government assumes the role of paternalism i.e. deciding what is best for the peasants.

5.3.2.2.4 Effect of structural adjustment programmes

The effect of structural adjustment programmes (SAP) at the micro-level is rather diffuse. However, in the wake of SAP some measures such as reduction of subsidy of farm inputs and cutting down government spending might have an effect on farmer either directly or indirectly. For instance a removal of subsidy on fertilizers is likely to affect agricultural production. The agriculture sector is dominated by smallholder farmers or peasants with limited resources. Some of them could not afford the price of fertilizer even when it was subsidized. Thus the removal of subsidy on fertilizer is likely to push peasants into marginal lands. It will simply encourage the continuation of mining and degradation of farmlands.

Having analyzed the land use problem in more general way it is deemed relevant to examine the problem at the household level using some aspects of farm household economic theory. This is the subject of section 5.4.

5.4 Analysis of land use problems using farm household economic theory

5.4.1 Definition and concept of farm household economy

Farm household economics can be considered as a theoretical framework used to analyze household production activities such as farming systems. It is based on the premise that, a peasant household works within the general economic framework in the quest to maximize the utility of family labour. The term utility connotes "the degree of satisfaction an individual obtains by consuming a commodity" (Stiglitz 1988). The concept of utility is often applied in welfare economics to reflect how well-off the society is relative to the available resources (*ibid*). By the same token, as the concept is applied to peasant household economic theory, utility measures the magnitude of both social and economic satisfaction obtained by consuming a commodity produced by family labour.

Family wants or needs are many and cannot be satisfied at once. Therefore, households often rank them in order or priority, an approach also referred to as "satisficing". Those wants which rank high in priority are the first to be satisfied. Thus in analyzing farm household economic system it is often useful to develop a conceptual framework for assessing these wants because they constitute the real "incentive" and strategy for production activities. A conceptual framwork used in this context is the one proposed by Holden (1991). The framework is outlined in Section 5.4.2.

5.4.2 Goals/needs of a farm household

The basic goals/needs of a farm household based on Holden (1991) are:

(a) food requirements (energy, protein, taste, preparation);
(b) housing (shelter) requirements (building material, building);
(c) energy requirements for cooking (woodfuel, collection);
(d) needs for water;
(e) needs for certain market purchased goods and services such as:
  - (i) salt, soap, matches, kerosine mainly for lighting;
  - (ii) clothes;
  - (iii) school expenditure (fees, uniform, books);
  - (iv) travel expenditure;
  - (v) food.

(f) security (risk avoidance);
(g) leisure assuming that the farmer is drudgery averse.

Holden's classification seems to be relevant in analysing household economy to the extent that it could be applied to modelling the farm household welfare situation. In management practise, however, some of the goals may be aggregated without decreasing the precision and ultimate utility of the outcome from the farm household model. A traditional classification is the Maslow's hierarchy of needs (see Kaoneka 1987). Maslow's model of needs was and is still used in managerial economics in developing motivational package. A conceptual framework of the Maslow's model is shown in Figure 5.1. The theory behind the model is that the social development of an individual or society is motivated, *inter alia*, by the satisfaction of his/her or societal needs. Once a need has been satisfied it ceases to serve as a motivator.

Considering Holden's classification, the goals/needs falling under (a), (b), (c), (d) and (e), would be classified as physiological needs in the Maslow's "model". In fact these are the true motivator to the peasant who produces largely for family consumption. Operating at the subsistence economic level, a peasant struggles to fulfill the physiological needs. The quest for satisfying family needs drives the peasant to marginal lands, where poor farming practices lead to land degradation and accelerated soil erosion.

Order of Prior-ity

Self actualization -sense of reaching a respectable position, highest

Ego centric or esteem needs -the feel of being responsible, respectable

Love needs -sense of social belonging, the need to love and to be loved

Security needs -security of job, property, income

Physiological needs -food, shelter, clothes.

Figure 5.1. A conceptual framework of Maslow's hierarchy of needs (adapted from Kaoneka 1987)

The quest to satisfy family needs forms the overriding objective of the peasant household's collective effort. The major means of peasant household production are land and labour. The key decision facing the peasant is how to "optimize" the allocation of land and labour in order to maximize the utility of family labour. In this regard, we may note also that time factor is a crucial element to the extent that peasant farm production is seasonal. This problem will be analyzed using the "Theory of Household Economy" based on Low (1986): Nakajima (1986) and Holden (1991).

5.4.3 Analysis of the farm household agriculture

One of the salient features of a peasant agriculture also referred to as smallholder agriculture is that it possesses a higher proportion of home consumption of the total output produced by the peasant household. In this analysis the view taken was that peasant household is producing at the subsistence economic level. Under this view-point, it implies that there is neither hired labour nor surplus production. Also it means that the family labour can be devoted to agriculture only.

Mathematically, this view is represented by the following equation as quoted from Nakajima (1986):

$$A = A' > 0 \text{......All family labour is devoted to farming and no hired labour.} \quad [5.1]$$

where

A = amount of family labour
A' = amount of labour input on its own farm

The rationality of equation [5.1] is based on a couple of premises. First the peasant household labour is unskilled, thus it has limited opportunities for alternative employment and most often has zero shadow price. Second the peasant households are often too poor to afford the cost of compensating hired labour.

A further assumption is that the bulk of the output produced by family labour is of one kind and is largely consumed in the peasant household. Mathematically this assumption can be presented as (after Nakajima 1986):

$$F = X > 0 \text{........subsistence farm production} \quad [5.2]$$

where
F = the amount of farm output
X = the amount of output consumed in the peasant household

The logic of equation [5.2] is that a peasant household is characterized by a relatively high level of poverty. Thus it is difficult for them to afford the cost of purchasing food. Therefore, a more convenient arrangement is to produce at least only enough to satisfy the household's demand for food.

Another salient feature of the peasant household economy is that a household has a utility function which is a function of income and the amount of family and that each of their incomes is an increasing function of the amount of family labour respectively. The underlying theory is that a peasant household earns income through utilizing its own family labour since hired labour would be prohibitively expensive. The object, as mentioned previously, is to maximize the utility of family labour.

A peasant household income has two major components, money income and income in kind. The latter type of income represents the proportion of domestic or family consumption. The money income represents the portion of output from family labour sold to the market.

Mathematically, a utility function for a peasant household is represented by the following relation (after Nakajima 1986):

$$U = U(A,M) \quad [5.3]$$

where
U = utility
A = amount of family labour (hours) in each year
M = income obtained during the same period

In analyzing the utility of family labour the following assumption is made:

$$U_A < 0, \quad U_M > 0 \quad [5.4]$$

where

U_A	=	marginal utility of family labour
U_M	=	marginal utility of money income

The term $U_A < 0$ means that, "labour brings direct disutility due to its physical and/or mental pains; it also generates indirect disutility by reducing leisure or free time" (Nakajima 1986). Therefore U_A assumes a negative sign (i.e. $-U_A$) and is referred to as the "marginal pain of labour" to the extent that it reduces the amount of leisure time (Holden 1991). The term U_M is referred to as the "marginal utility of income" which is always assumed to be positive to the extent that the peasant desires income from family labour (*ibid*).

The peasant household economic theory shows that the farmer operating at the subsistence level attempts to maximize the utility of family labour. That is,

Maximize $U = U(A,M)$

which, according to Nakajima (1986) and Holden (1991), constrained by;

$$M = P_x F(A,B) \qquad [5.5]$$

where

M	=	money income from family labour
P_x	=	the price of farm produce which is produced according to function F(A,B).
A	=	family labour
B	=	land

Here it is assumed that there is neither labour market nor land market. Also it is assumed that all farm produce is sold. Equation [5.5] represents another salient feature in the peasantry economy, that of heavy reliance on family labour and land. Family labour is a cheap input to the peasant due to reasons previously discussed. Land may not be that cheap because of its high opportunity cost. However, under the traditional or customary land tenure system land is considered to be a private property which is inheritable. Despite the weakening of this system due to political changes, inheritance remains to be by far the most important source of land to peasants in the Usambaras. In this analysis it is assumed that land cannot be sold because it is a family property.

For the sake of maintaining a certain level of production there is often, a decision to be made regarding the trade-off between leisure and income, because time spent in leisure cannot be available for activities which generate income. According to Holden (1991), the trade-off between leisure and income is represented by the term:

$$-U_A/U_M \qquad [5.6]$$

This term measures the marginal rate of substitution of family labour for money (income) or the marginal valuation of family labour. Now we can combine equations [5.3] and [5.5] in order to define what is referred to as "the subjective equilibrium of the peasant household economy" (Nakajima 1986; Holden 1991). Hence the subjective equilibrium condition can be defined, mathematically in terms of ;

Maximize $U = U(A,M)$
Subject to,
$M = P_xF(A,B)$

as;

$$P_xF_A = -U_A/U_m \quad [5.7]$$

Rearranging equation [5.7] we get;

$$U_M = -U_A/P_xF_A \quad [5.8]$$

where

U_M	=	marginal utility curve
$-U_A/P_xF_A$	=	marginal pain curve of money income at equilibrium point.

To the extent that the peasant aims at maximizing the utility of family labour, the subjective equilibrium equation (equation [5.8]) may be reformulated into;

$$U_M.P_xF_A = -U_A \quad [5.9]$$

whereupon the term $U_M.P_xF_A$ represents the marginal utility-productivity curve of family labour and $-U_A$ the marginal pain curve of family labour.

The main contention of the subjective equilibrium analysis is that "each peasant farmhousehold works to the point where the household's subjective evaluation of the marginal disutility of work equals its estimate of the marginal utility of output gained" (Low 1986).

The major strength of the subjective equilibrium approach in analyzing the peasant household economy is based on a couple of premises. First the subjective equilibrium approach takes into account family labour and land, which are both key inputs to the peasant household operating at the subsistence level. The second point is that, the subjective equilibrium analysis explicitly includes price for the farm produce. Needless to mention that, to the farmer farmgate price is the immediate economic incentive for increased production. Sometimes there is an argument that peasants are not sensitive to economic gains. But the fact of the matter is, peasants are indeed "profit maximizers". For instance, if the family labour can be employed at reasonable market price, the peasant may be willing to take off family labour from farming activities in favour a paid employment (Low 1986). The market compensation for labour can be used to satisfy family needs.

The simplified subjective equilibrium model presented here assumes that the peasant produces only a single crop (Low 1986). However, the model can be extended to cases of multiple crops, change of land area and possibility of capital investment on the peasant household farm (Nakajima 1986; Holden 1991). In the extended model, the explicit assumption is that the peasant is faced with "variable" rather than "fixed" conditions.

Even when terminating the analysis here, there are some useful aspects worth noting. First, the analysis has indicated some of the reasons behind the conflict between forestry and agricultural activities. Forestry activities have a relatively high demand for land and labour, the inputs that are used in agricultural activities. Therefore, forestry activities are competitive from the farmer's view point. Another lesson that can be gleaned from this analysis is that the subjective equilibrium of the peasant household economy can be used to analyze the allocation of family labour to various activities in the quest for maximizing the utility of family labour (Nakajima 1986). The available labour, *ceteris paribus*, very much dictates the amount of land area that a peasant household can cultivate to the extent that under peasant farm production labour hiring is limited. Also, due to increasing population coupled with the scarcity of land relative to the demand for it, the peasant is faced with a challenge of "optimal" allocation of land to various crops in order to maximize production.

5.4.4 Time factor in farm household economy

It is often argued that time factor is very important to the peasant in economic sense (Low 1986; Nakajima 1986; Holden 1991). Time factor is used here in to mean household labour availability. Low (1986) argues that household economic theory is more relevant to the less developed countries than it is to the high income countries because "the value of home production is not only large relative to the total family income, it is also produced predominantly by family labour and only in small part by purchased inputs because in low-income countries the purchased material goods that the household can acquire are very high in price relative to the economic value of time of members of the household".

This argument underscores the role of human time as a factor input and as a basic scarce household resource. The root of this argument is based on Schultz (1974) who notes that "in reality each consumer commodity has two price tags attached to it: (1) a money price as in the traditional theory of consumer choice and (2) a time cost of acquiring the consumer goods, and processing them in the household; and the time that is involved in consuming the commodities from this household activity". Therefore "the incentive to economize on time increases as its relative opportunity cost does" (Low 1986). In order to elucidate the important elements of time factor to the peasant household a few examples may be appropriate.

A case of married women's labour force: The extent of married women participation in household production is affected by her having children (*ibid*). The tendency is that women withdraw from the labour force when they have children on the assumption that children demand more time factor input than other goods produced within the household.

A case of rearing children: It is argued that "as the value of human time increases over time, fewer children are reared per household" to the extent that child rearing consumes a lot of time, "but each child embodies greater investment in human capital, which results in lower mortality and greater productivity in the economically active years" (Low 1986). Thus if an investment is incurred in such a way that it also increases the amount of human capital per individual, then the effect would be a commensurate increase in the value of a unit human time.

A case of technology absorption: In the peasant household economic principle, a new technology will become more attractive if the opportunity cost of time increases, because less time is needed to produce each unit of the consumption good produced and the value of this time-saving is increased (see Low 1986).

The preceding examples indicated that time factor is an important aspect in the peasant household production. In fact the peasant allocates "rationally" time to various activities in the household. If labour market is available, the amount of labour time allocated to participation in the market activities by members of the household is very much influenced by the value of their time in market production compared with that value of time spent in farm activities at subsistence level (Dean 1966).

Time factor considerations make the peasant averse to forestry activities. Characteristically, forestry activities constitute a long-term investment which embodies, in the face of the farmer, relatively high level of risk and uncertainty. Thus where agriculture and forestry land uses are competing the peasant tends to favour agriculture land use. Also where poverty is common peasants discriminate between long-term and short-term crops in the quest to concentrate on those crops that can generate quick income.

The analysis of the subjective equilibrium is terminated here. However the peasant household economic theory will be revisited once again in report 4 when analyzing a case study from Lukozi Village located on the West Usambaras, Lushoto District.

Having discussed the major land use problems in the Usambaras it may be appropriate to review some of the efforts taken to combat the land use problems. Specifically, we shall review the TIRDEP-SECAP approach.

5.5 SECAP's integrated approach towards sustainable use and erosion control

5.5.1 Brief history of SECAP

The acronym SECAP stands for Soil Erosion Control and Agroforestry Project in Lushoto, (West Usambara), Tanzania. The project started in 1981 with funding from GTZ (German Assistance for International Development) under pilot phase (Phase I). The project entered Phase II in 1984. The main objective of the project was to promote "soil erosion control and agroforestry land use practises in order to contribute to an ecologically sustainable and economically viable utilization of the potential of the land in the West Usambara mountains" (Woytek *et al.* 1987). The affiliated government agencies were District Agricultural Development Office (DADO), District Livestock Delopment Office (DLDO), District Natural Resource Office (DNRO). The review presented in this paper is based on two evaluation reports by Woytek *et al.*(1987) and Fischenich (1992)

5.5.2 Concept of sustainability in SECAP's approach

Young (1989) defines sustainability in relation to land use in the following context, "Sustainable land use is that which achieves production combined with conservation of resources on which that production depends, thereby permitting the maintenance of productivity". Expressed in a logical relation as:

Sustainability = Productivity + Conservation of Resources

The overriding objective of sustainable land use is the continuation of production over a long period, which is covered in the planning horizon of both policy makers and peasant. Sustainable land use is envisioned to ensure the maintenance of present production levels as well as providing for increased future production. This school of thought forms the root of the SECAP's approach which is discussed in the following sections.

5.5.3 A conceptual framework of the SECAP's approach

SECAP "hypothesized" that all factors causing soil erosion are interlinked. Further, the underlying logical framework is to integrate the most important sectors under peasantry economy, agriculture, livestock and forestry (Figure 5.2). The integration includes all pertinent factors from each of the sectors in such a way that the outcome should not only stop soil erosion, but also fosters a forward linkage that meets the basic needs of the peasant and increases their cash income while at the same time keeping a sound environment.

5.5.4 Modus operandi

SECAP proposed to operationize the conceptual framework stepwise as discussed briefly in the following sections.

5.5.4.1 Soil erosion control

In order to enhance sound environment and improve ecological value of the Usambaras, SECAP proposed to introduce soil erosion control measures and agroforestry systems which are ecologically sound, sustainable and increase productivity (SECAP 1988). To accomplish this objective, SECAP proposed a couple of measures intended primarily to keep erosion at minimum levels.

The first technique proposed was to establish macro-contour-lines (mcl) consisting of fodder grass, fodder bushes, leguminous creepers and trees. The microcontourline is to be planted every 8-15 m depending on the steepness of the terrain. The microcontourlines have two advantages, prevention of gully and sheet (surface) erosion and provision of fodder for livestock. The peasants who were not especially interested about fodder are advised to plant other cover crops such as banana, sugarcane, pineaples and other cover crops in the macrcontourlines. The second technique proposed was to adopt stall feeding (zero grazing) for livestock in order to minimize animal movements which would otherwise cause soil erosion. An added advantage is that manure can be collected from the animal paddocks and used in the crop fields to improve soil fertility which in turn provides conditions possible for the increase crop yield.

5.5.4.2 Improving agriculture

SECAP considers the present traditional farming practises as being less sustainable and unproductive. Thus it proposed a set of measures intended to improve agriculture. These measures include:

(a) planting in microcontourlines;
(b) green manuring using "marejea" (*Crotaralia ochroleuca*);
(c) crop rotation;
(d) mixed cropping;
(e) planting improved (better) crop varieties and
(f) diversification of crops.

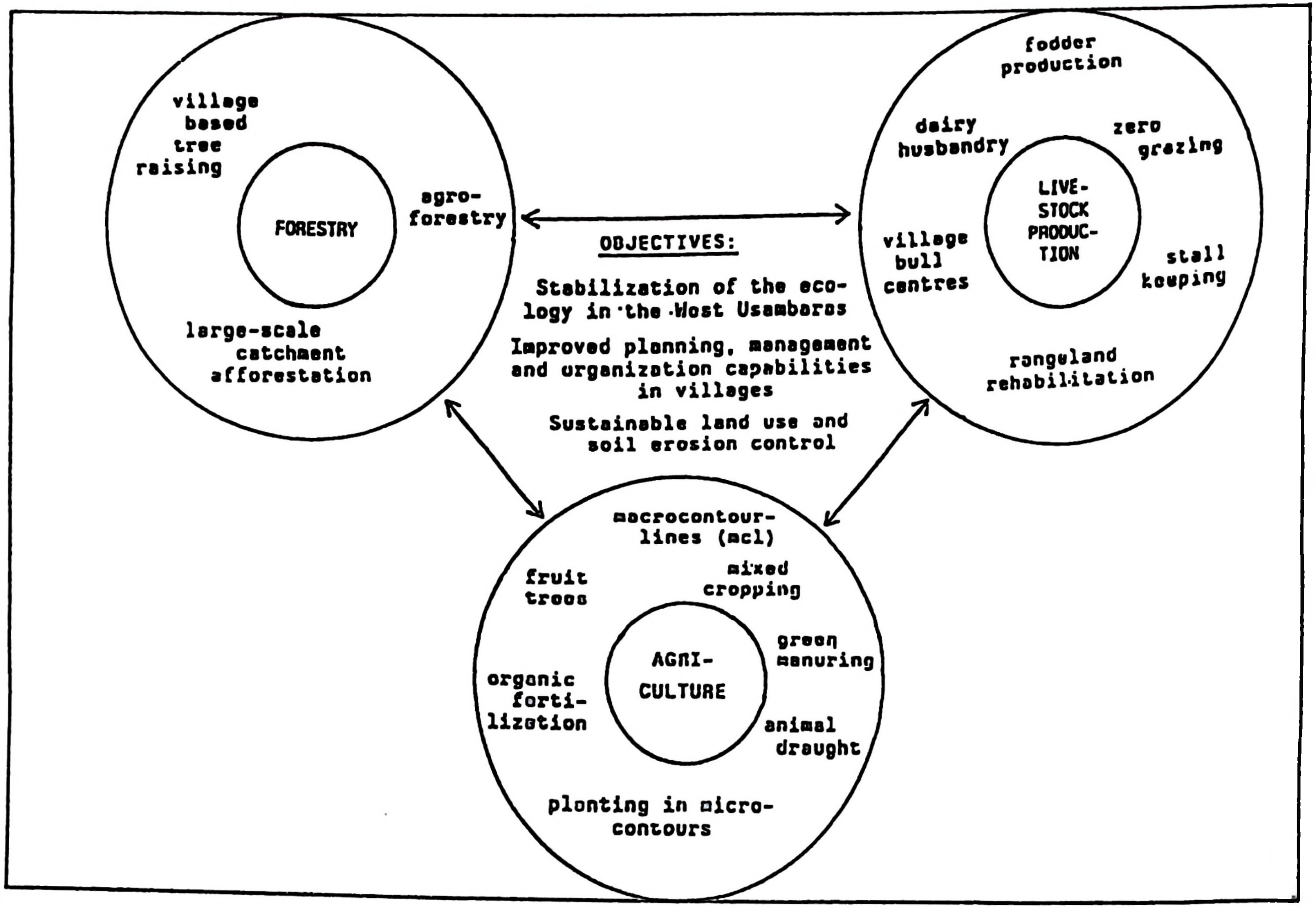


Figure 5.2 Objectives and components of SECAP's integrated approach (SECAP 1991)

Further SECAP made a provision that interested farmers can purchase draught animals, oxen and donkeys, and carts on credit (free of interest when provided solely by donor agencies mainly the GTZ-German Assistance for International Development). The draught animals, besides farm activities, can be used for transporation of farm produce and other goods to the market.

SECAP proposed also the introduction of improved dairy cattle in order to increase milk production for both domestic consumption and sale in order to generate cash income. An intitial technique, considered to be convenient and cheap to the farmers, was to use purebred bull. Each interested farmer can cross indigenous cows with the bull in order to produce improved heifers.

5.5.5 Cooperation with village communities

SECAP proposed several strategies which could foster a close cooperation with village communities which form the receiving clientele of the project's research findings and spillover services. These strategies are outlined in the following sections.

5.5.5.1 Establishment of nurseries

In the quest to enhance the tree growing effort, SECAP proposed the establishment of tree nurseries in villages and primary schools. SECAP promised to offer assistance in the establishment and management of the nurseries in which agroforestry trees are raised, training a nursery attendant, supply certain inputs including seeds and polythene bags and technical services. The village and primary schools were to offer labour supply, oragnization and distribution/sale of the tree seedlings.

5.5.5.2 Improvement of dairy cattle

SECAP proposed the establishment of bull/breeding centres in villages intended to produce improved heifers which would increase milk production. The project (SECAP) was to supply the purebred bulls and construct bull paddocks. Each village was to nominate a peasant who would serve as an incharge for the welfare of the bull. Also SECAP proposed the establishment of 0.5 ha or preferably 1 ha of pasture land for the improved cow breeds. The farmers were at will to use the services of the bull.

5.5.5.3 Promotion of forestry

SECAP proposed that villages embark on major catchment afforestation and other land rehabilitation activities in collaboration with the project's personnel. As a starting point, the proposal included closure of hilltops and heavilly eroded areas, demarcation and border planting and establishment of village woodlots as well as planting fodder grasses and bushes to rehabilitate severely degraded lands.

5.5.5.4 Extension services

SECAP extends some extension services to villages. The approach proposed was to arrange for:

(a) General campaign meetings before each growing (rainy) season.
(b) Macrocontourline improvement campaigns in each rainy season.
(c) Farmer's field days.
(d) Farmer's training days and seminars.
(e) SECAP committees.
(f) Seminars for village leaders and teachers.

5.5.6 Achievements of the SECAP approach

The following achievements were recorded as the project closed its second phase of operation in June 1988. Yearly reports are written, but the project leader says "they are not for public consumption".

(a) Soil erosion control measures:applied by 157 peasants in 5 villages.

(b) Dairy improvement programme:a total of 33 stall paddocks were constructed, a total of 33 heifers were distributed on a credit facility arranged jointly with CRDB, Lushoto Branch. In addition a total of 15 stall paddocks were constructed and 15 heifers delivered on cash basis. A total of 4 purebred bulls were supplied to 4 pilot villages. Livestock training seminars attracted 280 peasants for the entire period covered by the review.

(c) On nursery activities: 12 peasants were trained as nursery attendants.

Other elements that can be attributed to the presence of SECAP approach include :

(i) The project has attracted a concentrated group of well trained personnel (most of whom have Bachelor degrees in various fields) into one district (Lushoto).

(ii) The project offers transport and other logistical support to the extension workers attached to the District Agricultural Office.

(iii) SECAP is ditributing, at subsidized prices, farm inputs to some villages including seeds, fertilizers and chemicals.

(iv) On the social side, SECAP has provided employment to a substantial labour force since its inception in 1971. Also some of the employed personnel have received in-service training.

Generally, SECAP is considered to be a complimentary entity in relation to the District Agricultural Office (Mwaimu pers. comm.). That is the two institutions cooperate in such a way as to avoid duplication of efforts.

5.5.7 Failures of the SECAP approach

In spite of the achievements recorded, SECAP suffers from some failures in its approach (Woytek *et al.* 1987; Fischenich 1992 and own observ.). These failures are discussed in the following sections.

5.5.7.1 Improper operating assumption

The underlying operating assumption of the SECAP approach was that the traditional farming practises were both outdated, inefficient and unsustaining. Thus the project was determined to make a total change in the peasant's traditional farming practises. As a result the project did not conduct thorough analysis of the existing traditional farming systems in the Usambaras before embarking on its ambitious reform.

The Shambaa traditional farming systems have certain positive elements worth promoting. For instance the Shambaa people have a tradition of planting guatemala grass (*Tripsacum laxum*) across the contour to prevent soil erosion while at the same time using the fodder to feed domestic livestock (Woytek *et al.* 1987). Thus rather than introducing the new technology of macrocontourlines, the traditional technique could be improved and enhanced. Also the Shambaa people have a tradition of planting mixed crops such as maize/beans cropping mixture which is both productive and sustaining (*ibid*).

5.5.7.2 Introduction of "costly" proposals

Local people felt that some of the measures proposed by SECAP, viz: bull breeding, macrocontourlines (mcls) and use of draught animals were alien, unnecessarily expensive and risky (probably relative to their level of poverty). Therefore the response was low.

5.5.7.3 Improper selection of clientele

The target group of the SECAP approach was composed of the progressive farmers (a small fraction of < 5% of the total peasantry community in the Usambaras) who are relatively above the poverty line hoping that the new technology would permeate the entire peasantry society by way of induction. The notion was wrong and the new techniques did not reach the vast majority.

SECAP has also been criticized for spending a lot of money and time liasing with officials at the District Agricultural Development Office instead of visiting villages. Further, it was observed that SECAP used more top-down rather than bottom-up approach thereby missing the opportunity to understand grassroot problems of the peasants (Msangi pers. comm.).

5.5.7.4 Negligence of natural forest reserves

SECAP concentrated more efforts and resources on the agriculture sector and neglected the natural forest reserves which have both high ecological and socio-economic values.

5.5.8 Proposals after an evaluation mission of SECAP

SECAP was evaluated in November-December 1991 and the Missions Review Report was produced in March 1992. The report contained, *inter alia*, a set of proposals considered important for the conservation and improvement of natural forests in the Usambaras. These proposals as obtained from Fischenich (1992) include:

(a) Analysis of the endemic tree species and their pattern of distribution in the various existing forest reserves.

(b) Case studies on the negative effects of both mechanized logging and pitsawing.

(c) Studies on the hydrological functions of the natural forest reserves and identify watershed areas to be included into the forest land use and management plan.

(d) Regeneration experiments for the important tree species.

(e) Socio-economic studies of villages in order to develop a basis for remedial intervention.

(f) Zoning the National Forest Reserves into protection and utilization zones.

(g) Identification of natural reserves in the existing National Forest Reserves that are yet to be exploited. The activity may entail establishment of new boundaries.

(h) Demarcation of all National Forest Reserves boundaries as they exist today.

(i) Establishing a buffer zone to take over some functions of the forest for the villagers.

(j) Developing forest management and land use plans for the villages.

(k) Training for the village extension workers to become more of the village development work force than just serving as a civil servant.

(l) Managing the forest resource according to management plans.

(m) Incorporating agroforestry package into existing village land use system.

Fischenich (1992) contend that if the proposals are properly implemented it is possible to improve the value of forests and other land uses. The improvent could be judged from a number of management indicators including (*ibid*):

(a) Effective management of catchment forests.

(b) Controlled and sustainable harvesting of the forests.

(c) Remarkable increase on the people's awareness on the value of forest and land conservation.

(d) Fuelwood demand is satisfied largely from community or village forestry woodlot.

(e) Licencing timber harvest is regulated.

(d) Proper integration of agroforestry measures with other land use systems.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

On the basis of the discussion presented in this paper, the following conclusions can be drawn:

(a) The natural forest reserves, which form part of the remaining tropical rain forest, on the Usambaras have high ecological, high biodiversity and socio-economic value.

(b) Excessive exploitation of natural forest reverves in the Usambaras coupled with inefficient farming practises causes deforestation, ecological and general land degradation.

(c) Land use problems in the Usambaras seem to emanate from the conflicting perception between conservation and exploitation. The main agents of land use problems are fast population growth which results into increased derived demand for more arable land, intensive cash crop production and human settlements; extensive mechanical logging and uncontrolled pitsawing. These problems cause overuse and misuse of land-based resources.

(d) Measures, so far taken to combat the land use problems are inadequate. Hence the need for more strategic efforts to redress the land use problems in the Usambaras.

6.2 Recommendations

On the basis of the discussion and conclusions presented in this report it is recommended that a comprehensive, efficient and amicable land use plan be developed for the Usambaras. Further it is recommended that detailed case studies, such as the one presented in report 4 of this study, be conducted to constitute the base material for subsequent land use planning.

The baseline elements to be considered in developing a land use plans for the Usambaras in order to maximize the welfare of the society and optimize over time the utilization of land-based resources are outlined as follows:

(i) To stop the forest destruction and ensure the existence of intact tropical rain forests.

(ii) To improve and maintain the water catchment properties of the Usambara mountains.

(iii) To assure the sustainable use of forest resources.

(iv) To assure the future forestry resources for both local and industrial uses.

(v) To increase food production.

(iv) To increase public awareness of the value of these forests

Inter-disciplinary approach is needed, not easy, but once achieved, these elements can enhance the concept of sustainable resource use in the Usambaras. In an effort to redress the problem of land use in the Usambaras, the present study proposed a case specific research at the village level. Thus, a research was conducted at Lukozi Village which is located north of Lushoto town in the Usambaras. The findings of the research will be presented in report 4. To the extent that modelling in land use was applied in this study, it was deem appropriate to review some of the existing models regarding their relevance for application in Tanzania and the Usambaras. The review of modelling is presented in report 3 of this study.

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REVIEW AND EVALUATION OF SOME LAND USE PLANNING MODELS WITH RELEVANCE FOR APPLICATION IN TANZANIA

Report Number 3

SUMMARY

The report covers a review of models applied in land use planning in Tanzania, a review of some models with potential relevance for application in Tanzania and West Usambara mountains, and a discussion of quantitative versus qualitative approaches in land use planning.

The models which have been applied in Tanzania include Noninferior set estimation (NISE) and linear programming (LP). NISE was applied in forestry planning problem in Dodoma region, Central Tanzania. Linear programming was applied to three cases, an analysis of agroforestry farming system, economic evaluation of large scale forest-based factory and planning forest plantation management regimes at the project level.

The application of the models in all four cases were judged to be satisfactory with respect to the stated objectives and hypotheses. Further, the studies showed that the model results could be useful in management decision making. The application of models in the Tanzanian context is still at its infancy and that widening its scope could be desirable.

The models with potential relevance for application in Tanzania and West-Usambara mountains are ECOSIM, TEAMS and ILWIS. The review indicates that each of the three models has its strengths and weaknesses. There is no universal criteria that can be used as a guide in selecting a particular model. The choice of a model is very much dependent upon the structure of the problem, stated objectives and hypotheses as well as the subjective preference of the decision maker. A model is presented as a tool of analysis and the choice of application is vested upon the decision maker. In choosing a particular model, it is important that the decision maker understands and can tolerate its limitations and weaknesses.

The discussion on quantitative versus qualitative approaches to land use planning shows that each of the two methods has its strengths and weaknesses or limitations. The strength of quantitative methods hinges upon mathematical modelling and the ability to generate quantitative data which can be used in the decision making process. The method is limited, *inter alia*, by the fact that not all relevant factors in land use planning can be quantified and modelled. The strength of qualitative approach is attributed to its ability to integrate qualitative information into a decision making framework using managerial intuition. The approach is limited, however, because the use of managerial intuition invariably introduces biases and subjective value judgement. Therefore, none of the two approaches, quantitative and qualitative, is all embracing. Hence it could be more realistic to apply a combination of the two approaches in the decision making process. The optimal combination of the two depends on the available resources for solving a given problem and the decision-maker's understanding of the model used.

Key words: model, modelling, land use planning, decision making, quantitative methods, qualitative approaches.

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1.0 INTRODUCTION

1.1 Definitions and classification of models

A model represents a simplification of an object or phenomenon that exists in the real world. Models are created to predict how certain aspects of the real world will behave. A model becomes useful when it correctly and consistently predicts the behaviour of the real world for the phenomenon of interest. Models describe the relationships among data elements in order to predict how events in the real world will occur. Such knowledge or facts produced by models are used in decision-making processes.

The classification of models is broad depending on the intent and scope of the user. Models may be classified according to their function, subject, purpose, dimensionality or degree of abstraction, degree of cetainty, specified behaviour characteristics, form (structure, type) and process of solution (Dykstra 1984, Mgeni 1986, Solberg 1988). For instance in the forestry literature Jeffers (1964) divides models into descriptive, preductive and decision models, Hall (1967) into simulation and mathematical programming ana Dykstra (1984) classifies models according to type into iconic (physical representation of an object or situation) and analog (models analogous to a real object or sitation represented symbolically) models. For the purpose of this report our major focus will be on the classification by Hall (1967) - i.e. on mathematical and simulation models.

Mathematical models are characterized by "a large or infinite set of alternatives within a feasible area, a set of side-conditions, one or more objective functions, an algorithmic procedure selecting more preferred points in order to arrive at an optimum" (Solberg 1988). Mathematical models are developed through a process referred to as "mathematical programming" (Dykstra 1984). Mathematical programming involves the use of mathematical models to solve certain decisional problems (*ibid*). Mathematical models are characterized in terms of whether they are linear or non-linear, deterministic, when variables are assumed to be known with certainty or probabilistic or stochastic when some of the variables exhibit a random pattern (Dykstra 1984, Solberg 1988). An optimum solution is generated by mathematical models through a numerical method referred to as algorithm. An algorithm is "a set of logical and mathematical operations performed in a specified sequence" (Dykstra 1984).

An algorithm is thought to be an efficient and useful numerical procedure as long as it must exhibit certain features. These features include "each successive trial solution has to be an improvement over the preceding one; successive solutions must converge on the optimal solution, and they must do this within a finite number of iterations and the computational requirements at each iteration must be small enough that the solution of the problem as a whole remains computationally feasible" (Dykstra 1984). Furthermore, the efficiency of mathematical models is based on the premise that an optimal solution can be generated without exhaustive search.

1.2 Some essence of mathematical modelling in land use planning

"Hopefulness is not a very good way of confronting potentially dangerous situation, and so we construct computer models of what might happen in the event of a nuclear war, we formulate mental models of what to do if we meet a grizzly bear on the trail, and we make predictions about the possible environmental impact offorest management activities" (Dykstra 1984).

In essence, therefore, modelling can be viewed as a method of planning, evaluating management options, predicting the consequences of management actions and choosing the best course of action. The baseline feature of modelling activity is the abstraction of real or actual situations and the development of mathematical models that represent the decision-making environment. A fair knowledge of the decision making system or real situation is needed in conceptualizing, developing and applying models. Models as abstractions from reality are so simplified that they are much easier to understand compared to an actual or real situation (*ibid*). However, to be meaningful, a model must be able to "mimick" the real situation as close as possible and be able to answer pertinent questions. Thus, the power of a model as an analytical tool relies primarily on the accuracy by which it represents the actual or real situation. In fact the "utility of a model does not lie in its scientific ancestry, but rather in its practical applicability" (Ranfelt 1981).

Modelling approach is emphasized in the management of land-based natural resources in order to develop a "systematic" approach in the decision making process instead of using intuition and educated guesswork. Models offer quantitative information which enables the management to make more realistic decisions.

Natural resources, such as tropical rain forests are complex ecosystems. The complexity coupled with the multiple use of natural resources by the society constitute an even more complex whole with a lot of interactive factors. Modelling allows the mangement to depict these interactions and design appropriate management prescriptions.

The strength of modelling, notwithstanding, it is recognized that models are not "all embracing" to the extent that they are abstractions of real objects or phenomena. Moreover, models are tools of analysis only, they cannot substitute managerial functions or human intuition. However, fact there is an interlink between modelling *per se* (a quantitative approach) and managerial intuition (a qualitative approach) in the decison making process.

1.3 Objective of the paper

The broad objective of this report is to present a review of selected models relevant for land use planning in Tanzania with particular reference to forestry and agricultural lands. The paper also presents a comparative discussion between quantitative versus qualitative approaches to land use planning.

The more specific objectives are to:

(a) review models applied in land use planning in Tanzania;

(b) evaluate some selected land use planning models with relevance for application in Tanzania and in the West Usambara mountains;
(c) examine the essence, utility and limitation of quantitative land use planning;
(d) examine the essence, utility and limitations of qualitative land use planning;
(e) discuss the optimal relationship between quantitative and qualitative land use planning with particular relevance to the Tanzanian condition.

1.4 Working hypotheses

The main working hypotheses in this paper are:

(a) Some of the available models are better suited to land use planning than the others.
(b) Quantitative modelling is an important tool in developing elaborate land use plans.
(c) An effective and efficient land use plan must be based on an "optimal" balance between quantitative modelling and qualitative methods in land use planning.

The review presented in this text is limited in some ways. First in the case of a review of model application in Tanzania, only a few models are presented based on what is documented. It could be that some model applications exist while by way of academic and consultancy work are not documented. The same can be said about the models selected for review i.e. ECOSIM, TEAMS and ILWIS. These models were selected on the basis of "academic" exposure.

2.0 APPLICATION OF QUANTITATIVE MODELS IN LAND USE PLANNING IN TANZANIA

2.1 Selection of models for review

The purpose of this chapter is to present a brief review of some selected quantitative models that have been applied in land-use planning in Tanzania. The models selected for the review were limited to those which were considered relevant for the current study and whose literature or documentation was available.

2.2 Type of models

2.2.1 Multiobjective regional forest planning using the NISE method

2.2.1.1 Brief description of the model

The review on the application of multiobjective regional forest planning (MOP) using the noninferior set estimation (NISE) method is based on Allen (1986). The model was applied to Dodoma region located in central part of Tanzania. The aim of the study was to analyze the effect on forest policy as a result of introducing fast growing forest plantations and improved charcoal kilns. There were essentially two working hypotheses. The first hypothesis was that although at present forest plantations in central Tanzania are growing at only 3 m^3 ha^{-1} yr^{-1}, it is possible that faster growth could be achieved. The second hypothesis was that improved portable steel-ring charcoal kilns could be adopted and thereby double the efficiency of charcoal production (Allen 1986).

The noninferior set estimation (NISE) method was developed by Cohon *et al.* (1979) to "converge quickly on a good approximation of the noninferior set" (Allen 1986). The noninferior set is the set of all non-dominated solution to the MOP which must satisfy the Kuhn-Tucker condition for optimality (*ibid*). These condition require that:

a) the solution be feasible
b) an expansion of currently unused resources (nonbinding constraints) will not increase the value of the objective function ("complementary slackness"), and
c) movement away from the solution that increases all the objective functions simultaneously is infeasible, and movement in a feasible direction cannot simultaneously increase the objective function

The NISE method provides an approximation to the noninferior set consisting of N solutions obtained by solving N + 2 linear programmes (where N = the number of solution points, and 2 = the number of objective functions). The weights used to obtain NISE solutions are the trade-offs between the two objectives at that point and the maximum error of the NISE approximation can be calculated or shown diagrammatically.

The two objectives of the study were:

a) Minimization of costs of wood production, including planting, intermediate treatments and harvest in accordance with Forest Division Policy.

b) Minimization of the costs of transporting wood production to villagers in accordance with the national development policy.

The first objective represents plantation costs as the sum of fixed costs (i.e. site preparation, planting) and age-specific variable costs (i.e. weeding, thinning) on per hectare basis. The second objective represents transport costs as the product of the average hourly wage and the time required for a round trip between any wood production site and any village.

Due to scope limitation the entire mechanism of the internal working of the NISE method may not be covered in this report. However, a summary of the method is given by way of a graph (Figure 2.1). The graph shown in figure 2.1 depicts the noninferior set estimation (NISE) method for problem with two objectives Z_1 and Z_2. ADCEB is the estimated noninferior set produced by the NISE method, which finds N solutions A, B, C, D and E in consecutive order by solving N + 2 (seven) linear programmes (LP's).

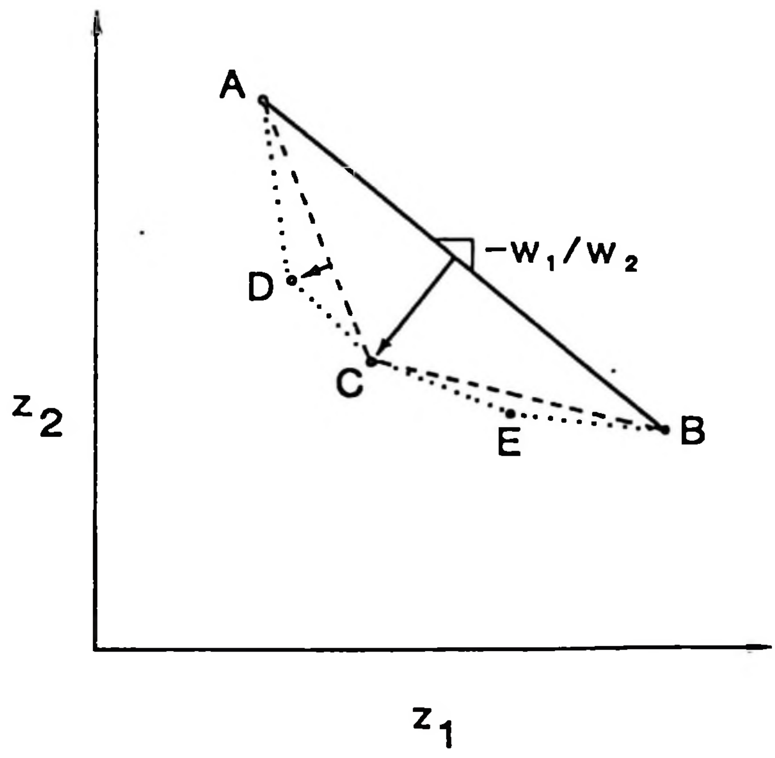


Figure 2.1. The noninferior set estimation (NISE) method for a multiojective (MOP) problem with objective Z_1 and Z_2 (adopted from Allen 1986).

Extreme solution A is obtained in two steps: first the problem is solved as an LP with objective Z_2 only to obtain an optimal solution X^*, and then the problem is solved with objective Z_1 only and Z_2 constrained to its previous optimum solution X^*. Solution B is obtained in the same way except that Z_1 is used in the first and Z_2 in the second LP. Intermediate solutions C, D and E are obtained by solving three additional LP's with weighted objective function; the weights in each new LP are determined from the slope of the line segment connecting the adjacent solutions.

2.2.1.2 Scope of application

The MOP for forest management in Dodoma was applied to 5 sites, 11 age classes, 2 species, 15 demand centres and a five-year-planning horizon. The size of the problem matrix was 1,850 decision variables and 1,055 constraints. In total fourteen LP solutions in three noninferior sets were generated from sixteen LP solutions obtained using the objective and constraint parametrization options (Allen 1986).

2.2.1.3 Main findings of the study

The base scenario showed that between 9 and 14 million m^3 of wood would be harvested for fuelwood from plantations to meet demand over a 5-year period, depending on the relative weights of the objectives. The use of efficient kilns, in scenario 2 (alternative scenario) would save 2 million m^3 of wood and avoid the harvest of 0.2 to 1.4 million ha compared to the base scenario.

The fast growth could be achieved on plantations (base scenario), up to 20 million m^3 of wood could be produced on a smaller area of 1.3 to 2.0 million ha. The fast growth policy costs 50 to 90 % less than the base case (Allen 1986).

2.2.1.4 Concluding remarks

The main strength of the NISE method is its ability to generate solutions with "intuitive trade-offs". The explicit presentation of trade-offs encourages flexible planning and balancing of objectives. In this application, NISE was used to examine trade-offs between two objectives only, but the algorithm has been extended to three objectives (Appino 1984) whereas further expansion is in progress (Allen 1986).

2.2.2 Linear programming models

The review in this report will divide linear programming models into three categories on the basis of intent and nature of decisional problems. The three cases reviewed relate to the application of linear programming in planning forest plantation management regimes at the project level (Mgeni 1986), economic evaluation of large scale forest-based factory (Kowero 1986) and analysis of agroforestry farming system (Dykstra 1980, 1984).

2.2.2.1 The application of linear programming in analyzing agroforestry system

2.2.2.1.1 Brief description of the model

The review of the application of linear programming models in analyzing agroforestry farming systems is based on the work by Dykstra (1980, 1984). The study was designed to illustrate the usefulness of LP as "a planning tool for community agroforestry programmes" (Dykstra 1980). Linear programming model was developed with the objective to minimize the total land under cultivation while assuring adequate production of food and fuelwood. A case study was applied to an Ujamaa Village in Mbeya, Southern highlands of Tanzania. The decisional problems were:

a) providing sufficient food to meet the nutritional requirements of the people, and
b) ensuring an adequate supply of fuelwood for cooking.

The proposed agroforestry system included three major crops, maize, beans and green vegetables and the tree species was *Eucalyptus melliodora*. Two alternatives were considered open-grown (monocropping) and interplanting (intercropping). Since the trees were intended for fuelwood a four-year rotation was assumed.

The application of LP model seeks to generate an optimum solution with the objective of minimizing land under cultivation on the premise that peasants are averse to the arduous work of tilling land with handtools. In essence, therefore, the decisions to be made involved "the allocation of land among alternative uses" (*ibid*).

A detailed review of LP technique is given in Kaoneka (1993 d) and thus will not be covered here.

2.2.2.1.2 Main findings of the study

The summary of the model solution is presented in Table 2.1.

Table 2.1. Summary of the optimal solution to the agroforestry problem.

Year	Hectares allocated to each alternative				
	Open-grown			Interplanted with Eucalyptus	
	Maize	Beans	Green vegetables	Maize	Beans
1	53.9	0	80.0	253.3	0
2	0	0	82.3	194.2	37.2
3	0	0	84.8	230.7	15.7
4	0	0	87.4	218.1	030.1

Note: Total area planted = Z^* = 1348.7 ha.

Source: Dykstra (1984).

The results in Table 2.1 represent an optimal solution to the agroforestry problem. One striking feature is that there is no land allocated to bean production under open grown system, whereas in intercropping bean production was absent in the first year and only marginal in subsequent years. Beans are a rich source of protein to most rural people. Therefore the optimal solution is likely to be resented/unacceptable to the village authorities. To overcome such a problem, it is possible to specify a minimum level of beans to be produced each year.

2.2.2.1.3 Concluding remarks

The formulation of the agroforestry problem presented in this review was simple yet can be a relevant tool in land use planning. Further, it may not be possible to have all the information necessary for extending the formulation (Dykstra 1984). However, the optimal solution may be a "point of departure than an end itself" and may be used, via shadow prices, to identify further data needs and extensions, and this in itself is a contribution to the management (*ibid*).

2.2.2.2 The application of linear programming in the economic analysis of a wood processing complex

2.2.2.2.1 Brief description of the model

This review is based on a study by Kowero and Dykstra (1986). A linear programming (LP) model was developed and applied to a forest-based (wood) processing factory - Fibreboard Africa Ltd. (FAL) in Arusha, Northern Tanzania. The study covered five units comprising FAL; a hardboard mill, a sawmill, an impregnation plant, a clogs factory and a flush door factory. The purpose of the study was to examine two optimizing policy objectives:

a) to foster efficient harvesting and utilization of forest products;
b) utilization of forest produce in public lands to the best advantage of the community

An LP referred to in the paper as the General Processing Model (GPM) with the objective of maximizing profits from the different FAL units, with the limitations of the production capacities of the units, wood raw material supply and market restrictions on the products. The entire GPM will not be reproduced here. But it may suffice to mention that the model had 38 decision variables and 26 rows (constraints). The model was run in HP-85 microcomputer in several (iterative) runs.

2.2.2.2.2 Main results of the study

The model solution indicated that if FAL implements the solution production programme, it will earn a net of TAS 24.6 million corresponding to US $ 3 million (at 1980/81 costs and price levels, exchange rate was TAS 8.2 = 1 US $). To achieve this level, FAL will have to meet two basic requirements first:

(a) FAL will require a recurrent expenditure of TAS 16.4 million (which was considered to be a realistic level of expenditure that could be met).

(b) All the plant machinery, vehicles and other equipment have to be in good working condition.

The numerical output of the model was extensive. However, due to scope and space limitation the detailed presentation of the model output is omitted in this paper. The main results are summarized in Tables 2.2 and 2.3 showing model production and overall FAL performance in 1980 repectively.

Table 2.2. Model optimum solution representing the FAL problem

Product	Output	Solution state	Net set of FAL (TAS)	Percentage of total FAL net revenue %
Flush-doors	50000 units	BS	1650000	6.9
Clogs	50000 pairs	BS	300000	1.2
Impregnated poles	7100 m^3	BS	1080000	4.5

BS = included in the basis solution.

Source: Kowero and Dykstra (1986).

The model solution indicated also that the sawmill should be operated at its full output capacity of 10,000 m^3/year. This will earn FAL a net revenue of TAS 5.8 million (> 76 % of the total FAL earnings).

Table 2.3. Overall FAL performance in 1980.

Mill	Installed output Capacity	Actual 1980 production	Capacity utilization(%)
Hardboard	8000 m^3	2500	28
Clogs	50000 pairs	5400	11
Flush-doors	50000 units	6500	13
Impregnation	12000 pieces	3000	25
Sawmill	10000 m^3	6000	60

Source: Kowero and Dykstra (1986).

The results in Table 2.3 show that the sawmill was more efficient in utilizing the output capacity (60 %) compared to the other units. It is not surprising, therefore, that the contribution of sawmill to the FAL financial earnings was substantially high (> 76 %). Equally true is the fact that sawntimber is a more marketable product compared to the other products.

2.2.2.2.3 Concluding remarks

The GPM solution was found to be useful as a basis for improving the performance of FAL. It provided an optimal solution which identified the different wood rawmaterial combination and the product combinations manufactured from them. Further the solution provided the management with alternative ways of running its units at full production capacity and enable them to weigh the economic implications of each alternative. In their view the authors conclude that "the study has successfully demonstrated the use of LP in evaluating some forest policy objectives relevant to FAL. It has also revealed the superiority of LP by identifying a profitable production programme for FAL".

2.2.2.3 The application of linear programming in planning forest plantation investments at the project level

2.2.2.3.1 Brief description of the model

The review on the application of linear programming in planning forest plantation investments at the project level is based on a study by Mgeni (1986). An LP was developed and applied to Sao Hill Forest Project located in Iringa Region southern highlands of Tanzania. Sao Hill Forest Project is the largest state-owned industrial plantation with 45,000 ha planted of pines and eucalyptus, supplying wood rawmaterial for a sawmill (Sao Hill Sawmill Ltd.) and an integrated pulp and paper mill (The Southern Paper Mills Co. Ltd.).

The LP was applied specifically to decisional problems related to determining optimal planting regimes which could satisfy the wood demand while observing certain "technical" constraints. In particular the problem was related to land allocation for planting annually over the entire planning horizon. In essence therefore this is a land use allocation problem "how many hectares of land should be planted with a particular tree species each year". The model size was 62 decision variables and 32 rows (or 95 sub-rows) for constraints including land area limits. Three tree species were analyzed, *Eucalyptus spp.*, *Pinus patula* and *Pinus caribaea*. A detailed description of the model is not covered in this report. However, interested readers may access the information regarding model formulation in Mgeni (1986). The detached coefficient matrix for the problem is presented in Table 2.4.

2.2.2.3.2 Main results of the study

The model solution was extensive. It will not be appropriate to reproduce all the results in this report. More detailed analysis can be obtained from Mgeni (1986). However, for illustrative purposes, part of the results representing an annual planting plan is presented in Table 2.5. A total of 1,652 ha were scheduled for planting in 1984/85 with different ttree species and in different site classes. One comment may be made regarding the sawlog and pulpwood working cycles. Pulpwood cycle entails close spacing and short rotations compared to saw log cycle. Sawlogs are produced from trees which have reached "financial maturity" hence longer rotations compared to pulpwood cycle. The land expectation value for each parcel or land considered was computed using financial, economic and social "prices".

The results showed that "the total value of the objective function generaly decreases with time at all levels of analysis (financial, economic and social") (Mgeni 1986). The linear programming solution select land parcels in descending order of productivity and net benefits. Furthermore, for each financial year, the value of the objective function increases as one moves sequentially from financial, economic to social stages of analysis. A comparative evaluation showed that economic and social rankings tend to favour land parcels whose land preparation is labour intenstive (Mgeni 1986). Such a trend indicated that it could be important to apply social cost-benefit analysis in land evaluation especially when a plantation project is undertaken partly as way of creating employment opportunities and income distribution.

2.2.2.3.3 Concluding remarks

The study has indicated some strength of combining linear programming and economic analyses in planning forest plantation investments. However, the study indicated also that the efficiency of such an approach relies on the acquisition of reliable quantitative data. In fact, this was the point of departure rather than an end itself as the study concludes "pending on data availability and with some modifications, the methodology can be applied elsewhere".

2.2.3 General discussion on the application of models in Tanzania

The models reviewed in this chapter are limited to micro-level and by way of pilot cases only. However, this may not be a deficiency per se to the extent that in most research and development (R and D) programmes, the starting point is the micro-level cases in building hierarchical models, at the meso- and macro-levels. Nevertheless, the fact is that models in

Table 2.4 Linear prgramming tableau for the Sao Hill problem

Item	Decision variable	Land facets					Sign	RHS
		X1	X2	X3 .... X60	X61	X62		
Objective function		PNV	PNV	PNV ... PNV	PNV	PNV	=	
Constraints:								
Seedlings:								
1. Euc.Div I	S_{j11112}	TC	TC	TC ... TC	TC	TC	≤	R1
2. Euc.Div.II	S_{j11122}	TC	TC	TC ... TC	TC	TC	≤	R2
3. Pc. Div.II	S_{j21v22}	TC	TC	TC ... TC	TC	TC	≤	Pc2
4. Pp. Div.I	S_{j31v11}	TC	TC	TC ... TC	TC	TC	≤	Pp1
5. Pp. Div.III	S_{j31v31}	TC	TC	TC ... TC	TC	TC	≤	Pp3
Labour:								
6. Div.I	$L_{jk=1,3;1v1v}$	TC	TC	TC ... TC	TC	TC	≤	L1
7. Div II	$L_{jk=1,2;1v22}$	TC	TC	TC ... TC	TC	TC	≤	L2
8. Div.III	L_{j31v31}	TC	TC	TC ... TC	TC	TC	≤	L3
Pulpwood								
9. Min.Euc.	$D_{j1k1v'221}$	TC	TC	TC ... TC	TC	TC	≥	D1e
10. Max.Euc.	$D_{j1k1v'221}$	TC	TC	TC ... TC	TC	TC	≤	D2e
11. Min.Pine	$D_{jk1vv'vv'1}$	TC	TC	TC ... TC	TC	TC	≥	D1p
12. Max.Pine	$D_{jk1vv'vv'1}$	TC	TC	TC ... TC	TC	TC	≤	D2p
Sawlog								
13. Min.Pine	$D_{jk1vv'vv'2}$	TC	TC	TC ... TC	TC	TC	≥	S1p
14. Max.Pine	$D_{jk1vv'vv'2}$	TC	TC	TC ... TC	TC	TC	≤	S2p
Total area to be planted								
15.		1	1	1 1	1	1	≥	0
Budget:								
16. Planting	$C_{jk1vv'v1}$	TC	TC	TC ... TC	TC	TC	≥	0
17. Pruning age 4years	$C_{jk14vv'v3}$	TC	TC	TC ... TC	TC	TC	≥	0
18. ... 22 Pruning	$C_{jk1t=5-8;10;vv'v3}$	TC	TC	TC ... TC	TC	TC	≥	0
23. ... 32 Thinning	$C_{j31t=10,12,14,15,19,20,23-28,vv'=1,3;14}$	TC	TC	TC ... TC	TC	TC	≥	0
Area of land facets to be planted.								
Land facet:								
X1		1	0	0 0	0	0	≤	$A_{jklvv'v}$
X2		0	1	0 0	0	0	≤	$A_{jklvv'v}$
X3		0	0	1,0 .. 0	0	0	≤	$A_{jklvv'v}$
.								
.								
X60		0	0	0 1	0	0	≤	$A_{jklvv'v}$
X61		0	0	0 0	1	0	≤	$A_{jklvv'v}$
X62		0	0	0 0	0	1	≤	$A_{jklvv'v}$

Key to table 2.4

Euc. = Eucalypt, Div. = Division, Min. = Minimum, Max = maximum, TC = Technological coefficient, PNW = Present Net Worth, RHS = right hand side.

Source: Mgeni (1986)

Table 2.5 Areas selected for planting in 1984/85 by the Sao Hill Forest management

Land facet characteristics

Number	Terrain	Division	Species	Site class	Working circle	Hectares planted in 1984/85
1	Slope 1	I	P_p	I	SWC	5.6
7	Plateau	I	Euc.	I	PWC	7.5
9	Plateau	I	Euc.	II	PWC	4.9
22	Slope 1	II	P_c	II	PWC	11.0
23	Slope 1	II	P_c	III	PWC	480.0
25	Slope 1	II	P_c	III	PWC	35.0
26	Slope 1	II	P_c	III	PWC	75.0
27	Slope 1	II	P_c	IV	PWC	28.0
28	Slope 1	II	P_c	IV	PWC	60.0
33	Plateau	II	Euc	I	PWC	55.0
50	Slope 1	III	P_c	III	SWC	120.0
52	Slope 1	III	P_c	III	SWC	360.0
53	Slope 1	III	P_c	III	SWC	70.0
58	Slope 1	III	P_c	IV	SWC	340.0
Total hectares planted						1652.0

Definition of symbols used:

Euc. = Eucalyptus spp.

Pc. = Pinus caribaea

Pp. = Pinus patula

PWC = Pulpwood working cycle

SWC = Sawlog working cycle

Slope 1 = terrain with gradient 5.1 - 10.0%

Source: Mgeni (1986)

Tanzania have been applied in rather few cases. Furthermore, the application has been in the form of academic pursuits, rather than being tailored toward practical application, which is the main focus in R and D programmes of this kind in most industrialized countries. Even with limited scope, this review has shown that models could be useful and have considerable prospects for increasing the scope of application in Tanzania.

The usefulness of models is attributed to the fact that they provide management with options and criteria for evaluating alternatives. Options are based on the premise that, in a given situation, resources are limited, thus it is important to develop a portfolio of options based on preferences by the decision makers. Alternatives define the course of action which can be pursued to achieve decision makers objectives. The choice of an alternative is often based on evaluative procedures. Evaluative procedures vary according to scope and stated intent of the decision maker. In most cases, a conceptual framework is designed, as a stating point. This is followed by operationalization of the conceptual framework in order to generate quantitative information. At this stage modelling becomes of interest. Models generate qualitative data which can aid the decision maker to select the best among the evaluated alternatives. This background gives one the reason to believe that by increasing the scope of model application in Tanzania, one may enhance and improve decisions related to land use planning. The trade-offs generated by models can be used as the basis in the decision making process.

In light of the limitation of the application of land use models in Tanzania, it is considered relevant to explore only those models which can be applied in Tanzania. Thus in chapter 3, a review will be presented of some models with the objective of evaluating their potential relevance.

3.0 EVALUATION OF SOME MODELS WITH RELEVANCE FOR APPLICATION IN TANZANIA

3.1 Selection of models

The models for the review were selected because they address or embody the ecological and economic issues in an integrated manner. In addition the selection was based on academic exposure. The models were seen as relevant for tackling land use planning problems, from the forestry point of view, to the extent that they were capable of mapping alternatives using both ecological (spatial) and economic criteria.

3.2 ECOSIM - Ecosystem COmponent SImulation Model

3.2.1 Brief background of the model

This review is based on Rogers *et al.* (1984). ECOSIM, an acronym for Ecosystem COmponent SImulation Models, is an integration of models representing resources, processes, and practices involved in forest management. The system has the capability of simulating tree growth and stand development including mortality, herbage yield, water yield, onsite soil loss, forest floor accumulation and decomposition of snags, logs, and debris, wildlife habitat and near-view scenitic beauty.

The system is designed to estimate outputs for forest planning alternatives in the National Forest System land management Planning (LMP) process. ECOSIM's outputs have a specified use as possible inputs to FORPLAN, the National Forest System's Scheduling and allocation model.

To simulate the effects of management prescriptions on various natural resources, the component models are integrated in a cascade fashion; that is, tree stocking affects herbage, water yield, and forest floor, which in turn affect onsite soil loss, scenic beauty and wildlife habitat. The term cancade is used here to imply that the system effects are unidirectional.

3.2.2 Structure of ECOSIM

ECOSIM consists of five major components: (1) main or executive programme, (2) input and initialization, (3) resource simulation, (4) activity simulation, and (5) output and summary displays. The programme was written in ANSI FORTRAN -77 for the UNIVC 110/84 system. The system is written as stand alone programme for either interactive or batch use. The general relationship of the system and present areas of capability are summarized in figure 3.1. The more specific relationships are briefly outlined in the following sections.

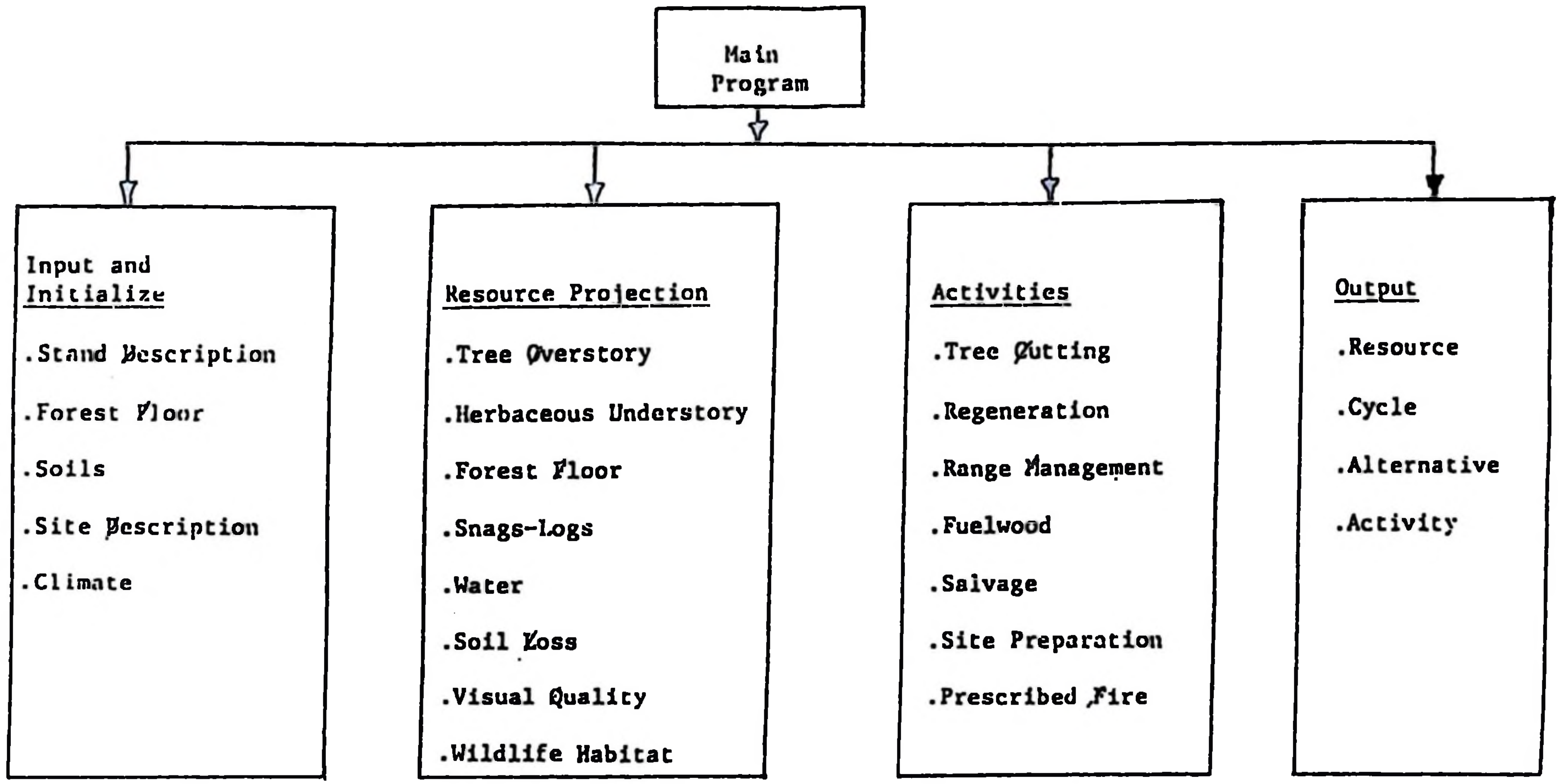


Figure 3.1 The main components of ECOSIM

Executive programme

The Executive Programme controls the simulation and calls other components in sequence. It is capable of simulating ten alternatives during a single programme execution.

Input and initialization

The Input and Initialization module reads user instructions and a stand description. It enables the user to select species, choose among optimal models for some species and define variables.

Resource projection

The Resource Projection module uses current - state description to predict the new state for that component for each annual step.

Tree Growth and Stand Development

Projects diameter growth and crown ratio, height, volume and product yield, mortality, age, cover density and regeneration. It accommodates pure or mixed stands.

Herbage Production and Carrying Capacity

These aspects are projected by models specific to vegetation types and are coverted to acres required per animal unit month (AUM) adjusted to local conditions by a grazing intensity factor (GIF).

Water Yield

Water yield is estimated based on winter precipitation, insolation and total inventory basal area.

Forest floors, snags, logs and debris

This module projects the accumulation and decomposition of litter, duff, and standing and down woody debris.

Onsite Soil Loss

The onsite soil loss module has options for projecting annual soil loss, soil loss from a single design event, both estimates or no estimates.

Wildlife habitat

The wildlife habitat module contains models for (1) Abert squirrel habitat, (2) red squirrel habitat, (3) hairy woodpecker habitat, (4) pygmy nuthatch habitat, (5) secondary cavity nester density, (6) nongame bird habitat, (7) pinyon-juniper habitat, and (8) vertical diversity.

Scenic beauty

The scenic beauty module provides an estimate of near-view scenic quality.

Activity simulation

The activity simulation module simulates several activities. These are outlined as follows:

Tree cutting

This module simulates cutting and removing standing live trees, debris loading and removal, product yield, and soil disturbance.

Site preparation

This module allows the user to remove a percentage of woody debris in the 1-inch (2.54 cm) and large size classes.

Regeneration

This module allows the user to simulate establishment of new trees and to add them to the stand.

Fuelwood removal

Cutting of fuelwood from logs or standing dead trees is simulated in this module.

Salvage

This module simulates salvage of merchantable standing dead trees greater than 12.0 inches (30.5 cm) dbh.

Range improvement

This module allows the user to change the forage condition, proper allowable use, and grazing intensity factor (GIF). These determine the conversion of total herbage production to acres required per cow animal unit month.

Prescribed burning

Prescribed burning is included as fuel consumption based on percent moisture content and total weight of forest floor debris.

Output and summary

Output and summary are provided as standard output both "cycle summaries", average resource outputs by decade and "summary of all options".

3.2.3 Data requirements

The data requirements for ECOSIM is quite extensive. Only a brief outline will be presented in this report. For a detailed coverage the reader is referred to Rogers *et al.* (1984).

Stand data

The stand data required for running ECOSIM are dbh, basal area, annual growth, site index, mortality, height, age, and herbage production.

Physical data

The physical data required are soil characteristics which include soil type (igneous, metamorphic and sedimentary origin), texture (sandy, loam, gravely loam, clay loam, silt loam) and depth; precipitation (annual average), water yield, terrain situation (aspect, slope) and elevation.

3.2.4 System operation

ECOSIM is composite of modules, Executive Programme, Input and Initialization, Resource Projection, Activity Simulation and Output and Summary working, in unison, cascade fashion. Each module consists of various entities. In fact each module is quite comprehensive (see Rogers et al. 1984). However, for the purpose of this report only a brief review of each module will be presented.

Executive Programme

The executive programme controls the simulation and calls other components in proper sequence. More specifically the system performs the following roles:

(a) Identifies itself to the user and provide some description of its current status;

(b) Provides for initialization of the entire stand and site description at the start of execution. After initialization, the user should be able to selectively edit or modify portions of the description without reentering the entire description.

(c) Provides the capability to simulate those resource outputs that are significant issues and concerns, or must be tracked for forest planning. The outputs are calculated or summarized in a way compatible with the planning process, analysis systems used and regulations.

(d) Allows evaluation of multiple alternatives during a single programme execution.

(e) Provides output displays and summaries directed toward various resource specialists. These includes:
   (i) The initial (year 0) status at the start of evaluation;
   (ii) The current status when requested at some point in time during evaluation;
   (iii) Summaries of effects of a simulated activity, such as volumes removed and/or left by harvest;
   (iv) Cycle summaries, which summarize resource status and yields at decade time intervals over the duration of projection. These would be used as input to analysis and planning systems;
   (v) Summaries for the entire analysis, which provide a comparative display of yields and effects for all alternatives evaluated in one execution of the programme.

(f) Provides a method of simulating the implementation of management prescriptions, allowing the user to modify the stand description at any year. The modification represent the results of applying a specific prescription to the area.

Input and initialization

The input and initialization module sets the stage for the resource projection component. The input and initialization is a set of modules that reads user instructions and a description of the stand and site characteristics. The system provides for both an interactive and batch mode for input.

The interactive mode provides a question-answer dialogue that enables the user to select species, choose among options, and define variables that provide all necessary descriptive information. The batch mode uses the same input, but eliminates the question-answer dialogue. The input is saved for reuse or selective modificaton by the user for each alternative evaluated. Further, inputs allow the user to specify the timing and choice of activities and the type of printed output.

Resource projection

After input and initialization have been completed, the system enters the simulation loop which is essentially a discrete system. A one-year time step (increment) is used. The system is defined by the existing ecosystem description in terms of the overstory, understory, forest floor, snags and logs.The state of the system for the following year is then determined from the existing year's inputs and ecosystem description. For each annual time step the resource simulation components predict the new state of the component. All outputs are obtained from information in the existing-state description of the system, that is, from the ecosystem description.

Resource projection is provided in the areas of tree growth and stand development's herbage yields and carrying capacity, forest floor, snag, log, and debris accumulation and decomposition; water scenic (beauty) quality.

Activity simulation

A major objective in the development of ECOSIM was to provide methods of simulating activities associated with management prescriptions. This would allow users to modify the stand or site description at any year. The modification would represent the results of applying a specific prescription, defined as a set of activities to the area. Capability should be provided for the major prescriptions used with the resources being simulated for the area of application.

Output and summary

The output and summary set of components provides summaries of the effects of management prescription on resource. Standard output is information considered by users as pertinent to forest planning. Detailed summaries of individual resources and activity impacts are provided as optional outputs.

The standard outputs include a "cycle summary" and a "summary of all options". The cycle summary provides information on simulated average resource outputs by decade. The data would be used for allocation and scheduling. The summary of all options provides information useful for comparing alternative management prescriptions.

Optional "resource summaries" provide detailed information on specific resources. This information is designed to aid in evaluation of effects of a prescription by resource specialists and interdisciplinary teams. The user can selectively choose output alternative management prescriptions.

3.2.5 Strength(s) and weakness(es) of ECOSIM

The main strength of ECOSIM lies on its ability to mimick (simulate) an ecosystem based on salient factors and/or characteristics. It allows the management to simulate the effects of various prescriptions given to a stand. The design of the model is flexible enough to allow the analyst and/or land managers to substitute optional models if deemed necessary and desired. Component models can be replaced with appropriately designed alternate models.

The main limitation of ECOSIM is that it is highly site (and species) specific. The model is calibrated only for forests growing in the southwest region of USA. Therefore its relevance for application elsewhere (transportability) has not been rigorously tested. Furthermore, the data input is quite expensive, thus unsuitable for small-scale applications or where funds are limited.

3.2.6 Prospects for wide-scale application

ECOSIM has not been tested on a wide scale. Thus Rogers *et al.* (1984) advise users of ECOSIM that "(1) models and/or systems are at best imperfect assessment of the real world and should never be used independent of professional judgement, and (2) ECOSIM, like any system yet developed, has inherent capabilities and limitations which must be kept in mind as the outputs are used in the decision making process".

Thus, ECOSIM may need further testing to render it more robust and more transportable but has some prospects for wide scale application. However, in its present form (as of 1990; pers. obs.) it has limited application for Tanzania. Modifications are needed, not only on the input, but also on the output modules.

More specifically the main input module that require modification are the yield equations used to simulate stand data *viz* to project over time production or yield. The present equations were developed using data for *Ponderosa pine*, a tree species which does not exist in Tanzania. Furthermore, yields are site specific thus, equations developed in the US can/may not operate in the Tanzanian conditions.

The output module need modification especially with respect to the time horizon or rotation age. More specifically, the time horizon must be shortened, because in the Tanzanian context, trees take much shorter time to reach the state of financial maturity. Units also need modification to the extent that Tanzania uses SI units, which differ from those commonly used in the US.

The simulation module is deficient, technically because it does not have a feedback loop or mechanism to the extent that activity simulation and output summary work in a cascade or unidirectional fashion.

3.3 TEAMS: Terrestrial Ecosystem Analysis and Modelling System

This review is based on Young (1988, 1990 and 1991) and Covington *et al.* (1988) and personal experience on the model.

3.3.1 Brief background of the system

TEAMS was developed as a *prototype* decision support system that may help planners and foresters bridge the gap between strategic planning and implementation" (Covington *et al.* 1988). The model has been revised in 1989, 1990 and 1991 by Bruce Fox (Young 1991). The main purpose of building TEAMS was to make use of it as "a tactical planning system designed to aid forest managers in developing site-specific management schedules that will conform to standards and guidelines specified by forest plans and will achieve the stated goals" (Covington *et al.* 1988). TEAMS is an interactive system. The utility of the output generated by the model depends largely on the users judgement and technical expertise in interpreting the results. The role of TEAMS is "to provide decision-makers with rapid feedback on the consequences of management alternatives" (*ibid*).

TEAMS is designed for use in sub-forest areas such as water-sheds, 10,000-acre blocks, or some other administratively determined units (*ibid*). The primary unit of analysis is the stand, which is defined as a contiguous area that is relatively homogenous in terms of site, structure (single- and two-storied), age-class (or classes if two-storied), and density.

TEAMS may be used in three ways. First, managers may directly specify how each stand within the management area should be treated. The system will then project and display on a computer screen the results of the prescribed treatment schedule that managers can subsequently compare goals, standards and guidelines. Second managers may specify goals, standards and guidelines for the unit and TEAMS will produce an optimal treatment schedule and project results. Third, a combination of the first two options may be employed with prescriptions for some stands specified by the managers and others determined by the system. Whichever option is applied TEAMS will make several runs to seek for a "satisfactory state" commensurate with the "overall design of the management schedule" (*ibid*). The initial intent was to develop a system with several modules in a composite design (Young 1991). Such a system should include:

(a) a relational database management system,
(b) a multiresource simulation model,
(c) economic algorithms for evaluating treatment costs and resource outputs,
(d) a constraint optimization model,
(e) a graphics output package, and
(f) the software which controls the flow of information among the other modules.

A detailed description of the model structure is given under section 3.2.2.

3.3.2 Structure of TEAMS

TEAMS has a "composite" structure made up of nine programmes linked together to form a decision support system for multiresource management. A flow-chart representing the different programmes and how they are linked together is shown in figure 3.2. The various components of TEAMS are briefly described in the following sections.

R: BASE 5000

R: BASE 5000 is a commercially available relational database management system. R: BASE 5000 stores all the initial inputs and final outputs produced by TEAMS. Input forms for stand, range, recreation and extra costs and benefits information were developed for entering initial values into the database. The R: BASE command LOAD is used to bring the TEAMS outputs into the data-base.

AECOSIM

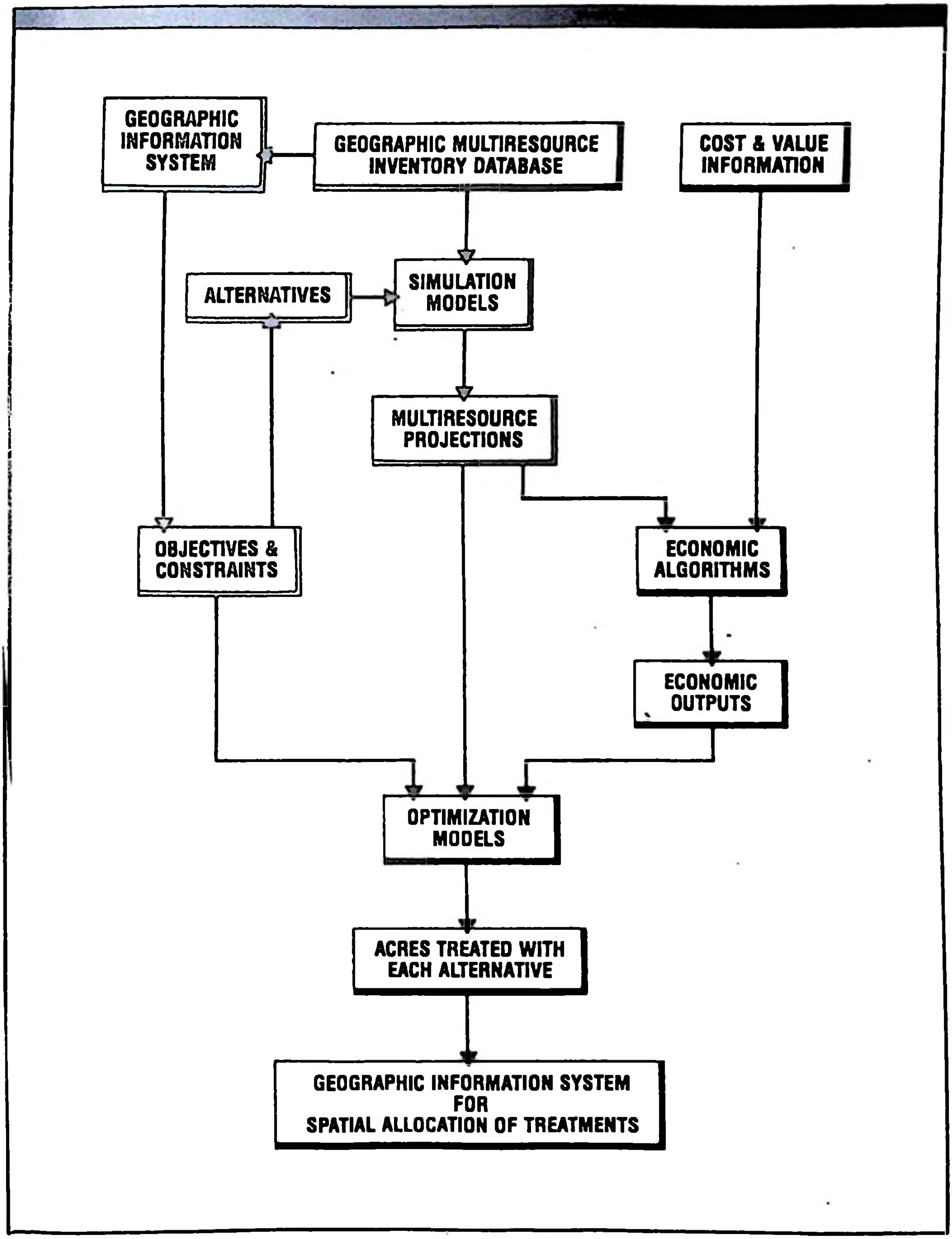
AECOSIM is an automated version of the ECOSIM simulation model maintained by the School of Forestry at Northern Arizona University (USA). ECOSIM consists of several modules (see Section 3.1), which together produce outputs for many different multiresource variables (Rogers *et al.*). Automation of ECOSIM allows for the analysis of one to fifty four alternatives for different stands with only the input of the initial stand characteristics.

RANREC

The RANREC programme calculates cash flows from range, recreation, and additional costs and benefits variables. The range subroutine reads AUMs from an AECOSIM output file, but that is the only AECOSIM output used for the programme. Other inputs are read from the files RECIN · SAM, RANGEIN · SAM and SCTBNIN · SAM which come from the R: BASE input forms. In each resource subroutine, outputs are costs and benefits per year (non-discounted), and NPV (net present value, costs and benefits discounted).

LINDO

LINDO is a commercially available linear programming package. LINDO is used to analyze the data produced by AECOSIM and RANREC, and to calculate an optimal harvest regime based on user-entered constraints and an objective function. Most constraints are entered into the LINDO matrix by the USER subroutine.



'igure 3.2 Flow chart for TEAMS decision support system

USER Subroutine

The USER subroutine generates the matrix accessed by the LINDO model. USER allows for the input of right-hand-side values, and then develops a matrix based on the constraints chosen. The matrix is filled with values from AECOSIM and RANREC programmes.

PROJECT

The PROJECT programme reads in the acres treated by alternative management regime (LINDO output), and the multiresource outputs by alternative (AECOSIM and RANREC output). These values are used to calculate stand and analysis area totals for each multiresource variable. PROJECT analyzes and stores the outputs from a single LINDO alternative.

COMPARE

The COMPARE programme is used to compare up to four LINDO solutions from PROJECT. Multiresource values produced by AECOSIM and RANREC are read into the programme along with LINDO solutions through PROJECT-generated files, and COMPARE then produces a series of files which can be graphed by CHART. These graphs compare the results of up to four LINDO solutions for each multiresource variable.

CHART

CHART is a commercially available graphics package. It is used to display graphically the outputs produced by the COMPARE programme. Variables that can be displayed graphically include: Costs, net cash flows, sawntimber harvested, pulpwood harvested, AUMs, water, sediment, scenic beauty, elk habitat, deer habitat, turkey habitat and Abert-squirrel habitat.

TABLES

The TABLES programme was constructed as a complement to the CHART programme. TABLES takes TOTALS1 · SAM and TOTAL · SAM files produced by PROJECT and COMPARE and produces a series of tables by stand for each of the multiresource variables. In other words, it gives a tabular display of the output PROJECT.

CLOUT

CLOUT is a comparison to R:BASE5000 which serves as an information retrieval tool. It allows the user to retrieve and display, with simple commands, all of the information that is stored in R:BASE5000.

3.3.3 Data requirements

Field measurements gathered from multiresource inventory, provide data input for the AECOSIM model, but almost all other inputs are based on user discretion. Excluding management constraints, all inputs are entered into the R:BASE5000 database management system. R:BASE input include stand, range, recreation, and extra cost and benefit data. A set of inputs is required for each stand and recreation area, but there is only one set of inputs for range improvements and extra costs and benefits data.

Management constraints are entered directly into the USER subroutine of the LINDO programme. These inputs become the right-hand-side (RHS) of the linear programming constraints. AECOSIM and RANREC outputs are automatically read into the USER routine, and become coefficients for the left side of the matrix. The USER routine automatically builds constraints for net present values, costs, net cash flow, and sawntimber and acreage, but the user also has the option to add additional constraints when the routine is finished. At the beginning of the USER routine, the user chooses an objective function from nine possible choices. Objective function choices range from maximize net present value to minimize on-site soil loss.

The data requirement for running TEAMS is fairly extensive. However, the level of detail and accuracy is determined by the user based on the stated intent for the analysis. For extensive details the reader is referred to Young (1988, 1989, 1990 and 1991) and Covington *et al.* (1988).

3.3.4 System operation

A detailed account of TEAMS operation is given by Young (1988, 1989, 1990 and 1991). For the purpose of this report only a brief review based on Covington *et al.* (1988) wil be presented. The general sequence of operations and user interactions as well as description of important system features will be covered in this review. As a starting point, stand inventory data are entered into R:BASE5000 and other pertinent map features are digitized using ARC/INFO, a GIS software. A parameter file appended to ECOSIM contains decision rules that, based on stand characteristics, automatically determine the treatment alternatives to be simulated for each stand. Stand alternatives are defined by type of treatment (e.g. harvest overstory, thin understory, harvest overstory and thin understory, no treatment), thinning intensity and a year of treatment. Each of the selected alternatives is simulated using ECOSIM, and biological, physical and economic yield tables are developed from simulation results. These tables include output projections such as timber, forage, wildlife habitat, and water yields as well as inventory characteristics such as projections of trees per acre, average stand diameter and basal area.

Economic results include costs, benefits and present net value. Users can enter information on recreational development alternatives, range improvement options and other unit-level alternatives to R:BASE5000; cash flows and present net values are then calculated by RANREC.

Whenever users have optimization objective, they must specify the objective function as well as constraints. USER generates relevant coefficient matrices with the aid of mixed-integer formulation with integer variables assigned to unit-level alternatives. The matrices are solved by LINDO and an optimal solution is displayed which indicates the treatment alternative (type, time, and acres of treatment) for each stand on the unit. GRAPHS project future yields of multiresource outputs, costs and net benefits associated with implementation of optimal solution (or user specified prescriptions). It also predicts future stand structures as they develop over time. Multiresource projections are displayed graphically by CHART whereas ARC/INFO is used to display maps of current and future geographic information using attribute files produced by GRAPHS as well as other spatial data entered by USERS.

Multiple objective functions may be entered sequentially using USER, then optimal solutions generated by LINDO may be evaluated using COMPARE programme.

The iterative procedure is considered useful in allowing best judgement to be used in project analysis.

3.3.5 Strengths and weaknesses of TEAMS

3.3.5.1 Strengths

Covington *et al.* (1988) observe that TEAMS has the following strengths:

a) The automated linkages provide for data transfer from one module to another and processed without human intervention.

b) When the user makes use of the optimization capability of TEAMS, constraints may be applied to inputs, outputs and forest structure, at any point within the analysis period.

c) TEAMS has the capability of automatically generating adjacency constraints that ensure that regeneration harvests may not occur within a specified period of time, say any 30 - 40 year-period.

d) TEAMS is capable of handling goal programming formulations.

3.3.5.2 Weaknesses

According to Covington *et al.* (1988) and personal experience TEAMS suffers from the following shortcomings:

(a) TEAMS is at present calibrated for southwestern *Ponderosa pine* only.

(b) Transport and road systems which are vital components of forest operations and multiresource activities, are not incorporated.

(c) Thinning and harvesting alternatives are the only stand-level treatments included.

(d) Requires extensive data input just like ECOSIM.

3.3.6 Prospects for wide application of TEAMS

Based on its initial construction, TEAMS has promising prospects for wide scale application both in the United States and other places like Tanzania where the concept of multiresource management planning is relevant. In order to be of wide-scale use certain technical modifications are necessary (see section 3.2.5.2). Also the model needs further testing with respect to its robustness and transportability.

The model is currently under review and modification (Dewhurst: pers. comm.) to cater for large scale application in Navajo Forest Projects. An attempt was made to produce a version of TEAMS for application in Tanzania (pers. exp.), but the work is yet to be completed. The rather high technical requirement, however, may render the application of TEAMS to small-scale projects difficult.

3.4 ILWIS - Integrated Land and Watershed management Information System

3.4.1 Brief background of the model

ILWIS is an acronym for Integrated Land and Watershed management Information System. The model was developed with the aim of supplying information which enhances flexible types of planning under dynamic situations. It was envisaged that ILWIS could improve the quality of information supplied to planners, policy and decision makers which in turn enhances improved quality of planning and implementation of development oriented activities.

ILWIS combines conventional Geographical Information System (GIS) procedures with image processing capabilities and relational data base. The system is designed for use with micro-computers. The system uses both vector and raster graphics data storage. ILWIS serves as a decision support tool to assist decision makers in evaluating proposed development/conservation plans.

The principal object of developing ILWIS was the interaction between humans and natural resources. The general objective of ILWIS was to contribute to the improvement of the availability and quality of information on which watershed (and resource) management can be based (Valenzuela 1988). The more specific objectives were to:

(a) assess the requirements, utilities and disutilities of such a system for regional planning, emphasizing watershed management,

(b) design, implement and test a computer-aided information system for the management of an actual river basin, and

(c) provide a technology transfer that disseminates knowledge to computer parts in developing countries and also to assist in setting up and operating national or regional geographic information systems.

3.4.2 The structure of ILWIS

ILWIS is a fairly complex model (see Figure 3.3). A detailed description of the model will not be given in this report. Interested readers are referred to Valenzuela (1988). ILWIS comprises of DATA GATHERING, DATA INPUT, DATA-BASE and DATA ANALYSIS modules.

Data gathering

Data gathering involves the acquisition of relevant data from various sources including remote sensing products, aerospace interpretation, field work and ancilliary information (see Figure 3.4). The data are gathered through image processing, digitizing, input forms and spreadsheet. Data are used as both input to various modules and as source of information to assist in the delineation of the terrain mapping units. Remote sensing products not only supply basic data, but also are used for monitoring and updating procedures.

Image processing techniques provide the tools to transform more efficiently the remote sensing data into information. Intensive field work and efficient sampling procedures are essential to ensure the validity and accuracy of the data incorporated into the system for further manipulation, analysis and modelling procedures.

Data input

During data input, ILWIS uses the capabilities of a relational database for keyboard data input to various tables. The general input procedure is shown in Figure 3.4. Input routines are designed for inserting data into each module on the database, easily and efficiently. Also trained analysts make use of spreadsheet facilities. Soil data stored in pocket computers in the field can be automatically transferred and translated into the system's soils database.

Database

ILWIS exploits the technology behind database management system (DBMS) and geographic information system (GIS). It uses a commercially-available relational database, ORACLE, which is linked to a graphics database and to a set of conventional GIS routines. A spatial database describes a collection of entities some of which have a permanent location on some global, dimensional space. Normally, there is a mixture of geometric (spatial) and non-geometric (a-spatial or non-spatial) entity types which may change in time. The spatial data describe the location and topology of points, lines and polygon features while the non-spatial data describe the characteristics of these features. The ILWIS database subsystem integrates both geometric and non-geometric entities.

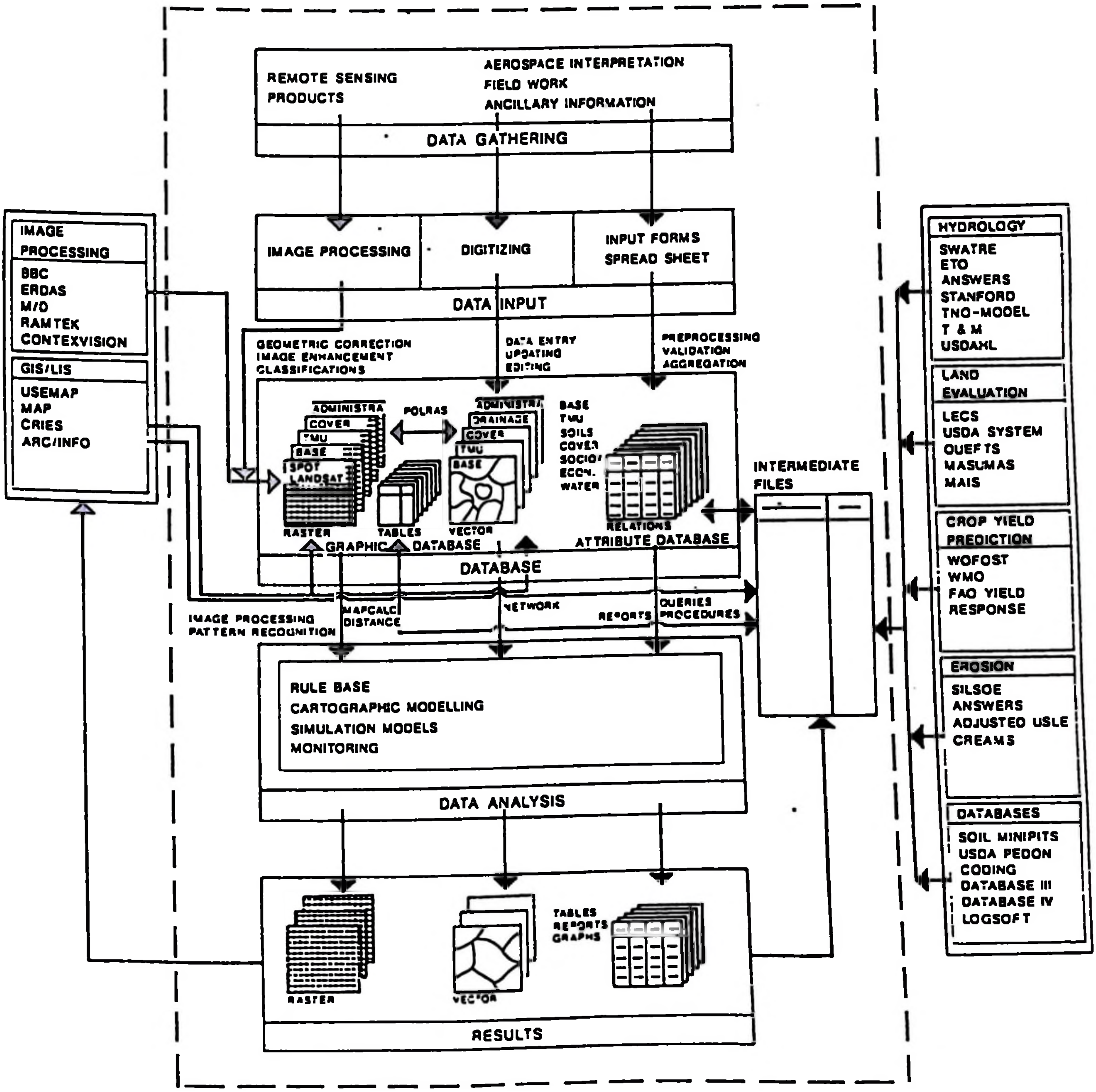


Figure 3.3 Schematic representation of ILWIS (adopted from Valenzuela 1988)

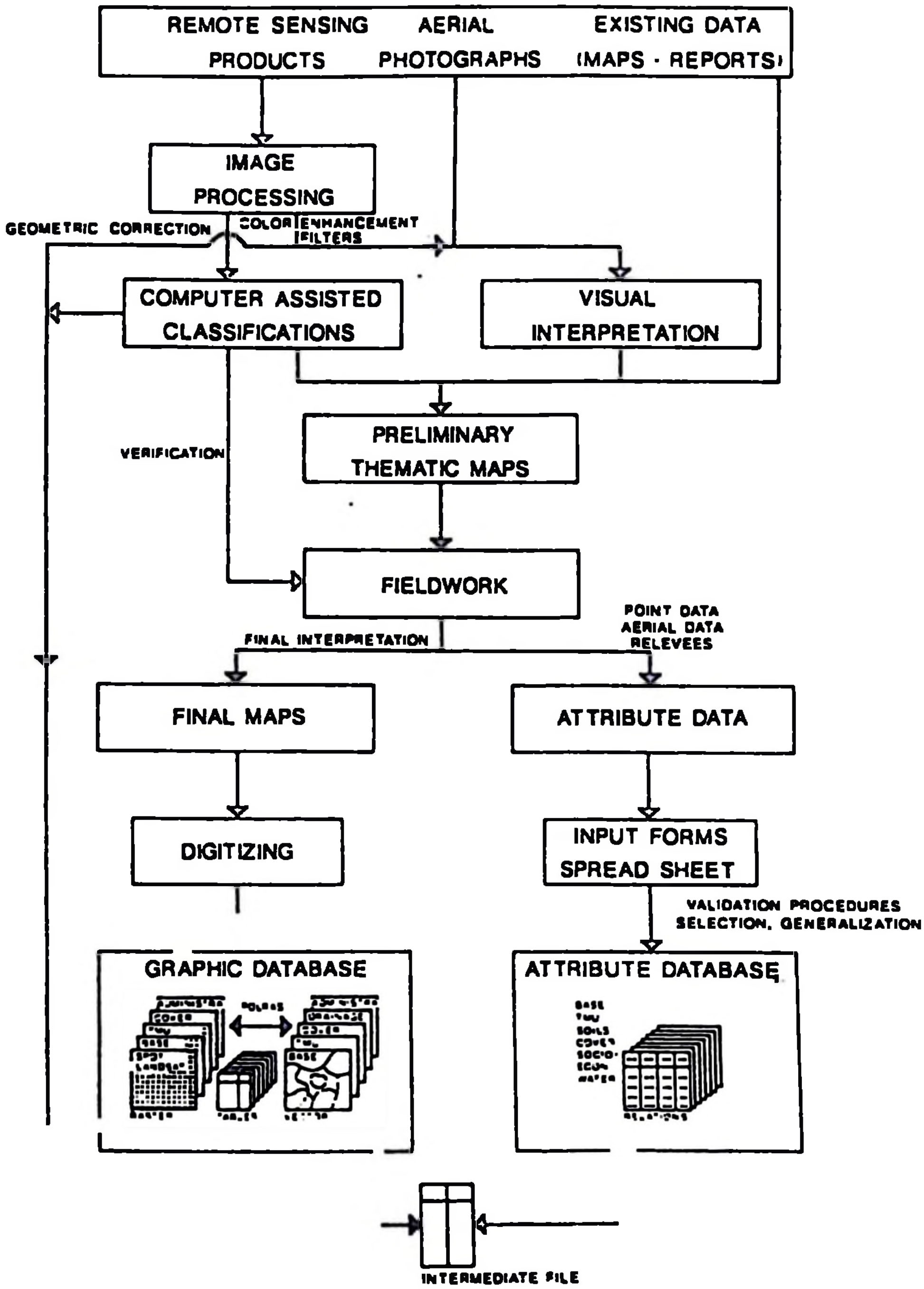


Figure 3.4 ILWIS data gathering and input procedures (adopted from Valenzuela 1988)

Graphics database

The ILWIS graphical database processes spatial information including attributes, a spatial location, extension or configuration. The geometric (spatial) attributes can be metrical which include position, shape and size that can be expressed by spatial coordinates; or topological attributes describing characteristics such as connectivity and adjacency that are invariant under distortions and changes of scale.

Attribute database

This is the module of the database intended to manipulate attribute data. The manipulation *per se* includes operations such as adding new data-sets to the database, inserting new data into existing datasets, updating and/or transforming data from existing data-sets, deleting data from existing datasets and removing datasets from the database.

The Oracle database system

The Oracle data-base system has the following modules:

(a) The base module: including data on administrative boundaries, transportation and communication facilities, settlements, sub-watershed and other related information.

(b) The terrain-soil geography (terrain mapping unit-TMU) module: describing and explaining the main land units and their corresponding soils. The TMU is based on a widely tested ITC system of geomorphologic mapping. It has the geologic-geomorphologic foundation as the key factor and includes aspects of the physiographic approach. It also incorporates morphometric descriptions.

(c) The land cover and land use (CUMU) module: with the main characteristics of vegetative cover and the dominant use type in the watershed. It includes a classification of cover, based on nature density and height, in addition to generally accepted land use classifications.

(d) The water module: presenting information useful in hydrologic models and water balance calculations. It includes station data (rainfall, evaporation factors, discharges and other measured variables. A large number of standard processing methods are included which are used for hydrologic analysis and models, such as agro-climatology, crop yield modelling, erosion and others.

(e) The social/economic module: providing information concerning social and economic characteristics in the area. Farming systems are the basis of the economic evaluation and planning function of the system. Data concerning the nature of the farming systems are collected on the basis of the land cover/land use map to include geographic variations.

Data analysis

Analysis and data handling in ILWIS are performed in both the attribute and graphics databases. ILWIS makes use of conventional GIS data analysis and manipulation capabilities such as map overlaying, reclassification, proximity analysis, optimum corridor and other cartographic modelling technique.

The capabilities are used either by themselves or in conjunction with other simulation or statistical modelling. These include land evaluation, agro-ecological, crop production, hydrologic, land degradation and erosion models.

Cartographic modelling uses the raster operations of MAPCALC. Fast overlaying techniques tied to report, query and display functions (that promote interactive data analysis) make more efficient use of the various models and decision rules. The main characteristic of the system's cartographic modelling is the use of "internal" tabular data, i.e., each map has one or several tables that include a specific single datum (attribute) of the pertinent map. These tables can be obtained from the relational database or generated by GIS operations. The use of internal tabular data reduces data storage requirements and allows rapid reclassification procedures.

3.4.3 Data requirements

ILWIS requires both spatial and non-spatial data. Spatial data includes remote sensing products, aerial photographs and existing data (maps and reports). The main input to ILWIS is spatial data. The remotely sensed data include vegetation, land-use pattern, water, soil including terrain mapping unit (TMU) and soil profile. The data size is quite extensive. Interested readers are referred to ITC Journal, Special ILWIS Issue (1988-1) for a detailed account.

3.4.4 System operations

ILWIS is tailored toward use with microcomputers which are relatively easy to obtain and maintain in most developing countries (target user/clientele). Data gathering procedures incorporate ITC's expertise in developing survey techniques and aerospace interpretation methods. Image processing is very important in data gathering particularly in areas with limited basic natural resource information.

Graphics data are entered with easy-to-use menu-driven procedures for digitizing maps; well structured forms are used to input attribute data. Digitizing is done in a free hand format. Geometric data are stored in both vector and raster structures.

Map manipulation and cartographic modelling are in the raster domain. Several procedures for point, aerial and neighbourhood transformations are available within the map analysis package. Fact overlaying constitutes an important characteristic of the system. For details see Valenzuela (1988); Gorte *et al.* (1988).

Maps can be displayed in both vector and raster structures, colour output (in up to 255 colours) can be displayed on the screen, and hard copies can be obtained using the Tektronix colour printer and the IBM ink-jet plotter or compatibles. Tabular data, statistics and reports are provided by the relational database.

Full integration of the relational database, map analysis package and image processing is being investigated and constitutes one of the main efforts of updating the ILWIS.

3.4.5 Strengths and weaknesses of ILWIS

3.4.5.1 Strengths of ILWIS

The main strength of ILWIS lies in its ability to provide users with the state-of-the-art data gathering, data input, data storage, data manipulation and analysis and data output capabilities, marrying and integrating conventional GIS procedures with image processing capabilities and a relational database. The system can be used with microcomputers which are available and maintained in most developing countries. It has been applied in several regions (Zabel *et al.* 1988; de Meijere *et al.* 1988; Andrade *et al.* 1988).

ILWIS is a fairly flexible information system integrated with modelling system. It may handle problems ranging from watershed management to agriculture planning.

3.4.5.2 Weaknesses of ILWIS

ILWIS does not embody the concept of economic criteria. The system uses spatial and socio-economic data to allocate land use according to land suitability, but does not indicate the economic returns, because it has no optimization module. The model requires extensive data input.

The system is fairly complex. Like all GIS models, the application of ILWIS entail some training in remote sensing and spatial data analysis. Such a training demand adequate facilities which are not readily available in developing countries like Tanzania.

3.4.6 Prospects for wide scale application of ILWIS

ILWIS is a fairly comprehensive model. It has capabilities for handling a wide range of spatial data analysis. Where equipment and trained personnel are available, ILWIS can be a reliable management planning support tool. Furthermore, the model has already been tested outside the Netherlands where it was developed. For example in analyzing farming systems and land use modelling in the upper Komering Watershed (Zabel *et al.* 1988; de Meijere *et al.* 1988) and land use planning in Llanos Orientales, Columbia (Andrade *et al.* 1988). In this way ILWIS has demonstrated its fair ability to be transported and that it is fairly robust. In the case of Tanzania, ILWIS can be useful for land use planning, such as, in miombo woodlands, high tropical forests or tropical rain forests as well as in farming systems.

3.5 Criteria for model selection

There is no absolute criteria for scientists to recommend or classify a model as being good or bad. Furthermore, there is no absolute test of validity or accuracy of a model, but only subjective judgements based on the proposed use of the model, the acceptable levels of errors, the availability of alternative models and other user-related practical considerations.

There are, however, some considerations which may be used as a basis for model selection. These are briefly outlined in the following sections.

3.5.1 Technical considerations

The user has to consider a number of technical factors before selecting a model for application. The technical factors that may be important include:

- Nature and scope of the problem
- Relevance of the model (such as linear or non-linear)
- Robustness of the model
- Complexity of the model

3.5.2 Socio-economic consideration

A model to be useful, it must be acceptable to the decision makers. Most often the decision makers evaluate a model using the socio-economic criteria viz cost versus benefits (Solberg 1988). Some of the cost elements (after Solberg 1988) include:

- Data collection (time, transport)
- Technical expertise (i.e. skills of the user)
- Technical equipment (hardware and software)
- Model development, adoption and training

Further, it can be said that a good model is the simplest model that predicts sufficiently correctly and consistently the behaviour of the real world for the phenomenon of interest. The more complex the model, the more costly it is to use. The cost may be in terms of computer charges, the time of experts, or the cost of understanding the model by the decision makers.

There is, however, a trade-off between cost and performance. Too low a performance level can be costly in errors caused by inaccuracies, by getting results too late or by missing reliable solutions. Too high a performance level can also be too costly by paying for effort that does not improve the actual decisions to be taken. Thus, it is expensive to tolerate performance levels that are too high or too low.

On the other side there are some benefits to be considered by the decision maker (user) contemplating on adopting and applying a particular model. Solberg (1988) argues that the user must consider the "potential improvement of the decisions" as a result of applying a given model. More specifically Solberg (1988) points out that the user must consider the following elements:

- Are conflicting interests a significant part of the problem?
- Are subjective preferences a significant part of the problem?
- Is the dynamic perspective (i.e. time) important?
- Do the decision makers have the necessary understanding of the method?
- What is the socio-economic value of the problem area.

The preceding discussion points to the need for special consideration before a model is adopted.

4.0 QUANTITATIVE MODELLING VERSUS QUALITATIVE LAND USE MANAGEMENT

4.1 Some aspects on the concept of decision making

Decision making is a process with divided tasks even if such tasks are not explicitly stated. Common tasks in decision making include the determination of the variables which predict the utility for any choice of action should be known, discovery of alternative choices of action and prediction of their outcomes in terms of the predicting variables of the utility function (Kilkki 1985). Decisions are of two types, genuine and automatic decisions (ibid). Genuine decisions presupposes that the decision maker makes conscious selection between alternative choices of action. Automatic decisions are consequences of genuine decisions and may be left to subordinates of the decision maker or even to the computer.

There are essentially three conditions in which decisions are made, certainty, risk and uncertainty. Decisions made under certainty assume that each alternative is known such that it results in a specific outcome. It is doubtful, however, that a certainty state can be achieved to the extent that most decisions relate to future events. Ostensibly, most often decisions are made on the assumption that there exist "perfect knowledge of the future" (Kilkki 1985). The main contention of decisions under certainty is that the probability of one outcome is 1 and the probability of the other outcomes are 0 (*ibid*).

Risk indicates a situation in which there is more than one possible outcome from a taken choice of action. The decision makers know the outcomes and also their probabilities. Risk may be determined *a priori* by deduction or *a posteriori* by measurement (Kilkki 1985). The number of decisions made under risk is important when the decision maker considers whether to shoulder the risk alone by himself or to share it with others. If more than one possible outcome is associated with a decision and the probability (P_i) and the utility (U_i) of each outcome i are known, it is possible to calculate the expected value of utility in the following way (*ibid*):

$$E(U) = \sum_{i=1}^{n} P_i U_i \quad i=1,\ldots,n$$

where n = number of possible outcomes, and

$$\sum_{i=1}^{n} P_i = 1$$

Uncertainty represents a state of knowledge in which the possible outcomes of the alternative choices of action are known, but their probabilities are unknown. Most often subjective probabilities are assigned. For instance two decision makers may choose different alternatives depending upon their subjective attitudes towards the uncertainty, even though their utility functions are similar (Kilkki 1985). In this case it is possible to find certain decision criteria which make consistent decisions possible under equal decision situations (Baumol 1977).

Under the environment characterized by uncertainty there are several criteria relevant in the decision making process, but usually the following three are the most important ones; the Wald or maximin, the Bayes or Laplace and the maximax criteria (Kilkki 1985). The main principle of the Wald or maximin criterion is that "the strategy is chosen, which yields the maximum utility given the worst possible future" (Kilkki 1985). The Bayes or Laplace criterion states that "the strategy must be chosen which maximizes the average utility" (ibid). Thus the use of this criterion corresponds to decision making under risk when the probabilities of possible future events are equally large. The Bayes or Laplace decision criterion suits the decision maker who is neither conservative nor daring in making decisions (ibid). The maximax criterion states that "the decision maker should choose the alternative which gives the highest utility if the best possible future is realized" (ibid). The maximax criterion is more relevant for the most daring decision makers such as gamblers.

The three criteria, Wald or maximin, Bayes or Laplace, and maximax can be presented as "pure-strategy" indifference curves plotted through strategies of equal values (Baumol 1977) (See Figure 4.1). The indifference curves are similar to the iso-product and iso-utility curves (see illustration in figure 4.1).

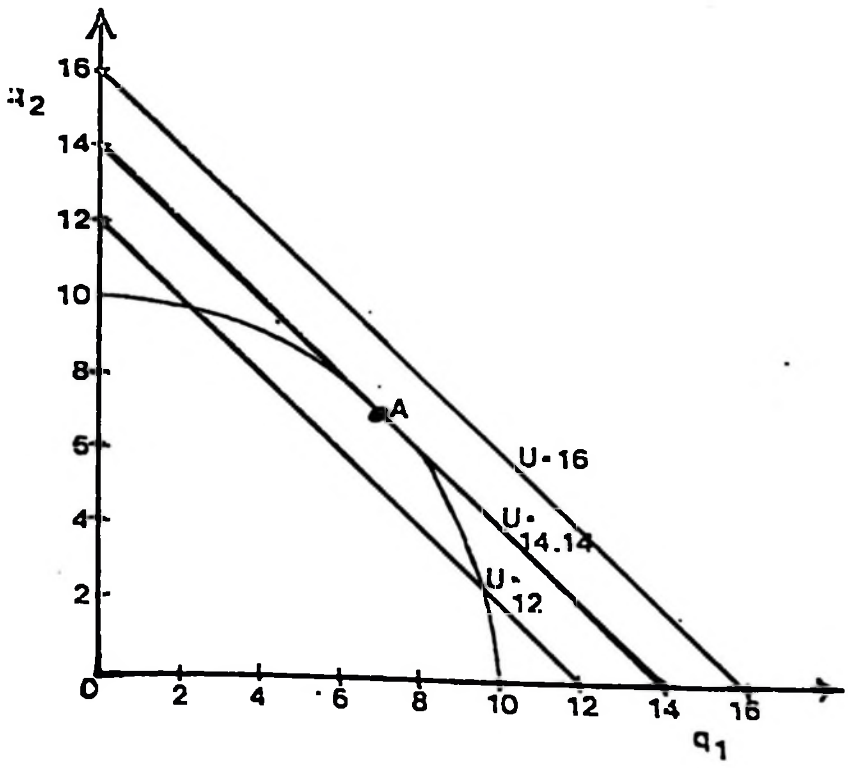


Figure 4.1. Maximization of the utility function (adopted from Kilkki 1985).

The curves U, U_2 and U_3 represent different utilities for two products, q_1 and q_2. Point A indicates the optimum which represents the "least cost combination or efficient level". A hypothetical case where the three criteria, the Wald or maximin, the Bayes or Laplace and maximax are used to make decisions about two alternatives. Alternative I and Alternative II are shown in figure 4.2. The indifference curves representing the Bayes criterion are straight-lines with a slope of -1 (figure 4.2). The indifference curves for the Wald (maximin) and maximax criteria are right angles whose points lie on the 45-degree line through the origin (figure 4.2). The Wald criterion is convex, whereas the maximax criterion is concave to the origin (figure 4.2). Notice that the alternative choices were allocated arbitrarily. All criteria between Wald and Bayes can be described by convex curves. Further it may be said that "these criteria represent conservative decision making" (Kilkki 1985). The concave curves between the indifference curves derived from the Bayes and maximax criteria represent "daring decision making" (ibid).

In all decision making situations, the decision maker has a choice to use quantitative (modelling), qualitative or both methods. Each approach has merits and limitations. Thus it is considered relevant to expose a theoretical overview of these methods. The exposure is covered under sections 4.2 and 4.3.

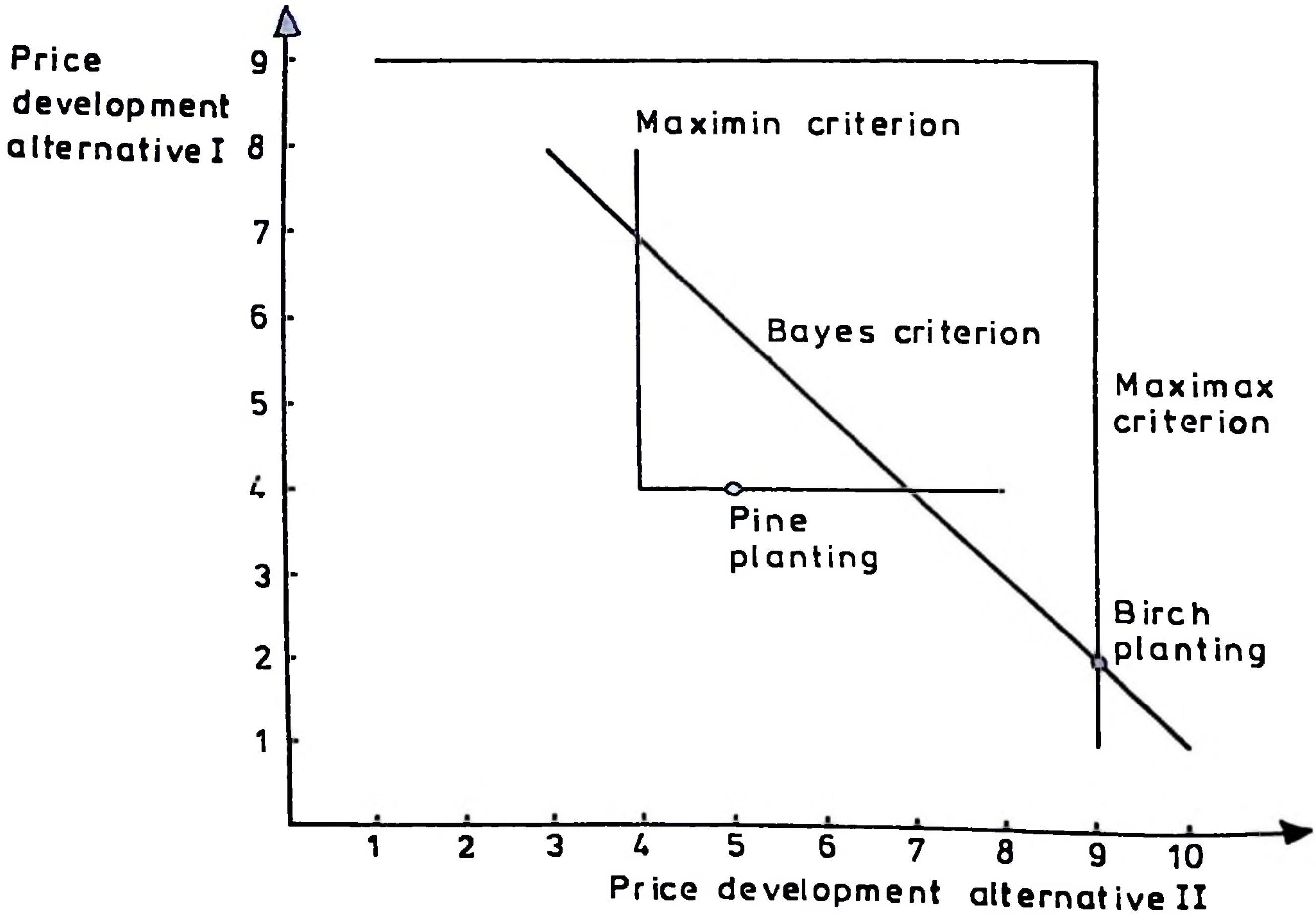


Figure 4.2. Choice of alternatives using the Wald, Bayes and maximax criteria (adopted from Kilkki 1985).

4.2 Quantitative modelling

4.2.1 The concept of quantitative modelling

Quantitative approach to decision making is based on the discipline of "management science". The term management science connotes an idea that decisional problems are defined, analyzed and solved in a logical, systematic and scientific fashion based on data, facts, information and logic instead of intuition and educated guesses (Mgeni 1986).

Quantitative approach to management decision making process, makes use of mathematical models. Mathematical models are a class of models known as symbolic models represented in form of a mathematical equation or a set of mathematical equations (Dykstra 1984). A model represents an object or phenomenon that exists in the real world. Models are created to predict how certain aspects of the real world will behave. They describe the relationship among data elements in order to predict how events in the real world will occur.

Models are developed using scientific method which constitutes a set of essentially four steps "observe, hypothesize, experiment and verify" (Dykstra 1984). The underlying notion is that the application of scientific method to problem solving results into increased managerial efficiency and effectiveness (Mgeni 1986).

4.2.2 Utility of quantitative modelling

Mathematical models serve as powerful tools of analysis provided they represent or describe a system with satisfactory degree of accuracy (Dykstra 1984). They assist decision makers in solving problems in a more objective manner by providing quantitative information.

Mathematical models allow the manager to understand the interactions in an ecosystem, depict the consequences of various actions (biological, economic or social) and choose an appropriate alternative (including the choice of "No Action" an all).

In the context of land management, experiences from industrialized countries and elsewhere (Bell 1976, Arp and Lavigne 1982, Van Del Zel and Walker 1988, Betters 1988, Pukkala and Pohjanen 1990, Sankhayan and Cheema 1991) have shown that quantitative models can provide an important tool for the policy decision makers to develop more reliable and resource efficient land use plans to the extent that they are based on data, facts and logic. Further, mathematical models provide a framework for making alternative calculations and efficient use of information (Solberg 1988).

4.2.3 Limitations of quantitative modelling

Quantitative modelling suffers from a number of serious limitations, the most important are:

(a) Quantitative modelling does not substitute for managerial intuition and judgement in the decision making process.

(b) Quantitative modelling, to be of practical application, depends on the availability of data which are often "constrained" by costs and time.

(c) In developing quantitative models we may abstract too far from the real situation to render the results meaningless (Dykstra 1984).

(d) Ecosystem are often complex. Thus it is very difficult to include all pertinent variables in the model. The inclusion of many factors may render the model too complicated to be of much practical use. Overzelousness to complicate the model may not only pose problem in understanding, but also in running the model without necessarily increasing the utility of the results. The real product, so observes Dykstra (1984), is the increase of the "computational burden".

(e) Human minds are fallible. Therefore it is difficult to develop a "fool-proof" model. Even the most commercially used software/package may have "bugs".

(f) Models are often complex to visualize. In order to benefit from quantitative models, decision makers need to have a fair knowledge or basic understanding of mathematical models.

(g) Due to data limitations managers sometimes accept "good enough" (or near-feasible and near-optimal) as opposed to "best" solutions, a philosophy dubbed as "satisficing" (Simon 1975). The idea behind accepting "good enough" is to keep the firm going or progressing under the existing resource limitations.

(h) Individual biases. Modellers have different paradigms. In developing models, there are personal preferences and biases. The bad side of it is that a modeller may not be able to discover/state his/her own biases. Further, because modellers have strong modelling biases, they tend to "force" problems into a particular model. This attitude tends to "distort" the intended objective of solving the problem (Seppälä 1985).

4.3 Qualitative land use management

4.3.1 Essence of qualitative land use management

Mathematical models are not *panacea*. Moreover, they are fallible and have some limitations (see section 4.2.3). It is due to the inherent limitations of mathematical models that recognition must be given to qualitative land use management using of managerial intuition. In economic perspective managerial intuition is vested upon entrepreneurs who discharge decisions based on intuitive (non-stated) assumptions, but could be quite efficient. Dykstra (1984) observes that "successful managers are frequently capable of integrating a great many seemingly unrelated pieces of information into an informal system for decision making". The systems we are dealing with are often complex. Thus, the managerial ability to perceive and conseptualize issues intuitively is a necessary step in not only discharging the "right decision", but also in managing resources.

In neo-classical management theory (see for instance Mintzberg 1983, Kaoneka 1987) firms and organizations are considered to constitute a system or whole entity constituting the strategic apex, technostructure, supporting staff and operating core. Of particular importance to decison making process are the strategic apex personnel who constitute the line people with formal authority and the technostructure personnel who in fact are the "experts" though have only informal authority. The line people discharge authority in the decision making process. In theory their decisions must be based on expert advises given by the technostructure personnel. However, often the two are "rival" groups. The line people accuse the staff personnel of being too theoretical and lack practical experience. The staff personnel accuse the line people of being ignorant because they are not experts. Nevertheless, it is argued that even though the line people lack expert or technical training, they have formal authority based on their personal ability to discharge "rational decisions" (Mintzberg 1983). Thus, technical expertise can only complement but not substitute managerial intuition (*ibid*). Ostensibly technical experts are important because they define the technological alternatives that are relevant and can conduct impact analyses (Solberg 1988). Qualitative land use management is based on those factors that are non-quantifiable such as many political, social, institutional and cultural factors. The baseline premise is that, although these factors are very important in designing proper land use plans, they cannot all be quantitatively measured and modelled.

4.3.2 The utility of qualitative land use management

The main utility of qualitative land use management is that it is easy to comprehend and apply in the decision making process. Moreover, it is cheap because it requires "limited" training and hardware compared to modelling or quantitative approach. This is especially important in developing countries where computer technology is relatively limited.

Moreover, in many developing countries the basic data, such as weather, soils and crops, are either not available or of such doubtful validity, that the results of the calculations are at best only rough indicators of the true coefficients. In the management of land-based resources some non-quantifiable factors are so important that unless decision-makers consider them, any land-use planning effort is likely to bear limited returns only. Some of the more important factors include political aspirations, social preferences, cultural values and institutional framework such as land tenure system. Yet these factors cannot be modelled to the extent that they are non-quantifiable. Although, they can be taken into account by decision makers using the qualitative land use management approach, perhaps in combination with quantitative modelling.

Further, decision makers with experience and vision may integrate a set of qualitative factors into the "decision making framework". For instance some entrepreneurs can be considered to have a reliable economic vision about the operations of a firm such that their decisions are "trusted".

4.4 Relationship between quantitative and qualitative approaches in land use planning

In section 4.2 and 4.3 we discussed the strengths and weaknesses of quantitative and qualitative approaches to land use planning. The strength of quantitative methods lies in modelling and the ability to generate quantitative data which can be used in the decision making process. The method is limited, *inter alia*, by the fact that not all pertinent factors in land use planning can be quantified and modelled. The strength of qualitative approach is attributed to its ability to integrate qualitative information into a decision making framework using intuition. The approach is limited, however, because by making use of managerial intuition, the qualitative approach invariably introduces biases and subjective value judgement.

These facts point to the need for "integrating" quantitative and qualitative techniques in the decision making process to the extent that none of the two methods is "perfect". Furthermore, while models generates quantitative data, managerial intuition is applied to "correctly" interpret model solutions during actual decision making. Models are tools of analysis only, and not decision makers. In addition managerial intuition is often applied as a supplement to quantitative methods by providing qualitative information or subjective data estimates. For instance, in land use planning *per se*, decision makers can apply linear programming technique to generate optimum farm plans given certain assumptions. Yet, the implementation of the plans is strongly influenced by such qualitative aspects as land ownership and tenure arrangement or system and social preferences, which though important can hardly be modelled. In essence, therefore, it can be said that quantitative and qualitative approaches in land use planning are complementary rather than competing methods. In fact, the results generated by models are useless, unless they are correctly interpreted and put to use by decision makers. Furthermore, the reliability of a model depends on proper conceptualization of the problem, a process which is largely intuitive. On the other hand, decisions based on managerial intuition are sometimes taken "sceptically" unless they are backed in some way, by hard facts or quantitative data.

Proponents of quantitative approach to land use planning such as Dykstra (1984) contend that "it is also well to realize that the alternative to mathematical modelling is often even more restrictive". Critics of quantitative methods (or proponents of qualitative) methods contend that "modelling, however, good it is, cannot substitute managerial intuition and subjective values" (see for instance Mgeni 1986). However, an inclination toward either method must be based on "the structure of the problem" and the overriding objectives of the decision makers or interest groups involved (Solberg 1988). Further, it is well to realize that there is no universal selection criterion "as each problem has to be considered separately" (Solberg 1988). Based on these views, there is a reason to recommend a balanced application of both quantitative and qualitative methods especially due to the existence of uncertainty and risk in decision making environments. Uncertainty and risk elements (discussed some under section 4.1) makes it important to apply both approaches in most decision making situations.

5.0 CONCLUDING REMARKS

Based on the review and discussion covered in this report it can be concluded that the results of the models applied in Tanzania were satisfactory. Further, it can be said that the scale of application was fairly limited. Therefore, the increase of the scope is desirable in order to increase the contribution and experiences of models as analytical tools in land use planning.

The review of models indicated that all three models, ECOSIM, TEAMS and ILWIS have considerable potential for application in Tanzania and the West Usambara mountains. However, proper calibration is important in order to enhance the relevance of the models for wide scale application. In terms of model selection for application there is no universal quiding criteria. The basis for model selection is the structure of the problem, stated objectives and hypotheses and subjective preferenceof the decision maker.

Both quantitative and qualitative approaches to land use planning have strengths and weaknesses. Thus, it could be more realistic to use a combination of the two methods in a given land use planning problem.

Finally, the review of this report is limited both in terms of scope and detail especially taking into consideration the broad coverage of modelling and qualitative management theories available world-wide. Therefore, the results of this report may be looked upon as a point of departure for further exploration into quantitative and qualitative approaches in land use planning and general decision making process.

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APPLICATION OF ECONOMIC ANALYSES AND MATHEMATICAL PROGRAMMING IN LAND USE PLANNING AT THE VILLAGE LEVEL IN THE WEST USAMBARA MOUNTAINS, TANZANIA

Report Number 4

ABSTRACT

The main objective of this study is to apply a combination of welfare economic theory and mathematical programming to analyze the optimal land use management at the village level in the West Usambaras. This involves the analysis of the existing farming systems, socio-economic relations between agriculture and forest lands and assess the sustainability of the present agriculture practises given the increase in population, and the effect of risk aversion on land use pattern. A budget procedure was used to assess soil productivity. The data for the study were obtained from both secondary and primary sources.

Micro-economic procedures are used to analyze the profitability and returns to labour of the present farming systems. In mathematical programming two techniques, linear programming (LP) and compromise programming (CP) are used to analyze the present farming systems, the effect of population on land use pattern, per capita cash income and consumption from own farm and the effect of risk aversion. Finally, the model results and soil analysis are used to examine/assess the sustainability of the present farming systems in light of population growth and income constraints.

The analysis indicates that population growth creates considerable pressure on forest lands especially where arable land is limited. The pressure emanates from increased demand for food which necessitates the expansion of farmlands. In areas of limited arable land such expansion is achieved by way of clearing forest lands. Therefore population growth accelerates the rate of deforestation as long as it remains profitable to the farmer.

The increased demand for food compels the farmer to allocate more land and family labour to the production of subsistence crops in favour of cash crops. Due to limited cash income labour hiring is hardly possible. Therefore, the allocation of more labour to the production of subsistence crops reduces the available labour for cash crop production.

The diversion of large proportion of land and labour to the production of subsistence crops has the effect of reducing the amount of cash income earned by a household. Hence the per capita cash income declines to the extent that farmers rely on agricultural activities for generating cash income. The reduction in per capita cash income affects the welfare of the farmer because it implies that the ability to purchase market goods becomes limited. Experience indicates, however, that in the rural sector of Tanzania, and in particular in the West Usambaras, population growth is seldom matched with a corresponding socio-economic growth. Therefore a decline in per capita income is not surprising.

The analysis presented in this study has indicated that the present farming systems can sustain the present population growth rate (2.1% per annum for Lukozi Village) and per capita income for a maximum duration of between 25 and 30 years whereas life expectancy in Tanzania is over 45 years. Thus the present farming systems cannot sustain even one human generation. Furthermore the assessment of soil productivity indicated that removals of soil nutrients through crop harvests alone are higher than the amount added to replenish soil fertility. The decline in soil nutrients causes a decrease in crop yields over time due to land degradation.

The analysis has indicated that risk aversion, especially the risk associated with over time variation in crop yields and product price, hence gross returns, has the effect of reducing income per capita and cultivated land area. In an extreme case, if the farming situation is perceived to be very risky, a farmer may produce only enough to meet the subsistence needs and attempt to earn cash income from off-farm activities. The risk elements are important to a farmer due to the biological nature of crop production and market variability of agricultural crops. In essence, therefore, the inclusion of risk makes the modelling more realistic and increases the utility of a model.

Key words: land use planning, farming systems, mathematical programming, linear programming, multiobjective programming, compromise programming.

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To all these institutions and persons I wish to say SHUKRAN.

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LIST OF ABBREVIATIONS

TAS	=	Tanzanian shilling
URT	=	United Republic of Tanzania
IUCN	=	International Union for Conservation of Nature
FINNIDA	=	Finnish International Development Agency
SECAP	=	Soil Erosion Control and Agroforestry Project
TIRDEP	=	Tanga Integrated Rural Development Project
GTZ	=	Germany Assistance for International Development
SUA	=	Sokoine University of Agriculture
CRDB	=	Cooperative Rural Development Bank
AUN	=	Agricultural University of Norway
TAF	=	Tanzania Association of Foresters
TFAP	=	Tanzania Forestry Action Plan
ERP	=	Economic Recovery Programme
SAREC	=	Swedish Agency for Research Cooperation with developing countries
TRDP	=	Tanga Regional Development Plan
RTC	=	Regional Trading Company
TARECU	=	Tanga Regional Cooperative Union
MOP	=	Multiobjective Programming
MCDM	=	Multicriteria Decision Making
LP	=	Linear Programming
CP	=	Compromise Programming

SI UNITS

mm	=	millimetre
cm	=	centimetre
m	=	metre
km	=	kilometre
ha	=	hectare
ppm	=	parts per million
me	=	milligram-equivalent
g	=	gramme

UNIT CONVERSIONS

1 cm	=	10 mm
100 cm	=	1 m
1000 m	=	1 km
$10000 m^2$	=	1 ha
1000 ha	=	$1 km^2$
1 ha	=	2.471 acres

CHAPTER 1 INTRODUCTION

1.1 Background

West Usambara Mountains, located in the north-east corner of Tanzania (Map 1) consist of high tropical rain forests forming a part of the Eastern Arc Mountains embodying the Usambara, Pare, Nguru, Uluguru and Udzungwa mountains. The eastern arc mountains are known worldwide because of their relatively high diversity of endemic and near-endemic floral and faunal species (Iversen 1987; Pocs 1988; Bjørndallen 1992; Kaoneka 1993b). The long-term existence of these important forests is threatened by the adverse human activities, such as, the expansion of agriculture lands and human settlements, overgrazing of livestock, illegal harvesting and indiscriminate forest fires in these mountains (Pocs 1988; Chamshama and Nsolomo 1990; Kaoneka 1990 and 1993b; Bjørndallen 1992). The most prominent problems arise from the encroachment of forests in form of expanding agricultural lands and human settlements. However, due to scope limitations the current study is limited to the Usambara mountains, particularly the West Usambaras.

In the past most land of the West Usambaras was protected by natural forests and the population density was low, thus making soil erosion and general land degradation a less serious problem. Moreover, the farming practises of shifting cultivation, mixing of trees with farm crops (traditional agroforestry) and minimum weeding were all practises considered to be "in harmony with the environment" because of their limited impact on land degradation (Scheinmann 1986).

Overtime, however, the resource/man ratio changed due primarily to relatively fast increase in population thereby tilting the balance of resource utilization. People overexploited the natural forests to pave way for agricultural lands and settlements. Furthermore the colonial administration introduced cash crops, such as, tea, coffee and cardamon which needed not only monoculture systems but also forest conditions because they needed ameliorated conditions and the adoption of monocropping farming systems (Scheinmann 1986; Iversen 1987; Woytek *et al.* 1987; Shenkalwa 1989). These factors resulted into the degradation of the forest and other land-based natural resources due to deforestation (see figures 1 and 2) and frequent and high nutrient uptake through the farming systems. Also the introduction of monocropping system, which demanded clean weeding, increased the potential of soil erosion (Shenkalwa 1989). A detailed account of the factors which cause land use problems in the West Usambara is given in Kaoneka (1993b).

A reconnaisance survey carried out in 1991 showed a considerable level of encroachment in natural forest reserves managed by the Shume-Magamba Forest Project. The encroachment was mainly in the form of expanding farmlands. The encroachment was seen as a symptom rather than a cause *per se*. It can be looked upon as a manifestation of inefficiency of the subsistence form of agriculture and general bad farmland management practises. Moreover, there is increasing demand for food and other basic needs caused by population growth. Due to limited arable land and low per hectare productivity, most farmers meet the increased household needs by expanding their farmlands through forest clearing. This was more evident on the north-eastern part of the Shume-Magamba Forest Project especially where border

Figure 1.1 Degraded lands of the West Usambaras

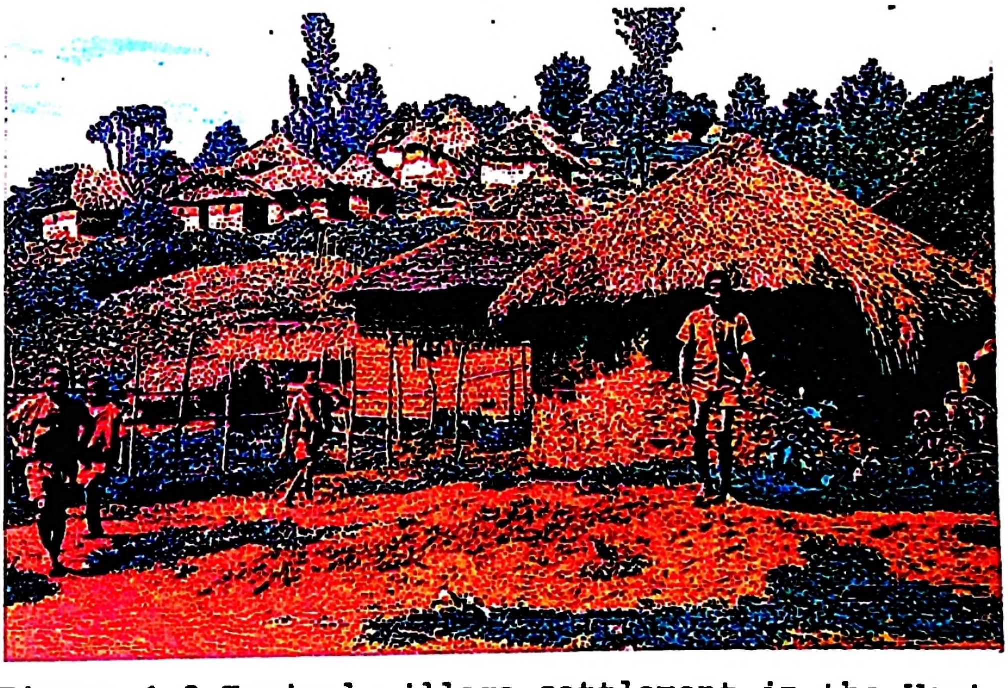
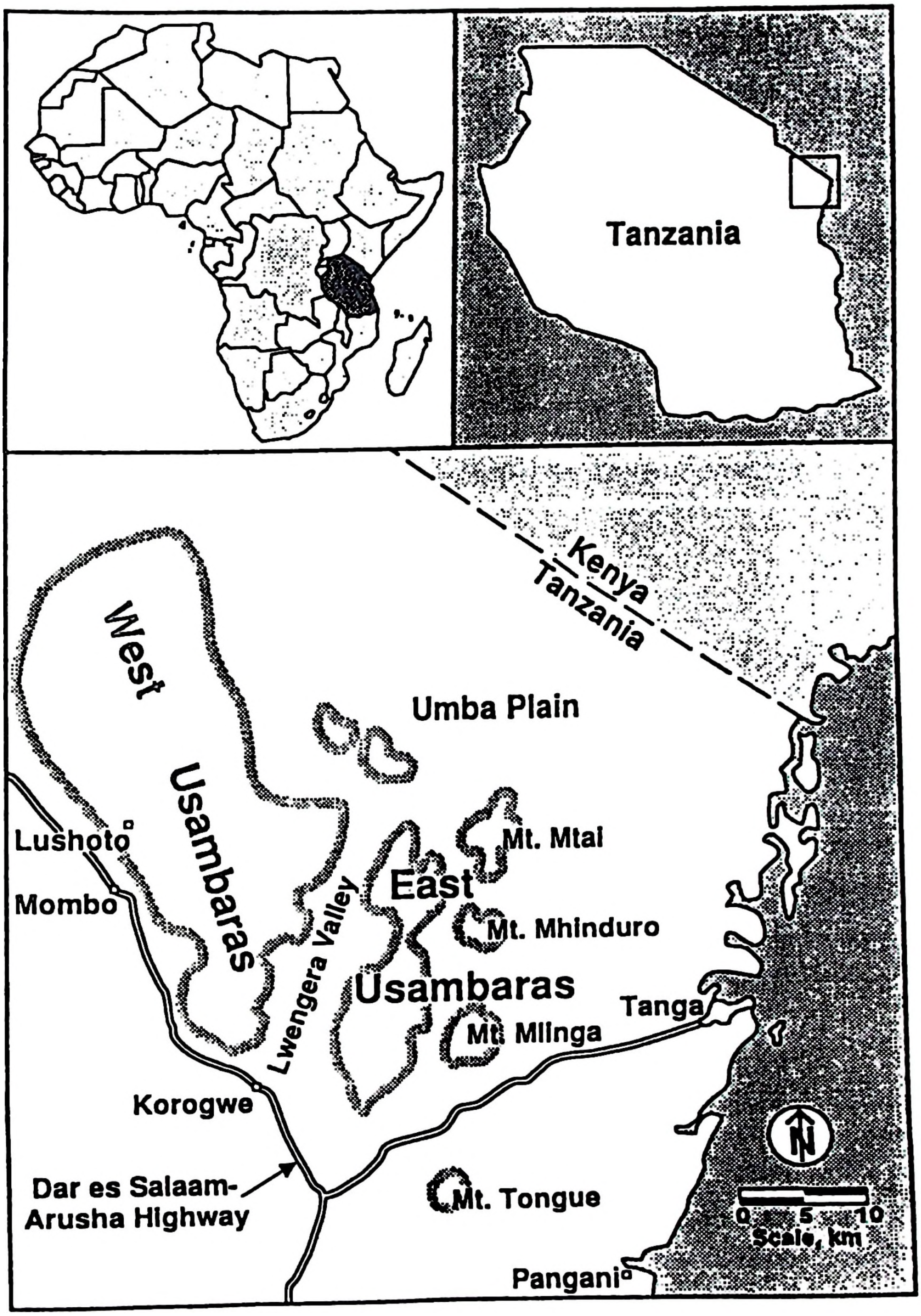


Figure 1.2 Typical village settlement in the West Usambaras



Map 1.1 Geographical location of the West Usambaras

demarcations are not distinct.

On the basis of this background it was deemed relevant to conduct some studies at the micro-level in the Lukozi area where high levels of encroachment and land degradation was observed. The analysis presented in this report has dual purpose. First, to assess the performance of the existing system in meeting the needs of the farmers. Second, to evaluate the performance gap by comparing present resources and outputs *vis-a-vis* what the farmers are actually producing relative to the existing biophysical potentials or resources. Also, the study will be used to analyze the relationship between population growth and deforestation. A single village was chosen as a study area due to time limitations.

1.2 Objectives of the case study

The main objective of this study is to apply a combination welfare economic theory and mathematical programming to analyze the existing farming systems, socio-economic relations between agriculture and forest lands and assess the sustainability of the present agriculture practises given the present increase in population, and the effect of risk aversion on land use pattern.

The more specific aims of the study are to:

(a) Describe of the existing farming systems and the resource use under these systems in Lukozi Village.

(b) Conduct micro-economic analysis to examine the following aspects:
- (i) labour demand and timing of farming activities,
- (ii) yield levels on smallholder farms and
- (iii) relative returns to limiting resources.

(c) Apply mathematical programming models to:
- (i) determine the optimum allocation of land to various crops with the aim of maximizing net cash income while meeting subsistence needs of the household family,
- (ii) determine the optimal cropping pattern under monocropping and intercropping farming systems;
- (iii) analyze the effect of population growth on agriculture/forest relations, per capita cash income and subsistence consumption from own farm,
- (iv) conduct sensitivity analyses to elucidate the effect of changes in farm-gate (producer) prices and total working capital on optimum farm plans, *viz*, net cash income and land allocation to various crops and
- (v) analyze the effect of risk aversion on land use pattern, per capita cash income, subsistence consumption and pressure on forest lands.

(d) Analyze agroforestry as an alternative to the present farming systems.

(e) Discuss the sustainability of the present farming systems.

1.3 Working hypotheses

The working hypothesis in this study are:

(a) Given the present population growth trends, the present farming sytems are not sustainable.

(b) Population growth will cause deforestation over time due to the expansion of farmlands.

(c) Family labour is not adequately utilised in the present farming systems.

(d) Provision of credit facility increases the rate of deforestation due to expansion of farmlands.

(e) Risk aversion reduces the area under farm crops which in turn leads to decreased deforestation.

1.4 Structure of the report

This report is divided into five chapters. Chapter 1 gives introduction and statement of the problem and outline the objectives of the study. Review of some theoretical aspects as background to the study is presented in Chapter 2. The theoretical aspects reviewed are those related to production economics, farm household economics, linear programming and compromise programming in a multiobjective framework. Chapter 3 describes the methodology used in the study *viz* study area, method of data collection, overview of techniques used in data analysis, the development and application of mathematical models. Chapter 4 presents the discussion of the results. These include analysis of existing farming systems, analysis of agriculture/forestry relations, *stochastic* analysis of farming systems, an economic analysis of agroforestry systems and assessment of soil productivity. Finally, the discussion of the sustainability of the present farming systems and general conclusions are given in Chapter 5.

CHAPTER 2 THEORETICAL AND LITERATURE REVIEW

This chapter reviews some theoretical aspects of production economics, household economics, cost-benefit analysis and mathematical modelling as background for the empirical part.

2.1 Some theoretical aspects of production economics

2.1.1 General perspectives of production economics

The economic theory of production deals with problems of allocation and utilization of scarce resources, which have competing alternatives, by individual firms (Joyce *et al.* 1983; Gregory 1987). A firm is looked upon as a technical entity which engages in production, a process of transforming inputs into outputs. Inputs are the factors of production or resources, which include land, labour, capital, fertilizers and others which are used in the production system. Outputs are those commodities produced by the firm such as sawn timber, fodder, maize and others that are needed in order to increase the welfare of the society. A typical production system has essentially three parts, input base (raw material), processing unit which transforms the inputs into consumer and intermediate goods, and output base consisting of consumer and intermediate commodities (see also Figure 2.1). The feedback mechanism has dual role, recycling of a part or whole of the output and relaying signals for improvement or adoption of new technologies.

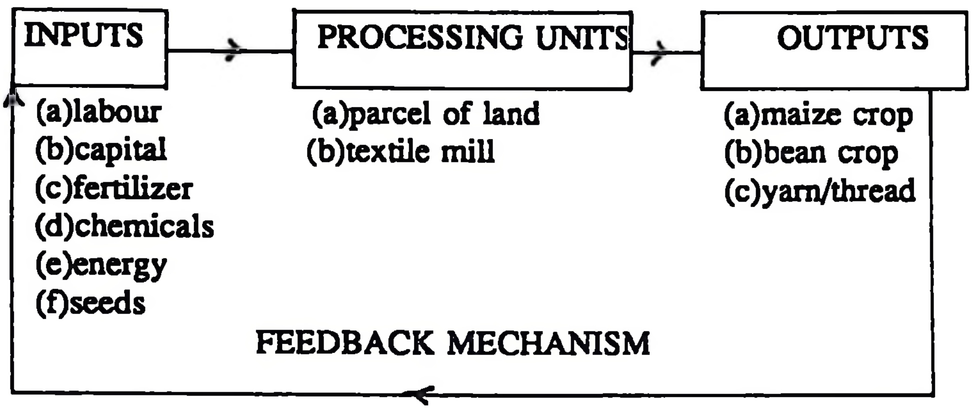


Figure 2.1 A conceptual framework depicting a technical production system

In the peasant economic system, a household can be considered to be a "technical unit" capable of transforming inputs into outputs using largely family labour (or time). During the production *per se*, a single output or multiple outputs may be produced. The two concepts are so important in production economics that they merit a brief review, which is the topic of sections 2.1.2 and 2.1.3.

2.1.2 Single output production

In the case of a single output production, a firm may specify the maximum output that is obtainable from combining the available inputs or resources. Such an arrangement is considered to be technically efficient (Joyce *et al.* 1983).

A mathematical expression that relates inputs and outputs through a technically efficient production process is called a production function. A production equation is symbolically presented as follows (Mansfield 1988):

$$Q = f(I_i) \qquad [2.1]$$

where

Q	=	quantity of output per unit of time	
I_i	=	quantity of *ith* input per unit of time	$i = 1, 2, \ldots, n$

If we now consider a peasant household producing a single crop, maize, the general equation [2.1] can be transformed into a more specific equation as follows:

$$Q_m = f(L, F, S) \qquad [2.2]$$

where

Q_m	=	maize output, kg ha^{-1} or t ha^{-1}
L	=	labour, mandays or hours
F	=	fertilizer, kg
S	=	seeds, kg

All the above variables are expressed on per unit of time basis, such as, a year.
A production function can be either linear or non-linear. The main use of a production function is to predict output empirically. There are two concepts related to production function worth mentioning, average and marginal (physical) product (APP and MPP). An average product is the average output per unit of input for all tested quantities of the variable factor (Gregory 1987). It is estimated arithmetically by dividing the total (physical) product by the input required to produce that amount. Hence,

$$APP = Q/I \qquad [2.3]$$

where

APP	=	average physical product
Q	=	total (physical) output
I	=	total inputs (in physical terms)

A marginal (physical) product represents the amount of change of output caused by a unit change of input. It is determined as the first derivative of a production function. Therefore if the production function is specified as, for example;

$$Q = c + b_1X + b_2X^2 \qquad [2.4]$$

where

Q	=	total output
X	=	input factor
c	=	constant (the Y-intercept)
b	=	"regression" coefficient ($b = b_1$ and b_2)

Then,

$$MPP = \delta Q/\delta X \qquad [2.5]$$

where

MPP	=	marginal physical product
$\delta Q/\delta X$	=	1st derivative of production function

For this function,

$$MPP = b_1 + 2b_2X \qquad [2.6]$$

Using the non-linear theory of binomial and polynomial functions, the maxima are computed when the slope of the curve is zero. By the same rationale the maximum MPP occurs when the slope of the curve is zero. Mathematically this argument represents,

$$b_1 + 2b_2X = 0 \qquad [2.7]$$

In this way the maximum MPP may be determined by ordinary factoring procedure of a polynomial function. The factors of production are sometimes substitutable. This situation occurs where a factor of production, I_1, can substitute factor I_2. The technical substitution provides a marginal condition for optimizing production which is represented by the equation;

$$\frac{\delta f/\delta I_1}{\delta f/\delta I_2} = RTS_{12} = \frac{C_1}{C_2} \qquad [2.8]$$

where

RTS_{12}	=	rate of technical substitution of I_1 substuted for I_2
C_1	=	market price of factor (input) 1
C_2	=	market price for factor (input) 2

I_1 and I_2 remain as previously defined

The term $\frac{\delta f/\delta I_1}{\delta f/\delta I_2}$ represents the ratio of partial derivatives of the production function which is the ratio of marginal products of the two inputs I_1 and I_2. The ratio is also referred to as the rate of technical substitution (RTS) which expresses the rate at which one input can be substituted for another in production while maintaining the same level of output (Joyce *et al.* 1983). Figure 2.2 depicts RTS as the slope of an isoquant which in turn is the locus of all combinations of I_1 and I_2 giving the same level of output.

The term C_1/C_2 is the ratio of market prices for the two inputs. The level of least cost production is determined by equating the RTS and C_1/C_2 (ratio of marginal products or rate of technical substitution and the ratio of market prices for the input. Thus,

$$RTS = \frac{C_1}{C_2} \quad \text{(c.f. equation 2.6)} \qquad [2.9]$$

The relevance of this concept to the analysis of peasant household production depends largely on whether or not family labour can be substituted by hired labour, assuming that other inputs are fixed in their use (Holden 1991). Labour hiring is often constrained by the scarcity of cash income in peasant households.

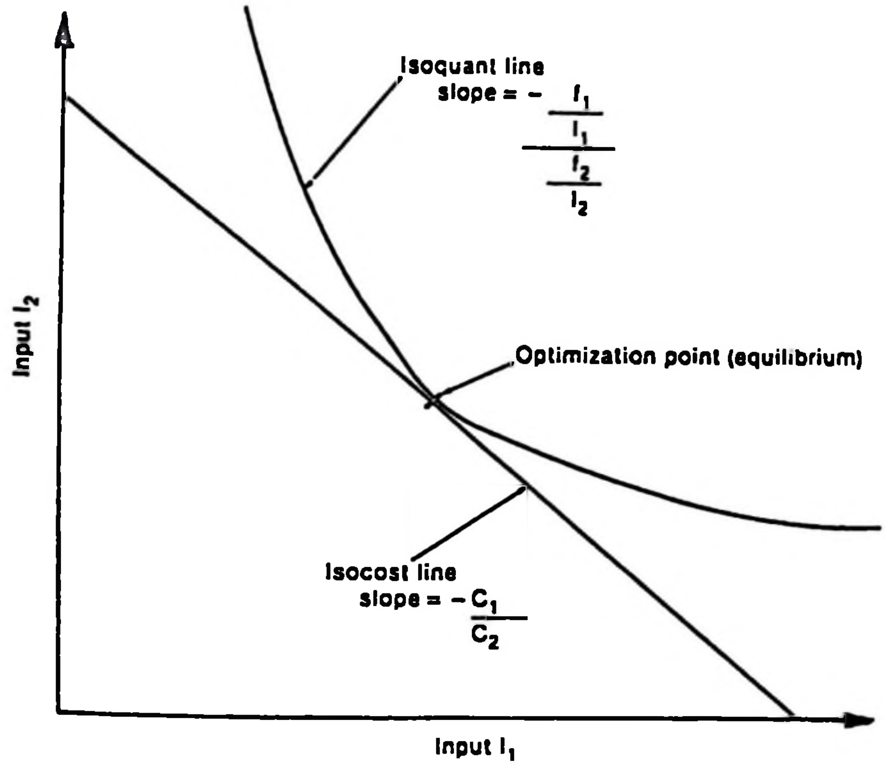


Figure 2.2 Isoquant and isocost equilibrium (adopted from Joyce *et al.* 1982)

The level of production is assumed to be influenced by some market forces. Further, it is assumed that a firm seeks to optimize production in order to meet food and cash income needs. The firm may have to make three general decisions:

(a) Maximization of output subject to a fixed (often limited) budget or disposable cash income with which to purchase market inputs;

(b) Minimization of the cost of inputs subject to producing a given level of output;

(c) Maximization of profits where both budget and output quantities are variable.

2.1.3 Joint production

Joint production occurs when the same production facility (or same factory) is used to produce two or more products herein referred to as multiple use or multiple outputs (Gregory 1987). In forestry the concept of multiple use is very relevant to the extent that a forest as an ecosystem has multiple benefits to both individuals and the society, such, as timber production, recreation, soil conservation, water catchment, gene pool conservation and general ecological function. Thus for a given forest it is possible to practice management systems that can ensure the production of multiple outputs. The same rationale can be applied to agriculture where bare land has multiple or alternative uses. On the same hectare of land a farmer can produce jointly maize/beans or maize/potatoes or other possible crop mixtures.

The underlying principle of a joint production is that "at least one of the factors, often the entire group of fixed factors, is jointly used" (Gregory 1987). There are two variations of joint production. One is that in which products or outputs are produced in technically fixed proportions. In this type of joint production the entire range of possible product combinations hold a constant ratio to each other in the short run. In this case it is not possible to compute average costs for the multiple outputs. This may hold true also to other joint production systems. It is possible, however, to calculate marginal costs for both outputs. The marginal costs derived in this manner contain all the additional costs incurred by the production of the particular output (*ibid*). In fact it is the marginal costs that are especially relevant to decisions related to production though it is a rare component in the context of forestry (*ibid).*

The second type of joint production is that in which the outputs are produced with technically variable proportions. This type of joint production is common in forestry as most forest products are produced jointly but in variable proportions. For the purpose of maximizing net present value (NPV) both costs and revenues are included and where intangible goods are considered imputed values are assigned to them. The costs and revenues so included apply to the technical aspects of product combinations (Gregory 1987).

In most cases the net present value (NPV) criterion is used to evaluate mutually exclusive alternatives which have economic goals as the overriding objective (Munasinghe 1992). The technique embodies the concept of cost-revenue structure. Thus it is logical to review the cost-revenue theory as it applies to production systems. A conceptual example may be used to clarify the concept. Let us consider a joint production where two outputs are produced in such a way that each combination gives the same level of costs, also known as isocosts. By the same token, any combination must give equal level of revenue or isorevenue since the objective is to obtain the same amount of returns for a given production system in which two or more products are produced jointly.

The concept can be illustrated graphically as shown in Figure 2.3. An isorevenue curve represents equal revenues generated from varied combinations of timber and fodder outputs. An isocost represents equal costs incurred in producing jointly, but in variable proportions timber and fodder outputs [Note: Fodder is measured in animal unit month, AUM]. The point of tangency between production possibility and isocost curves defines a least cost combination of the two products jointly produced for a given level of resources. The tangency points define the points where revenues are at maximum for any cost outlay (*ibid*). When a "family" of isocost and isorevenue curves are drawn on the same graph (as is the case in figure 2.3), the different tangency points are joined together by a line referred to as the expansion path. This line defines the lowest cost and maximum revenue hence more efficient product combinations. Therefore "any rational producer would always operate in such a manner as to produce one of the product combinations identified by a line connecting all these points of tangency; that is, the producer would always operate at some point on the expansion path" (Gregory 1987).

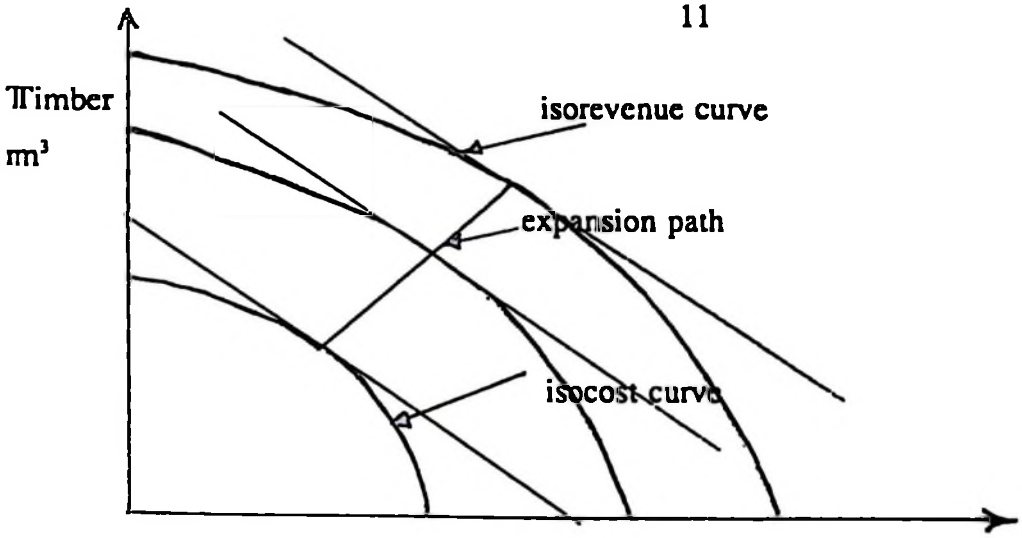


Figure 2.3 Joint production of timber and fodder in variable proportions (adopted from Gregory 1987)

In a joint production the marginal cost can be determined for each output. For the moment let us consider that a technical system produces only two products, X and Y jointly. The total cost function is given by;

$$TC = f_c\,(X,Y) \qquad [2.10]$$

where

TC	=	total cost
X	=	timber
Y	=	fodder

The marginal cost (MC) is normally determined by taking the first order derivative of the total cost function of each product. Thus, the MC of timber (X) and fodder (Y) can be determined, respectively, as follows;

$$MC_x = \delta(TC)/\delta X \quad \text{and} \quad MC_Y = \delta(TC)/\delta Y \qquad [2.11]$$

where

MC_x	=	marginal costs of timber
MC_y	=	marginal cost of fodder

TC, X and Y remain as previously defined.

Note that the term δ(TC)/δ(X) represents the change in TC that accompanies a unit change in the output of X, when the output of Y is held constant. The term δ(TC)/δ(Y) can be interpreted in the same way.

The concept of joint production is especially relevant in analyzing intercropping and agroforestry farming systems with particular reference to peasant households. Under these farming systems more than one product is produced jointly (O'Kting'ati 1984). For instance under intercropping system both maize and beans can be produced jointly whereas under agroforestry system fuelwood, maize and beans can be produced jointly. To the extent that the current study is tailored towards analyzing peasant farming, a review of the peasant household economic theory is deemed appropriate and is covered in section 2.2.

2.2 A review of household economic theory

2.2.1 Development of peasant household economic theory

This review is based largely on Low (1986), Nakajima (1986) and Holden (1991). Nakajima (1986) developed, in an operational framework, the Chayanov (1966) household economic theory into a subjective equilibrium framework. Low (1986) developed it further and applied it to a peasantry society in Lesotho in Southern Africa and discussed its strengths and weaknesses. Holden (1991) built on both Chayanov (1966) and Nakajima (1986) and developed a conceptual framework which he used to analyze the peasant agricultural systems in Northern Zambia. In the analytical framework Holden (1991) combines the household economic theory and mathematical modelling in analyzing the peasant farming systems.

The main premise used by Low, Nakajima and Holden is that peasant households have high reliance on family labour. And that the overriding objective is to maximize the utility of family labour. In this regard, therefore, a peasant household works within the general economic framework with the aim to maximize the utility of family labour. The term utility connotes "the degree of satisfaction an individual obtains by consuming a commodity" (Stiglitz 1987). The concept of utility is often applied in welfare economics to reflect how well-off the society is relative to the available resources (*ibid*). By the same token, as the concept is applied to peasant household economic theory, utility measures the magnitude of both social and economic satisfaction obtained by consuming a commodity produced by family labour. The general household economic theory was further developed by Nakajima (1986) into what is known as the "subjective equilibrium" which is reviewed in section 2.2.2.

2.2.2 Review of the subjective equilibrium theory

This review is based mainly on Nakajima (1986) who developed the subjective equilibrium theory of the farm households such that it can be used "for the analyses of farm firms, commercial farms, farm household and subsistence farms". Holden (1991) makes a distinction between farm households as those which rely primarily on family labour and farm firms as those which use largely hired labour. In this report the term peasant household will be used throughout to mean that household which relies primarily on family labour for farm production.

The Nakajima subjective equilibrium principle hinges on the assumption that a peasant household depends heavily on family labour for farm production. The opportunity for hired labour is either absent or limited due to scarcity of cash income. The main economic objective of a peasant household is to maximize the utility of family labour. Building on the general theory of household economics Nakajima (1986) specifies the utility function as;

$$\text{Maximize } U = U(A, M) \qquad [2.12]$$

where

U = utility

A = amount of family labour (hours) in a year
M = money income obtained during the same period

Equation [2.12] assumes, hypothetically, that the farm-household sells all the produce and buys market goods at the same price. Further, it is assumed that all family labour is devoted to farm activities such that;

$$A = A' > 0 \qquad [2.13]$$

where
A = total amount of family labour
A' = family labour devoted to farm activities on household farms

The implication of equation [2.13] is that all family labour is used in agriculture production, and that there is neither surplus labour supply nor extra labour hired. Moreover, Nakajima (1986) assumes that only one kind of output is produced by family labour. Therefore,

$$F = X > 0 \quad \text{for subsistence production} \qquad [2.14]$$

where
F = amount of farm output by family labour
X = amount of output consumed in a peasant household

If equation [2.14] holds true, there is no surplus production i.e. all the family labour production is consumed. This is a typical feature in peasant households where the bulk of farm produce is consumed by the family.

Although one may get the impression that family labour in a peasant household is only tailored towards production, Nakajima (1986) thinks differently. He assumes that there is a component of "leisure" in family labour. Thus the more labour produces the less time is available for leisure. Hence the development of two components "marginal utility of family labour" and "marginal utility of income". The assumption relating the two components is specified as (after Nakajima 1986);

$$U_A < 0, \ U_M > 0 \qquad [2.15]$$

where
U_A = marginal utility of labour
U_M = marginal utility of money income

The term $U_A < 0$ connotes the view that "labour brings about direct disutility due to its physical and/or mental pains; it also generates indirect disutility through reducing leisure or free time" (*ibid*). By the same token it is considered logical to designate the utility of labour with a negative sign as $-U_A$ hence called "the marginal disutility of labour or the marginal pain of labour" (Nakajima 1986; Holden 1991). This especially true because peasants have "reservation price" for leisure of family labour (Gittinger 1982). For instance the period just after harvest is the time for family festivals. Thus any farming activity proposed for such a period brings high marginal disutility of family labour. In a complimentary way it can be said that the "reservation price" for leisure of family labour is greater than returns earned from a farming activity undertaken outside the farming season especially the period just after harvesting (Gittinger 1982).

The term $U_M > 0$ connotes that the marginal utility of income brings about pleasure to a peasant household. Hence it is assumed to be always positive (Holden 1991). There is a trade-off between marginal utility of labour and marginal utility of income. The trade-off condition is defined as $-U_A/U_M$, which represents "the marginal rate of substitution of family labour for money" or "the marginal valuation of family labour" (Nakajima 1986; Holden 1991). Nakajima also assumes that there is diminishing marginal utility of income and encreasing marginal disutility of labour (i.e. decreasing marginal utility of leisure).
The income constraint of the household can be written down as;

$$M = P_x F(A,B) \qquad [2.16]$$

where

M	=	money income from family labour
P_x	=	price of farm produce which is produced according to function F(A,B), (x = product)
F	=	the production of farm output as a function of A and B
A	=	family labour
B	=	land

Equation [2.16] assumes that there is neither labour market nor land market and that all the farm product is sold. Nakajima (1986) combines equations [2.12] and [2.16] to define the subjective equilibrium condition as;

$$P_x F_A = -U_A/U_M \qquad [2.17]$$

where F_A = $\delta F/\delta A > 0$

Rearranging equation [2.17] the following equation is derived;

$U_M = -U_A/P_xF_A$ (hence called the "subjective equilibrium equation") [2.18]

where

U_M	=	marginal utility of money income
$-U_A/P_xF_A$	=	marginal pain of money income at equilibrium point

The left side of equation [2.18] represents the marginal utility and the right hand side the marginal pain of money income at the equilibrium point. The subjective equilibrium equation may be reformulated into;

$$U_M P_x F_A = -U_A \qquad [2.19]$$

whereupon the term $U_M P_x F_A$ represents the marginal utility of family labour with respect to cash income and $-U_A$ the marginal pain of family labour. The main contention of the subjective equilibrium theory is that "each peasant household works to the point where household's subjective evaluation of the marginal disutility of work equals its estimate of the marginal utility of output gained" (Nakajima 1986). A graphical presentation of Nakajima's subjective equilibrium is shown in Figure 2.4. hh' represents the maximum attainable income. Other notations remain as previously defined.

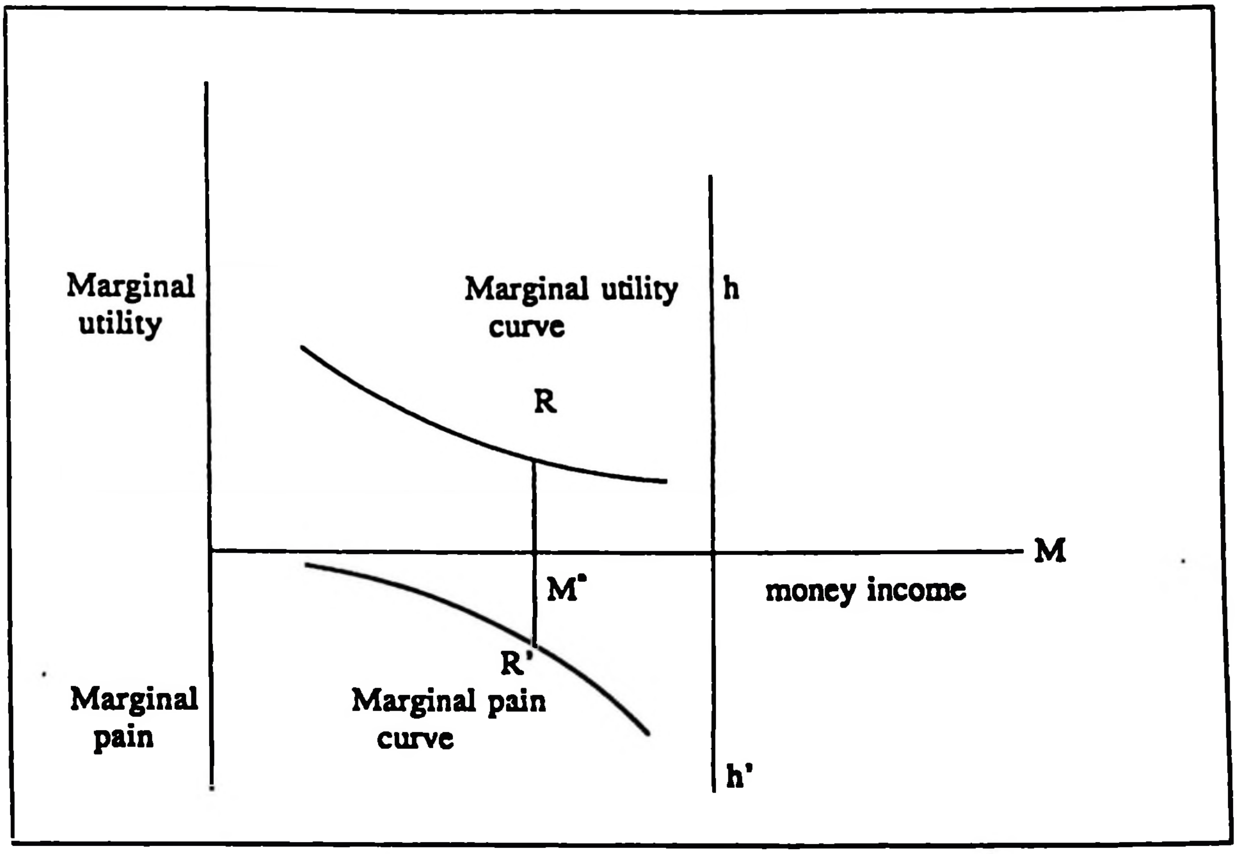


Figure 2.4 Nakajima's subjective equilibrium in utility and income space (adopted from Holden 1991).

In an alternative graph Nakajima presented the subjective equilibrium in utility and labour space (Figure 2.5). The line HH' represents the upper limit of the family labour force. The subjective equilibrium can also be graphed in income and labour space to conform more to neo-classical economics whereby the utility function is represented by indifference curves and income is represented as a production function times the price (Holden 1991).

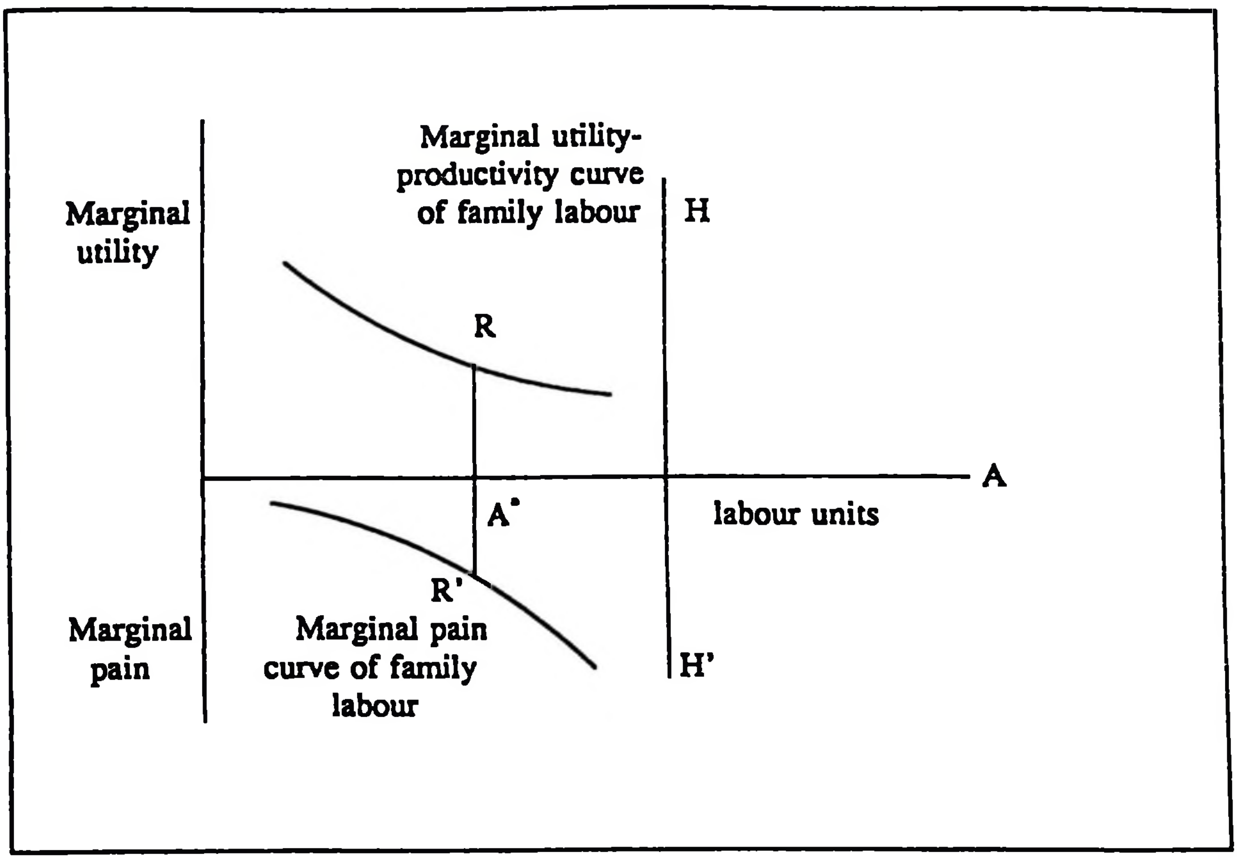


Figure 2.5 The subjective equilibrium in utility and labour space according to Otsuki and Nakajima (adopted from Holden 1991)

An illustration is presented in Figure 2.6. The OG curve represents the income as a function of family labour. The equilibrium point is where the income curve has a tangency point with an indifference curve, given that indifference curves are upward sloping and convex and the income curve is concave to the origin. The minimum subsistence requirement is illustrated by the M_0M_0' curve and the maximum labour is illustrated by the HH' curve.

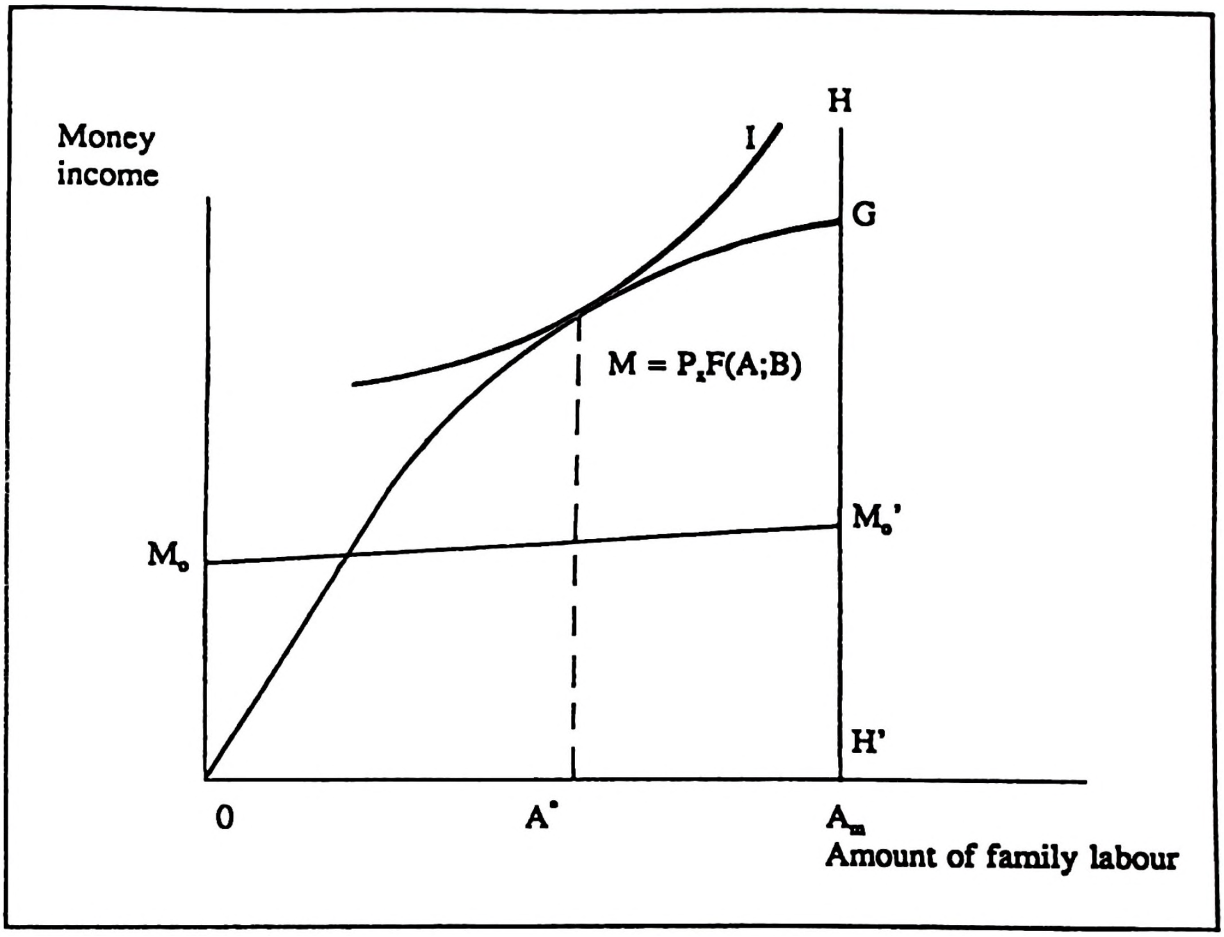


Figure 2.6 The subjective equilibrium of the farm household in income and labour space (Holden 1991)

The general household economic theory has been developed into what is known as "new home economics" or "new household economics" with increasing application in fairly diverse situations (Holden 1991). It is not the intention of this study to present a detailed review of such situations. However two case studies which were considered relevant for the present study are reviewed. These are studies in Southern Africa by Low (1986) and Holden (1991) presented in section 2.2.2.

2.2.3 Some applications of household economic theory

2.2.3.1 Application by Low

Low (1986) applied the household economic theory in Southern Africa covering Botswana and Swaziland by developing a basic function which represents the maximization of utility of family labour as the objective of a household. This function is presented, mathematically, as follows:

$$U = U(Z_1, Z_2, \ldots\ldots\ldots\ldots Z_n) \qquad [2.20]$$

where Z_i is the *ith* utility component for the household, i = 1,....,n

The Z_i are produced by the household using vectors of market goods and quantities of its own time T_i. Thus:

$$Z_i = F_i(X_i, T_i) \qquad [2.21]$$

F_i in the above relations is a prediction function of Z_i.

Equation [2.21] is referred to as the production-function constraint. Another constraint is imposed by the household's available time in allocating labour to various activities. The time constraint can be represented as:

$$\Sigma H_j = \Sigma T_{jw} + \Sigma T_{ji} \qquad [2.22]$$

where

H_j = the total time available to the jth household member

T_{jw} = the time spent by household member j in the labour market (off-farm activities)

T_{ji} = the time spent by household member j in producing Z_i.

Also there is an income constraint which is stated as:

$$I = \Sigma P_i X_i \qquad [2.23]$$

where

I = income to the household

P_i = price of the market-good input, e.g., fertilizer

X_i = quantity of the market-good input used in producing Z_i

Equation [2.23] is also referred to as resource constraint whereupon

$$I = \Sigma P_i X_i = W + V \qquad [2.24]$$

where

W = earnings from the farm

V = income (off-farm income).

If equation [2.22] times the potential wage rate is substituted into equation [2.24] the following equation is obtained:

$$I = \Sigma E_j T_{jw} + V = \Sigma E_j \Sigma T_{ji} = \Sigma E_j H_j + V = S \qquad [2.25]$$

where

E_j = the market earning potential of member j per unit of time

S = full income constraint

Equation [2.23] is looked upon as "the definition of money income equation". Time is, as previously mentioned, a critical factor in peasantry economy. The economic validity of time factor is achieved when it is translated into some value. The time value is then added to equation [2.25] to obtain a "full income" constraint, S.

Thus,

$$I + \Sigma E_j \Sigma T_{ji} = \Sigma P_i X_i + \Sigma E_j \Sigma T_{ji} = \Sigma E_j H_j + V = S \qquad [2.26]$$

In the words of Low (1986) "this full income constraint then embodies both money income and the household-time constraint and its magnitude is independent of the fraction of time that the household chooses to allocate to income-earning activities". The full income constraint equation simply states that the value of labour plus other non-labour earnings must equal the value of market goods plus the value of time spent in procuring non-market consumption commodities, including leisure (*ibid*).

In applying the subjective equilibrium theory, Low (1986) included a labour market using several market wage rates. The use of several weights was based on the premise that they might vary among persons in the same household. For example women may receive lower wage compensation than men who do off-farm work. The implication is that "some hosehold members have a comparative advantage in the labour market" (Holden 1991). Low focussed more on the choice between farm work and off-farm work because they bear different income utilities to the household. Another feature of the Low model is that allowance was provided for a flexible access to land. Holden (1991) contend that such is "the most common situation in Southern Africa". However, in the advent of increasing population pressure such flexibility may be limited.

The model was applied to maize production which is produced for both subsistence and as a cash crop. The implication was that maize crop has several prices, *viz*, the production cost (price of subsistence production), the market price and the purchase price (for household buying maize) (Holden 1991). The model put emphasis on the choice between production for home consumption and for sale *vis-a-vis* the possibility of purchasing food. The latter case stems from the fact that farmers may face deficit in maize production. Labour in the household was translated into standard farm-household labour units. Low valued the time not used for off-farm work at the same wage rate as the off-farm activities such that the model could be used to find "full income" of households.

Low's model can be represented graphically as shown in Figure 2.7 (based on Holden 1991). The model illustrates 3 households with three labour units each but which face different wage rates in off-farm employment. The labour units are organized such that they depict a decreasing comparative advantage in off-farm employment from left to right.

The off-farm wage rates for households 1, 2 and 3 are represented by the W_1W, W_2W and W_3W curves. The X on the x-axis indicates the amount of labour required to produce the subsistence requirements of the household assuming that all three households have the same number of consumers. Household 1 will then allocate 2 labour units to off-farm employment because their wage rates are higher than the opportunity cost of purchase. This household will then be a deficit producer using only one labour unit for subsistence production (A_1) and purchase of food up to the point X to meet the subsistence requirements. Household 2 with the wage line W_2W will allocate one labour unit to off-farm employment while the two other units will be allocated to farm production because the slopes of the the wage-line units A_1 and A_2 are less steep than that for commercial returns line. The household will be a surplus producer with an output of up to X for home consumption and surplus XA_2 for sale.

Finally, household 3 will allocate all its labour to farm production because the off-farm employment opportunities are less favourable than producing and selling farm produce. The household will be a surplus producer with an output equal to XA_3 for sale. This model assumes households to be profit maximizers and ignore risk in both the farm and off-farm activities, implying that labour and food markets and production conditions are stable.

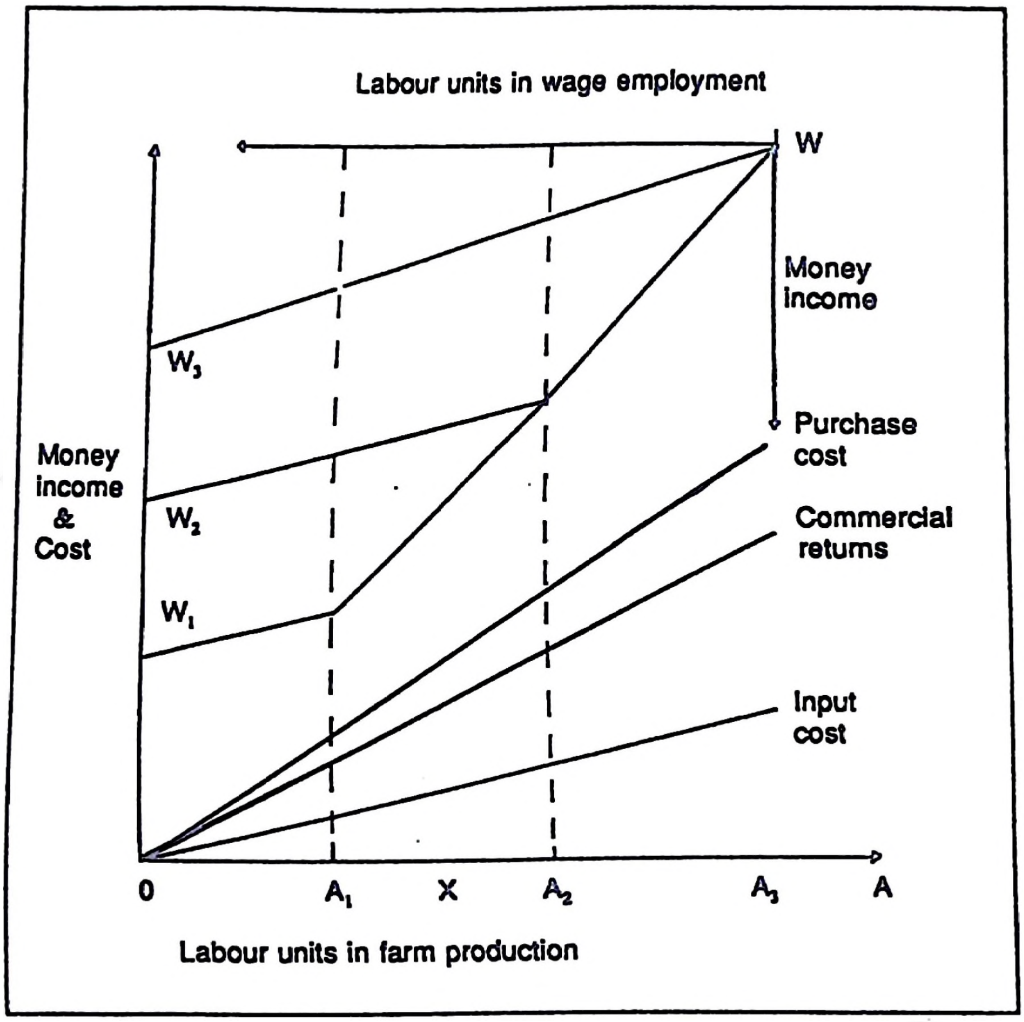


Figure 2.7 The Low farm household model (adopted from Holden 1991)

The main contention of Low's application was that it was possible to use household economic theory to analyze farming systems. One of the major implication emanating from th application of Low's farm-household model was that the time of members with the lowe off-farm wage earning potential will be allocated to subsistence production first, followed b members with increasingly higher wage potential. Household members with low wage employment prospects will often be used to produce subsistence food crops in preference to non-food cash crops because they can produce more food than could be purchased with the proceeds of the cash crops they might otherwise grow. Cash crops may be more profitabl than the production of surplus food crops for sale after household subsistence needs have been met. However, the employment opportunities of household members not needed to produce subsistence requirements will often be more attractive than cash cropping. This implies that cash crops need to provide better returns to labour than either subsistence crops valued a retail prices or than the wage employment opportunities of the better-qualified household members.

It was also found that commercial crop production is more prevalent in regions where wage opportunities are limited and is more common among households which have low consumer/worker (C/W) ratio (Low 1986). Also it was observed that the structure of the farm-household has an important influence on the pattern of production. This concludes this brief review of Low's application of the general household economic theory. The other review which is based on Holden (1991) is presented in section 2.2.3.2.

2.2.3.2 Application of household economic theory by Holden

Holden (1991) used the general household economic theory based on Chayanov (1966) and Nakajima (1986) to conduct microeconomic analysis of farming systems in Northern Zambia. The household economic theoretical framework was combined with mathematical prgramming in the study. The main intent was to analyze the possibilities of reducing the nonsustainable use of land resources by introducing new technologies and by changing the government policy.

Holden applied the basic principle of Nakajima's subjective equilibrium, hence he termed his model a subjective equilibrium model. The extensions made by Holden was the inclusion of risk/uncertainty and seasonality such that the model holds at any one point in time (short-time periods). The inclusion of seasonality in the model implies that there will be a new subjective equilibrium in every time interval. Also there will be some possibilities for substitution between time periods. Thus Holden's model which incorporates the risk/uncertainty condition and time preference can be stated as;

$$EU_m{*}E(P_X){*}E(F_A) = -U_A \qquad [2.27]$$

The notations remain as previously defined in Nakajima's model and E = expected outcome.

Holden contend that, contrary to previous theories, the marginal pain of labour may vary between different types of work as some forms of work are more painful than others. The implication is that each type of work has its own marginal pain curve and the subjective equilibrium problem may be to maximize total net marginal utility within each time period. A graphical presentation of Holden's model is illustrated in figure 2.8. The notations on the model remain as previously defined (see Nakajima's model)

Holden found that a Chayanov model explained to a great extent the variation in peasant behaviour in Northern Zambia. A large variation was found between households in terms of basic resources such as cash and labour. Access to off-farm income sources was found to have a considerable influence on the cash situation of households. Also households were observed to combine different cropping systems with the objective of increasing returns from their limited resources.

In an extended analysis, Holden combined subjective equilibrium with mathematical programming. The extended analysis was based on two hypotheses, "limited material wants" and "weighted income and leisure". The modelling techniques applied were linear programming (LP) and goal prgramming (GP). The main contention was that modelling is a useful tool in generating and evaluating different technologies. One of the main advantage of models is their ability to simultaneously handle and weigh important constraints against each other for typical model households. Models, however, need frequent review, parameterization and careful interpretation of the results to the extent that they cannot substitute human judgement.

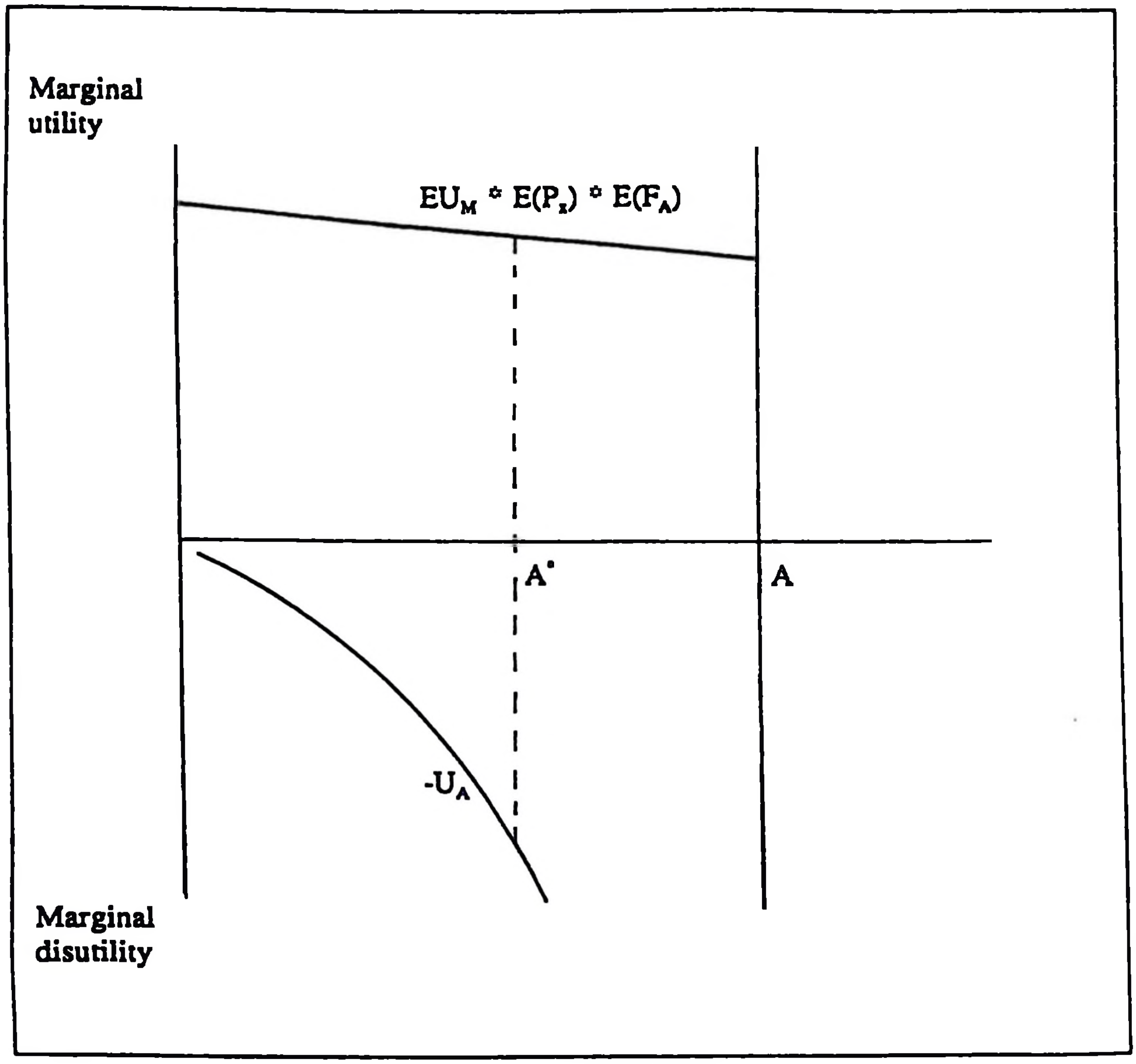


Figure 2.8 Marginal utility diagram for a production activity (after Holden 1991)

The approach of combining mathematical modelling and household economic theory was seen to be a relevant approach to the current study. The economic principles can be used to depict the behaviour of farmers as a response to changes in some factors affecting farm-households. Modelling allows the analyst to mimick the household farming systems and simulate possible outcomes. Further the incorporation of risk/uncertainty is seen as a stregth in Holden's approach to the extent that farming undertaking embody an element of risk due to many factors including weather, market and pricing mechanisms. Therefore, by taking these important factors into account Holden's approach seem to draw much closer to the real situation facing farm-househods. This study will make use of Holden's approach. The household economic theory will be combined with mathematical programming *viz* linear programming (LP) and compromise programming (CP) in multiobjective programming (MOP) framework. These approaches are reviewed in sections 2.3 and 2.4 respectively.

2.2.4 Relevance of household economics in analyzing peasant farming systems

Most often workers in the field of social studies consider peasants as being indifferent to profit generation. However, Low (1986) points out that peasants are "profit maximizers". In that peasants can take the labour off the farm activities if the market price for labour is high enough elsewhere to compensate for food needs as well as household income.

The major features in peasantry economy is the reliance on family labour and land. Most goods in households are produced using family labour and only a fraction of market inputs such as fertilizer. The reason is that in low income countries, like Tanzania, the price of market inputs tend to be very high compared to the economic value of the time of household members. Family labour is so important to the peasant farmer that even the quest for high number of children is attributed to the need for adequate labour supply and as a social security to the old-age. For instance in the Shambaa tribe social life is characterized by extended familiesas a kind of risk aversion phenomenon. Thus the value of a child is gauged in terms of his or her contribution to family labour production (Low 1986). Land is considered cheap to the extent that it is obtained largely through inheritance. However land has high opportunity cost, from economic point of view, basically it has alternative uses.

The other feature of traditional or peasantry householas which lends itself to analysis using household economic theory is that most of the labour production is for family consumption and a small portion is sold for generating income. For instance at Lukozi Village of the total farm production, about 80, 50 and 50% of maize, beans and potatoes respectively are consumed by the household family. Only about 10 % of the vegetables is used for consumption by the households. In the analysis of farm crops it is assumed that the produce is sold at the "market price". Agriculture is an economic activity which entail both costs and revenues. In analyzing the viability of an agriculture system it is often found useful to make use of some economic analysis techniques. One such technique is the cost benefit analysis. A theoretical review of this technique is given in section 2.2.5.

2.2.5 A brief review of cost-benefit analysis (CBA)

Cost-benefit analysis (CBA) is "a systematic method of identifying and measuring the economic benefits and costs of a project or program" (Hufschmidt *et al.* 1986). The main contention of cost-benefit analysis is that it "seeks to asses costs and benefits using a common yardstick" (Munasinghe 1992).

Cost-benefit analysis is a method based on neoclassical economic theory, which emphasizes the philosophy of consumer sovereignty (Hufschmidt *et al.* 1986). Social economic welfare is assumed to be the sum of the self-expressed welfare of all individuals in a society. The self expressed utility of an individual can be represented in a mathematical form as:

$$U = U_0(C_1, C_2, \ldots C_n) \qquad [2.28]$$

where

U	=	total utility
C_1	=	consumption of the first commodity
C_2	=	consumption of the second commodity
C_n	=	consumption of the nth commodity

The combination of individuals or group utility function produces what is referred to as social indifference curve which represents equal welfare levels to society (see also figure 2.9). A social indifference curve may be defined as those combinations of utilities of different individuals among which the society is indifferent. Social indifference curves provide a convenient way of thinking about the kinds of trade-offs society often faces in which one group in made better off and another worse off. Referring to figure 2.9, points on the social indifference curve labeled W_2 yield a higher level of social welfare than do points on the indifference curve labeled W_1.

A fundamental assumption of benefit-cost analysis is that "the degree of satisfaction or level of economic welfare experienced by individuals can be measured in terms of the prices they were prepared to pay for the consumption of goods and services" (*ibid* 1986).

Under the Pareto Welfare Criterion, variously known as Pareto Optimality and Pareto Efficiency, the allocation of resources will be economically efficient when it is impossible to

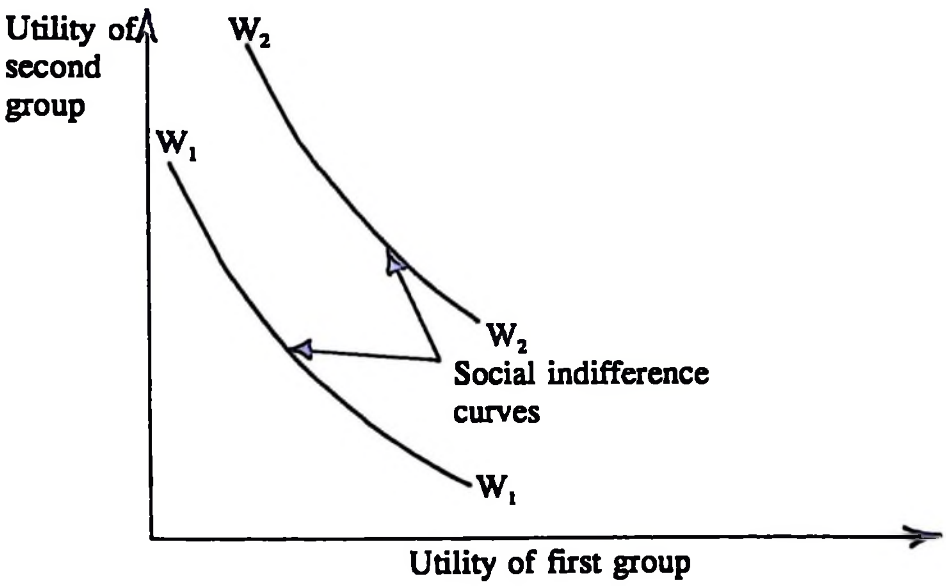


Figure 2.9. Social indifference curves (adopted from Stiglitz 1988).

make one individual better off without making some other individuals worse off (Baumok 1972, Stiglitz 1988). Cost-benefit analysis is, however, based on the concept of a potential Pareto improvement (Hufschmidt *et al.* 1986). The main contention of this approach is that a change is economically desirable if, in principle, the gainers can compensate the loosers. Thus, the increase in total monetary benefits must exceed the change in total monetary costs. Even if actual compensation is not paid, the increase in net monetary benefits is judged desirable because of economic efficiency.

When the cost-benefit analysis is performed, benefits are defined in terms of their effects in contributing to the improvement of human welfare. Costs are defined in terms of their opportunity costs, which is the benefit foregone by not using these resources in the best available alternative application.

Cost-benefit analysis makes use of some criteria, namely net present value (NPV), internal rate of return (IRR) and benefit/cost ratio (BCR) in valuing competing projects or economic ventures. These criteria have been reviewed by several authors, a recent one is by Munasinghe (1992). Each of the three criteria, NPV, IRR and BCR has its strengths and weaknesses. It is commonly agreed, however, that NPV is the recommended criterion to use. Therefore, for the purpose of this study the NPV criterion will be used. The results from an economic analysis will normally rank economic venture in terms of the net present value generated. This does not, however, always secure an optimal allocation of resources. For example, the maximization of returns from farm activities at Lukozi Village is constrained *inter alia* by the available land and family labour especially during the peak seasons. Therefore this study combined the application of both household economic theory and mathematical programming, in particular the application of constrained optimization techniques using linear programming, one of the widely applied constrained optimization technique. A review of some important issues regarding linear programming is covered in section 2.3.

2.3 Linear programming: theory and application

2.3.1 General overview of mathematical programming

Mathematical programming aims at maximizing (for example net present value) or minimizing (for example operational costs) "the value of some mathematical expression subject to a number of restricting equalities or inequalities, all of which must be solved simultaneously for the values of the variables found in all expressions" (Hall 1967). Such variables are called "decision variables" (Dykstra 1984) or "real activities" (Mansfield 1988). Mathematical programming builds a set of mathematical equations that must be solved simultaneously to provide an optimum solution (Mgeni 1986).

The algorithm used to solve the set of simultaneous equations is based on matrix algebra. In the management of land-based natural resources we often encounter problems related to the allocation of resources in order to "optimize" returns. The first part of the problem is "economic" in nature to the extent that it entails the allocation of "scarce resources" among competing ends. However, the second part is a mathematical programming problem since it demands a simultaneous solution to a set of conditions or resources (Dykstra 1984). One of the mathematical techniques widely applied to handle such problems is linear programming. It is a technique that allows decision-makers to solve a linear maximization and minimization functions where there are certain linear constraints which limit the range of possible alternatives.

Linear programming technique has found wide application in solving problems related to the allocation and optimization resources (see for instance Dykstra 1984; Mgeni 1986; Pukkala and Pohjonen 1990) because of its computational advantage compared to other methods

(Mansfield 1988). The development and wide application of linear programming in resource planning has been helped along by the emergence of computers which can handle the many computations required to solve large linear programming problems. In the case of Lukozi Village, the problem is related to the allocation of land among various "competing" land uses (the term land uses is used here to mean farming systems) in order to maximize net cash income while meeting subsistence requirements. This problem lends itself to the use of linear programming technique which is further described in section 2.3.2.

2.3.2 Linear programming technique

2.3.2.1 Historical perspectives

The history of linear programming can be traced to Leontief's input-output method of analysis (Thierauf and Klekamp 1975). Over the time linear programming developed into a useful technique for analyzing a range of decisional problems related to the management of natural resources. The current form of linear programming formulations find roots in Dantzig (1963) (cited in Dykstra 1984) who introduced the "simplex method" as a systematic procedure for solving linear programming problems (Dykstra 1984; Mgeni 1986). Linear programming technique has been found useful in solving a wide ranging problems (see Kaoneka 1993(a); section 2.3.5.1), however of particular interest to this study is the application of linear programming technique in solving problems related to the allocation of land to various land uses in order to optimize production output and maximize returns. The technique has been used elsewhere for similar purposes (see for example Betters 1988; Shakya and Leuschner 1990; Pukkala and Pohjonen 1990; Sankhayan and Cheema 1991 among others) which resembles in one way or the other with the problem addressed to in Lukozi Village. The main strength of linear programming is that it "provides computational advantage" (Mansfield 1988). Furthermore, linear programming conforms to certain type of production economics because it assumes that there exist a production function with "fixed" set of inputs which must be used up in the production process in an optimal manner to satisfy the criterion or objective function (*ibid*). In formulating a linear programming problem the production function and the inputs are developed into a set of mathematical equations representing the objective function and constraints (Dykstra 1984).

Linear programming as a constrained optimization technique can be used to analyze "complex allocation problems involving multiple resource constraint" (Mgeni 1986). A linear programming formulation seeks a solution that can best optimize the allocation of land while observing resource constraints over a specified period of time. An optimal allocation desired is determined by an *apriori* selected criterion or objective function such as maximization of net present value or minimization of labour time (Dykstra 1984; Mansfield 1988). For instance, in this case study for Lukozi Village linear programming model was developed with the general aim of seeking an optimal allocation of land among farming systems in order to maximize net cash income subject to the family consumption requirements and other constraints. Since there exist alternative combinations, the choice of optimal allocation of land among the competing farming systems is an important decision which can be aided by use of linear programming (Mansfield 1988).

2.3.2.2 Basic assumptions underlying linear programming

The application of linear programming technique presupposes essentially five basic assumptions, linearity, divisibility, deterministic, technology and nonnegativity. These assumptions are so fundamental to linear programming that they merit a brief review. A review of the underlying assumptions as well as the implication of their violation during the application of linear programming technique is presented in sections 2.3.2.2.1 through 2.3.2.2.5.

2.3.2.2.1 Linearity

Linearity is a mathematical term used to describe systems of simultaneous linear equations of first degree and it embodies the elements of proportionality and additivity. Proportionality refers to the fact that doubling (or tripling) the production of an output will exactly double (or triple) the profit and the required resources, that is, the possibility of realizing economies of scale is assumed to be of no significance (Mgeni 1986; Mansfield 1988).

Additivity means that the effect of two different programmes of production is the same as that of a joint programme involving the same activity (production) levels. An activity level of a process is "the number of units of output that is produced with the process" (Mansfield 1988). In land allocation problems an activity level may mean hectares of land under a particular farming system. Except for the influence of the constraints, this requires the activities to be independent from one another, that is , the scale of one activity in no way affects the costs, returns or physical process of others. Linearity also precludes the interaction or collinearity among the activities.

Dykstra (1984) sums up the linearity requirement by stating that "the objective function and all constraints must be strictly linear over the entire domain (the entire range of permissible levels) of each activity". Linearity is very fundamental to linear programming formulations, yet some difficulties have been encountered in practical application especially to problems related to land use planning. For instance Pukkala and Pohjonen (1990) found out that the objective function coefficients of forest activities were not constant because the unit price of transmission poles depended on demand. In instances where linearity does not hold, either for the objective function or a set of constraints, then the problem is a nonlinear programming (Mgeni 1986).

2.3.2.2.2 Divisibility

Divisibility is a requirement which entails that each decision variable or activity like the number of hectares to be allocated to a particular crop is *continuous*, that is, it can be divided into fractional levels to assume any real number within a given range. More precisely "each decision variable can assume any real value, including both integers and fractions" (Dykstra 1984).

In certain situations, either this assumption does not hold or it is irrelevant. When the assumption of divisibility is violated by restricting some or all variables to integer values, the problem falls in the domain of integer programming (Mgeni 1986).

2.3.2.2.3 Deterministic

The determinacy assumption entails that the information on technology, resources, strategies and their consequences (net benefits) is known with complete certainty resulting in a unique payoff. In essence, therefore, the technical coefficients and the right hand side (RHS) values are assumed to be known with certainty. That is, "they are numbers which we can write down, and they are fixed for any given application" (Dykstra 1984). In practice, however, these values are not always known with certainty. Moreover they are not always fixed. Whenever the deterministic situation is considered to be unrealistic and that some or even all parameters of the problem can be described by random variables, then the problem can be solved by stochastic programming (Mgeni 1986). Ostensibly Dykstra (1984) argues that if the idea is only to apply linear programming technique, then "to some extent uncertainties and randomness can be dealt with by means of sensitivity analysis" used in the form of a "formal experiment".

2.3.2.2.4 Fixed technology

The fixed technology assumption, implies that production requirements are considered to be fixed during the planning horizon meaning that there is a net benefit per unit of each product or service regardless of the scale of production (Mgeni 1986). Furthermore, only one decision is required for the planning horizon, implying that "the decision problem is a single-stage problem, and it is operative in a static environment as opposed to a multistage dynamic problem (Mansfield 1988). These features often give linear programming models a "static" character.

In practice, however, there are situations where this assumption does not hold. For instance in agriculture technology may change as a constant socio-economic development. In cases where fixed technology assumption is violated, then the problem falls in the domain of dynamic programming (Mgeni 1986).

2.3.2.2.5 Nonnegativity

The nonegativity requirement entails that "all activity levels must be at least equal to zero; negative assignments are not permitted" (Dykstra 1984). The nonnegative restriction is imposed by the algorithm used to solve linear programming problems numerically. The main utility of this restriction is to avoid ambiguous solutions such as negative hectares to be planted to a particular crop. On the other hand negative values can be valid, for instance when the problem is related to the determination of optimal temperature for storing biological specimen, especially when the unit of measure is degrees in celsius (°C). In practice this problem can be avoided by specifying the unit of measure as kelvin (°K) (*ibid*).

2.3.2.3 Mathematical formulation of linear programming problems

2.3.2.3.1 General formula

A typical linear programming problem is defined in terms of maximizing or minimizing a linear objective function of a number of variables subject to linear constraints and non-negative restrictions. Thus a general formula for a linear programming problem may be stated as:

$$Maximize(Minimize)\ Z = \sum_{j=1}^{N} C_j X_j \qquad [2.29]$$

such that,

$$\sum_{j=1}^{M} A_{ij} X_j \begin{bmatrix} \leq \\ = \\ \geq \end{bmatrix} \beta_i \qquad i = 1,2,\ldots\ldots,M \qquad [2.30]$$

and

$$X_j \geq 0 \qquad j = 1,2,\ldots\ldots\ldots,N \qquad [2.31]$$

where

N	=	number of decision variables
M	=	number of constraints
X_j	=	decision variables
C_j	=	objective function coefficient (often called cost coefficient regardless of whether objective function measures cost) corresponding to variable X_j
A_{ij}	=	technological coefficient corresponding to variable X_j in a constraint i
β_i	=	right hand side (RHS) constant for constraint i

Notice that decision variables are also referred to as real activities. They can be controlled in the short run to influence the total value of the objective function. Technological coefficients are constants that represent the contribution to the constraint of a unit increase in the activity levels associated with the variables.

The general formula, (equation [2.30]), can be applied to specific problems such as the one related to the land allocation. In such a situation the main aim is to seek the allocation of the available land to various farm crops with the objective of maximizing net returns (net income). Such a problem may be stated as follows:

Maximize $Z = \Sigma N_{ij}A_{ij}$ (objective function) [2.32]

subject to,

(1) $\Sigma L_{ij}A_{ij} \leq L$ (labour constraint) [2.33]
$i = 1,2,\ldots I$ (number of crops)
$j = 1,2,\ldots J$ (number of farming systems)

(2) $\Sigma S_{ij}A_{ij} \leq S$ (seeds/seedling constraint) [2.34]

(3) $\Sigma F_{ij}A_{ij} \leq F$ (fertilizer constraint) [2.35]

(4) $\Sigma M_{ij}A_{ij} \leq M$ (manure constraint) [2.36]
(5) $\Sigma H_{ij}A_{ij} \leq H$ (hand-tools constraint) [2.37]
(6) $\Sigma C_{ij}A_{ij} \leq C$ (chemical constraint) [2.38]
(7) $\Sigma Q_{ij}A_{ij} \leq Q$ (output allocation) [2.39]
(8) $\Sigma A_{ij} \leq A$ (land area constraint)
(9) $L_{ij}, S_{ij}, F_{ij}, M_{ij}, H_{ij}, C_{ij}, Q_{ij}, A_{ij} \geq 0$ (Nonnegativity condition) [2.40]

where

Z	=	objective function (in this case maximization of net income)
N_{ij}	=	net income generated by planting crop i in farming system j
A_{ij}	=	hectares of land planted to crop i under farming system j
A	=	total land area (hectares) available per household
L_{ij}	=	labour (mandays) required to plant crop i under farming system j
L	=	total labour available per household
S_{ij}	=	seeds required for planting crop i under farming system j
S	=	total amount of seeds available for planting
F_{ij}	=	amount (kilogrammes) of mineral fertilizer required to plant crop i under farming system j
F	=	total amount (kilogrammes) of fertilizer required for planting
M_{ij}	=	amount (tonnes) of manure required to plant crop i under farming system j
M	=	total amount (tonnes) of manure available
Q_{ij}	=	output allocation for crop i grown under farming system j

2.3.2.3.2 Detached coefficient matrix

Most often a linear programming problem is complex and therefore somehow difficult to visualize in mathematical terms, especially for users who have limited mathematical background (Dykstra 1984). In order to minimize difficulties in communication it is useful to summarize a linear programming problem in a tabular format commonly referred to as detached coefficient matrix (*ibid*). A general form of a detached coefficient matrix is shown in Table 2.1.

Table 2.1 A general detached coefficient matrix of a linear programming (LP) problem

Row identity	Activity (decision variable) X_1	X_2	X_3	X_4	Type	RHS[1]
0	C_1	C_2	C_3	C_4	Max./Min.	Z
1	A_{11}	A_{12}	A_{13}	A_{14}	$\leq$	B_1
2	A_{21}	A_{22}	A_{23}	A_{24}	$\leq$	B_2
3	A_{31}	A_{32}	A_{33}	A_{34}	$\leq$	B_3

Note: [1]RHS = right hand side

The information contained in the detached coefficient matrix is then subjected to a simplex algorithm to generate "optimal solution(s)".

2.3.2.3.3 The simplex algorithm

The simplex algorithm, which is used as an efficient technique to solve a linear programming problem numerically was developed by Dantzig in 1947 (cited in Dykstra 1984). The mechanism of the simplex algorithm is to find an optimal solution by examining the "corner points" systematically in an iterative manner (Dykstra 1984). At each trial solution, starting with the first basic feasible solution, the instructions specify whether to stop the computation or to proceed to a new trial solution. Iteratively the computation proceeds until a finite optimum solution is found, if there exists one.

In applying the simplex method, which has been used to develop linear programming packages such as LINDO, there are some useful concepts worth explaining. The first one is the case of infeasibility. An infeasible solution occurs due to overrestriction of the feasible region. This may be caused by "overzealousness in setting constraint limits" (Dykstra 1984). The second aspect is the occurrence of an unbounded solution which happens "when the value of the objective function can be made arbitrarily large, but the solution remains feasible" (*ibid*). Conversely, an unbounded solution may exist if the value of the objective function can be made arbitrarily small and yet the solution remains feasible. That is, the value of the objective function being maximized would be equal to infinity where as in the case of minimization the value would equal negative infinity. An unbounded linear programming problem has no practical significance and it is often a result of improper formulation of a given decision problem. In essence therefore, unbounded solutions seldom occur, "and when they occur, one should examine the problem statement carefully for mistakes or misrepresentations" (*ibid*).

2.3.2.3.4 Sensitivity analysis

The main aim of sensitivity analysis, also known as "post optimality analysis" and "parametric programming" is to elucidate the relationships between the optimum solution and possible changes in the various components of a decision problem (Mgeni 1986; Schrage 1991). In practice sensitivity analysis is conducted as a series of "what if" experiments. For instance, the experiments conducted to test the effect of changing the value of the right hand side (RHS) parameter on the value of the objective function are referred to as "RHS ranging analysis" (Dykstra 1984; Schrage 1991).

An extensive range of "what if" questions (also known as scenarios) can be conducted and evaluated for a linear programming problem besides "ranging analysis". In fact the capability to compute many solutions and inexpensively, thus contributing to the possibility of a rich and extensive investigation, is one of "the most attractive features of linear programming" technique (Dykstra 1984). Most available linear programming packages include a module for conducting sensitivity analysis. An output from sensitivity analysis shows, among other things reduced cost, shadow prices and range analysis report embodying objective coefficient and right hand side ranges.

The reduced cost of a variable "is the amount by which the profit contribution of the variable must be improved before the variable in question would have a positive value in an optimum solution" (Schrage 1991). Normally a variable which already appears in the optimum solution will have a zero reduced cost. Thus it follows that the "reduced cost is the rate at which the objective function value will deteriorate if a variable currently at zero is arbitrarily forced to increase a small amount" (Schrage 1991).

Shadow prices, also known as dual prices and imputed value or imputed cost of the constraint, represents the rate at which the objective function value will improve as the right-hand-side or constant term of a constraint is "relaxed" by a unit or "small change" (Dykstra 1984; Schrage 1991). In economic sense, shadow price is a measure of marginal value. For instance in a land allocation problem, shadow price measures the marginal value of land, i.e., it is a measure of the worth of an additional hectare of land, judged from the amount of increase in the objective function.

The information obtained from RHS ranging analysis "indicates the range over which the RHS value of a binding constraint can vary without changing the shadow price associated with the constraint" (Dykstra 1984). Generally the value of the shadow price associated with a particular linear programming constraint remains constant until the constraint has shifted so far that it no longer binds the optimal solution, then the shadow price drops to zero (*ibid*).

2.3.2.3.5 Economic analysis of linear programming solution(s)

A substantial amount of interesting economic information can be gleaned from the solution report of a linear programming problem. Furthermore, optional reports such as range analysis can add more information. The usual method to obtain the additional or optional information is to conduct a series of "what if" experiments. Some typical kind of what if questions, from economic point of view, are: What would be the effect of increasing a capacity or demand? What if a new opportunity becomes available, is it worth an opportunity? sections 2.3.2.3.5.1 and 2.3.2.3.5.2 review the economic implication of some of the aspects in an optimum solution.

2.3.2.3.5.1 Economic relationship between reduced cost and dual (shadow) prices

In the previous discussion it was shown that the reduced cost of a variable x measures the rate at which the solution value deteriorates as x is increased from zero; and the dual price of x measures the rate at which the solution improves as the right hand side (and thus x) is increased by one unit. The economic implication is that reduced cost of an unused activity represents the amount by which profits will decrease if one unit of this activity is forced into the solution (Schrage 1991). Also the dual or shadow price of a constraint represents the "amount by which profits will decrease if the availability of the resource associated with this constraint is reduced by one unit" (*ibid*). Thus, the reduced cost of an activity is, in essence, its net opportunity cost if we "cost out" the activity using the dual prices as charges for resource usage. This is because, if one unit of an activity is forced into the solution, it effectively reduces the availability of the resources it uses. Therefore the reduced cost of an activity equals the weighted sum of its resource usage minus its profit contribution rate, where the weights applied are the dual prices. A minimization objective is treated as having a dual (shadow) price of +1, whereas a maximization objective is treated as having a dual price of -1 in the "costing out" process (*ibid*).

2.3.2.3.5.2 Economic implication of ranging analysis

The meaning of ranging analysis has been covered in the previous discussion. In general, if the objective function coefficient of a single variable is changed within the range shown on the linear programming model solution report, then the optimal value of the decision variables will not change. The dual prices, reduced cost and profitability of the solution may, however, change. A complimentary situation is that, if the right-hand-side of a single variable is changed within the range specified in a solution report, then the optimal values of the dual prices and reduced cost will not change. The values of the decision variables and the profitability of the solution, may, however, change.

It can be proved that, when a single objective coefficient is changed, in case of a maximization problem, the optimal total profit as a function of a single objective coefficient always has a "bowl shape" or convex function. When a single right-hand-side value is changed, the optimal total profit as a function of a single right-hand-side value always has an "inverted bowl shape" or a concave function (Schrage 1991).

Most often it is argued that theory and practice are complimentary entities. But they are not one and the same. The understanding of the theoretical aspects of a model, technique or method does not always guarantee a successful application. The same observation can be made about linear programming. The theoretical coverage of linear programming is vast, yet when it comes to application, difficulties are encountered, not only in formulating the problems but also in generating almost ambiguous results (the same argument was raised by Sankhayan and Cheema 1991). In an attempt to develop the linear programming model for Lukozi Village to analyze peasant farming systems and land allocation problem, the strategy proposed by Dykstra (1984) was found to be useful. This strategy is outlined in section 2.3.2.4.

2.3.2.4 A strategy for formulating linear programming problems

This strategy for formulating linear programming problems is based on Dykstra (1984). In order to retain the ancestry of the strategy, no explicit or implicit modification was made.

(a) Find an activity set and define an x_j for each decision variable. Often it is useful to think of activities as the "things that are going on" or the "things about which a decision is to be made". They must always be things whose impact on the objective can be measured.

(b) Define the objective function in terms of the decision variables.

(c) Define the resources which will be used up in producing the activity levels associated with any solution. Assign a row index to each of these resources. For problems requiring both miximum and minimum levels of resource use, two constraints would be associated with the resource: one type $\leq$ and the other type $\geq$.

(d) Note the technological coefficients A_{ij}, which express the quantity of resource i that is used (required, purchased, produced) per unit of activity level j. Proceeding row by row or column by column, form a detached coefficient matrix.

(e) Write down the net flows of items; these are the restrictions or requirement levels (right-hand-side elements) of each constraint. Each RHS element B_i may be thought of as the net requirement or availability of resource i.

(f) Determine the type of equation or inequality (that is, =, $\leq$ or $\geq$) that represents each constraint.

(g) Check to ensure that units are consistent. The units within each column must be consistent, and so must those across each row. Thus, the A_{ij} act as conversion constants between the rows and the columns.

2.4 A review of compromise programming (CP) in a MOP framework

2.4.1 Definition and concept of risk

Agricultural production occurs in a risky environment. The biological nature of crop and livestock production, interacting with variable weather and environmental conditions, and changing demand as well as unpredictable government policies, affect agricultural prices and can lead to wide year-to-year and seasonal cycles in agricultural incomes and the well-being of farm decision makers. The severity of these risks varies from farming situation to farming situation, as do decision maker's responses. Unless these risk responses are adequately reflected in the planning models, the results generated in empirical analysis may bear little (or in an extreme case no) resemblance to actual decisions and may be of little use either in direct decision making or in policy analysis. It is well known that the imperfect knowledge about future events or situation may be either risky or uncertain. Risk may arise due to forecasted cost, yield and prices for individual activities, activity requirement for fixed resources or total fixed constraint levels (Hazell 1971). At the same time the occurrence of a particular event is uncertain. In order to make subsequent discussion simpler, risk and uncertainty are used interchangeably to represent a situation where no single sure outcome is possible or that the outcomes are *stochastic* i.e. the occurrence of over time events are random. Risk is used in this study to connote a situation in which knowledge of future yields and product prices are limited to estimates of the possible outcomes. The cost and levels of inputs are assumed to be fixed constraints and known at the time of decision making, hence this aspect of risk has not been incorporated.

This study attempts to extend the traditional linear programming (LP) technique to include elements of risk in a multiobjective programming (MOP) framework using compromise programming (CP) technique. There were two prime reasons for extending the analysis. The first reason was to investigate whether or not risk aversion reduces pressure on forestlands. The idea is to investigate as to what degree risk aversion causes deforestation through clearing land for agriculture. The second reason is to elucidate the influence of risk on the optimal behaviour of the farmer, *viz*, risk neutral versus risk aversion. The focus in this case is how the farmer allocates resources including land under risky conditions. The risk elements considered in this study are those related to yields (farm outputs) and product prices which jointly affect the objective function of the traditional linear programming model, which in this study was maximization of net cash income (i.e. gross cash income less the cost of cash market farm inputs).

Generally, modelling *per se* is an activity which must be based on an appropriate theoretical framework. The theoretical base is useful in building up conceptual framework, selection of variables and parameterization of model equations. Therefore, a review of theoretical basis underlying the multiobjective programming (MOP) approach to modelling under risk environment is deemed appropriate. This is the subject of section 2.4.2.

2.4.2 Theoretical basis of risk programming

The major part of this review is based on Hazell (1971) and Boisvert and McCarl (1990). Much of risk programming (RP) are based on quadratic programming technique, first proposed by Markowitz (1952) used in analyzing a given set of portfolio hence called "portfolio analysis". The technique was later considered relevant for analyzing gross margins uncertainty in farm planning (Camm 1962; How and Hazell 1968: McFarquhar 1961). Quadratic programming applied the expected income-variance (E-V) criteria on the assumption that "a farmer holds preferences among alternative farm plans solely on the basis of their expected income E and associated income variance V" (Hazell 1971). Ostensibly this assumption holds true if the farmer has an E-V utility function (*ibid*). Further, quadratic programming assumes that the iso-utility curves are convex, or that the farmer is a risk averter (see figure 2.10). Thus, along
every iso-utility curve $\delta E/\delta V > 0$ (the farmer would prefer a strategy with higher V only if E were also greater) and $\delta E^2/\delta V^2 > 0$ (i.e. compensation must increase at an increasing rate with increase in V). The purpose of applying quadratic programming is then "to develop the set of feasible farm plans having the property that variance V is minimum for associated expected income level E" (*ibid*). Such plans are called E-V pairs and define an efficiency boundary over the set of all feasible farm plans (segment OQ in Figure 2.10).

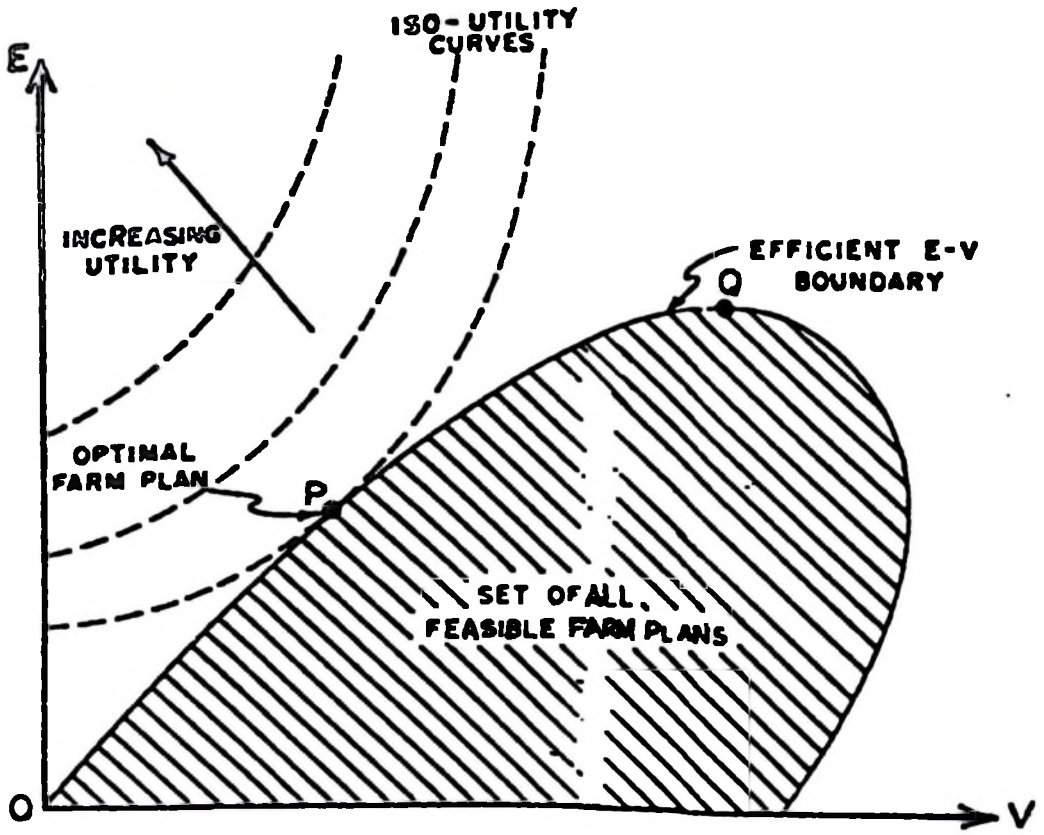


Figure 2.10 The optimal E-V farm plan

Quadratic programming technique has two serious limitations. First, QP technique requires access to a special computer code of which there are only a few in existence (Boisvert and McCarl 1990). Second QP must be performed on a time series or cross sectional data (*ibid*). Based on these limitations Hazell (1971) proposed the use of mean absolute deviations (MAD) as a measure of income variability in place of sample variance. Hazell's approach lends itself to linear instead of quadratic programming formulation (Boisvert and McCarl 1990).

Therefore, it became possible to include elements of risk in traditional linear programming formulations, hence the development of risk programming (RP) models. Risk programming (RP) models are based on a number of decision criteria (*ibid*). Some RP models are direct applications of expected utility theory and attempt to identify a single optimum decision given the utility function. Other models are consistent with expected utility maximization but only identify efficient portfolio of decision alternatives. The other criterion is based on more *ad hoc* decision making environment.

In this study the second criterion will be applied to the extent that the aim is to identify efficient points which reflect the expected maximization of net cash income within the environment of expected variation (which constitute the risk elements associated with crop yield and prices over time). The approach used as a theoretical framework in conceptualizing the problem and subsequent model development is the risk efficient analysis (REA) based on Boisvert and McCarl (1990). The REA approach is described in section 2.4.3.

2.4.3 The risk efficiency analysis (REA) approach

The risk efficiency analysis (REA) approach attempts to develop sets of efficient solutions (Boisvert and McCarl 1990). REA approach is based on the expected utility maximization framework but does not require full specification of the utility function (*ibid*). REA assumes that all individual's preferences can be mapped out and represented by a utility function. An efficient criterion is a decision rule that provides a partial ordering of choices for the decision makers whose preferences conform to a specified set of conditions placed on the utility function (King and Robinson 1981).

Generally risk efficiency analysis involves imposing a set of conditions or restrictions (Boisvert and McCarl 1990). The efficiency criterion is an optimal one if it is both a necessary and sufficient condition for expected utility maximization. An optimal efficiency criterion minimizes the efficient set of choices discarding those that are inefficient on the premise that any further reduction in the efficient set requires additional restrictions on the admissible set of utility function (*ibid*).

Perhaps the simplest and most widely used REA criterion is the mean-variance (E-V) analysis. The E-V criterion is based on the proposition that, given any two distributions with equal means, a risk averter will prefer the distribution with the smallest variance (*ibid*). In effect, the E-V criterion can be stated as:

> "If A and B are two uncertain actions and $\mu_A \geq \mu_B$ while $\sigma^2 A \leq \sigma^2 B$, with at least one strict inequality, then A is preferred to B" (*ibid*). By plotting each

action in mean-variance space, the efficient set of actions can be identified as all those that maximize μ for a given σ^2 or minimize σ^2 for a given μ.

In most applications of risk programming technique, the analyst chooses the key element of risk to be studied and this in turn determines which parameters of the model, the objective function coefficients, technical coefficients or right-hand-side (RHS), are to be considered uncertain. The next step is to develop probability distribution (or estimate moments of the distribution) for selected parameters and determine how these distributions as well as the behavioural response to risk can be adequately represented in the model (*ibid*). Although these distributions may be based on sample data or subjective information, mathematical models usually treat these probability distributions as if they were known with certainty i.e. as population distributions (*ibid*).

In this analysis, based on household surveys, the risk elements considered were those related to yield (crop output) and product price (unit or marginal return). These two aspects jointly affect or have a bearing on net cash income. The overriding assumption is that peasant farmers seek to maximize the expected net cash income and minimize risk. Further, peasant farmers aim at minimizing over time fluctuations in the net cash incomes. The risky elements were determined or measured as the total absolute deviations associated with yearly gross returns from agricultural activities over a period of five years. The method of measurement used was absolute deviations. Thus, it was found relevant to apply the minimization of total absolute deviations (MOTAD) technique. The details of MOTAD technique is presented in section 2.4.4.

2.4.4 A theoretical review of MOTAD

The acronym MOTAD stands for "Minimization Of Total Absolute Deviations". The approach was proposed by Hazell (1971), as linear programming alternative to quadratic models for solving E-V problems which were found to be relatively harder to solve compared to traditional linear programming models. The MOTAD approach reviewed in this chapter is based largely on Boisvert and McCarl (1990).

In a MOTAD model, risk is measured by absolute deviations from mean returns rather than by the variance of total returns. Thus the MOTAD model depicts trade-offs between expected profits and the absolute deviation or variances associated with profits (Romero and Rehman 1985; Romero, Amador and Barco 1987).

Since absolute value operator is not linear in the decision variables (X_j's), the model is transformed or reformulated into a linear programming (LP) framework (Boisvert and McCarl 1990). Such reformulation entails the recognition that any number (A) can be written as the difference of two non-negative variables, i.e., $A = A^+ - A^-$. Once there is a guarantee that both these components can never appear in the basic solution, then $|A| = A^+ - A^-$ (Boisvert and McCarl 1990). This was the basic principle used to develop the MOTAD model (Hazell 1971). If it is assumed that there are K states of nature, then the total absolute deviation of profits from the expected value under the k^{th} state of nature (D_k) is given by (*ibid*):

where

$$D_k = \sum_{j=1}^{n} C_{kj}X_j - \sum_{j=1}^{n} C_jX_j \qquad [2.41]$$

C_{kj}	=	the per unit net return of X_j under k^{th} state of nature, where k = 1,2,.........,K and j = 1,2,......,n
X_j	=	the decision variable
C_j	=	the mean net return to X_j, where j = 1,2,.....,n.
n	=	number of decision variables

Equation [2.41] gives the absolute value of the difference between income under the k^{th} state of nature and mean income. That is;

$$\sum_{j=1}^{n} C_{kj}X_j - \sum_{j=1}^{n} C_jX_j \qquad [2.42]$$

Total absolute deviation (TAD) is the sum of the D_k over K. When variables depicting positive (d^+) and negative (d^-) deviations are included, the following equation is obtained:

$$TAD = \sum_{k=1}^{K} D_k - \sum_{k=1}(d_k^+ + d_k^-) \qquad [2.43]$$

In application a weight is assigned to the above equation by the decision maker to connote level of risk aversion. Such weight is referred to as "risk aversion coefficient" (*ibid*). In a model aimed at maximizing returns under risk environment, the risk aversion coefficient is included. Thus the objective function can be stated verbally as that "which maximizes expected net returns less some risk aversion coefficient, ϕ, times the TAD" (*ibid*).

By defining the objective functions which is linear in the decision variables, the total MOTAD model can be written down as;

$$maximize \left[\sum_{j=1}^{n} C_jX_j - \phi\sum_{k=1}^{K} (d_k^+ - d_k^-)\right] \qquad [2.44]$$

Subject to:

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i \qquad for\ all\ i \qquad [2.45]$$

x_j, d_k^+, d_k^- ≥ 0 (non-negative restrictions)

$$\sum_{j=1}^{n} e_{kj}x_j - (d_k^+ - d_k^-) = 0 \qquad for\ all\ k \qquad [2.46]$$

where

ϕ	=	risk aversion coefficient
a_{ij}	=	technical coefficient
b_i	=	right-hand-side (RHS) constant
e_{kj}	=	deviation from the value expected for the j^{th} variable under the k^{th} observation (i.e. $e_{kj} = C_{kj} - C_j$)
d_k^+	=	positive deviation of the k^{th} income occurrence from mean income
d_k^-	=	negative deviation of the k^{th} income occurrence from mean income

Other variables remain as previously defined.

The general MOTAD framework presented here suffices to meet the needs of the present study. However a detailed coverage of the same can be found in Boisvert and McCarl (1990).

To the extent that peasant farmers operate under risky situation they always trade-off between how much returns can be acceptable in light of the existing level of risk. Logically, therefore, rather than aiming at minimizing risk *per se*, peasant farmers adopt a strategy of "compromise" between maximizing expected net cash income and minimizing risk (measured as TAD). In essence, therefore, the peasant accepts "the best-compromise set" rather than absolute "optimum solution". Such a situation follows closely the satisficing principle proposed by Simon (1975). A technique which has, in the recent times, been found useful to tackle such farm planning problem is compromise programming (Zeleny 1976; Romero and Rehman 1984; Romero, Amador and Barco 1987; Sankhayan, Prihar and Cheema 1988; Sankhayan and Øygard 1993)). Therefore, this study proposed to combine the traditional linear programming (LP) and MOTAD models in a multiobjective programming (MOP) framework using the compromise programming (CP) technique. The theoretical base of the CP technique which will be used to conceptualize and develop a CP model is reviewed in section 2.5.5. It may be observed that CP technique is fairly new and its applications to agricultural planning are still limited (Romero, Amador and Barco 1987).

2.4.5 Compromise programming

Compromise programming (CP) technique is based on multiobjective programming (MOP) framework (Cohon 1978). MOP or vector optimization technique involves simultaneous optimization of several objectives subjected to a set of constraints (Romero, Amador and Barco 1987). Multiobjective programming (MOP) "seeks to find the set of efficient solutions, also called non-dominated or Pareto-optimal solutions" (*ibid*). The elements of the efficient set are feasible solutions such that no other feasible solution can achieve the same or better performance for all the objectives and strictly better for at least one objective (Romero and Rehman 1984).

There are three major approaches which can be used to generate or at least approximate the efficient set as proposed by Romero, Amador and Barco (1987). First is the weighting method in which each objective is weighted and then summed. The efficient set is obtained by parameterizing the weights. Second is the constraint method, in which one of the objectives is optimized while the others are specified as restraints. The efficient set is obtained by parameterizing the right-hand-side of the objective placed as restraint. Third is the multicriterion simplex method where all the extreme efficient points are obtained by moving from one extreme (efficient) point to the adjacent extreme (efficient) point. For the purpose of this study the constraint method will be applied.

Several methods can be used to select an optimal solution or the best-compromise set of solution or efficient points. In this study, the CP technique will be used for the same purpose or task. The first step in compromise programming (CP) is to establish the so-called *ideal point* (*ibid*), the coordinates of which are given by the optimum values of the different objectives. When the ideal point is infeasible, the efficient solution closest to the ideal point is defined by CP as the optimum or best-compromise solution.

A review of the operative structure of CP presented in this study is based largely on Cohon (1978), Romero, Amador and Barco (1987) and Sankhayan, Prihar and Cheema (1988). First the degree of closeness d_j between the j^{th} objective and its ideal is defined by the following relation in case of maximization problem;

$$d_j = Z_j^* - Z_j(x) \qquad [2.47]$$

where

d_j	=	degree of closeness
Z_j^*	=	ideal value, j = 1,2,...,p
Z_j	=	best-compromise solution
x	=	vector of decision variables X_j
n	=	number of objectives

In case of minimizing the j^{th} objective the above equation can be stated as;

$$d_j = Z_j(x) - Z_j^* \qquad [2.48]$$

According to Zeleny (1973), in instances where different units of measure are applied to the objectives, then relative rather than absolute deviations are used. In which case the degree of closeness is defined by the following relation:

$$d_j = \frac{Z_j^* - Z_j(x)}{Z_j^* - Z_{*j}} \qquad [2.49]$$

where, Z_{*j} = the anti-ideal point, i.e., most distant point from the *ideal point* for the j^{th} objective and the other variables remain as previously defined.

In this study the same units of measurement, i.e. TAS, were used for both objectives, maximization of net cash income and risk minimization. Therefore absolute rather than relative deviations could be used.

CP model generates solutions denoted by L_p, where L represents the distance between ideal and best-compromise solutions. According to Cohon (1978), when the L_1 metric (p = 1) is used, the total deviations are minimized and when the L_∞ metric (p = ∞) or "Chebysev" metric is used, the maximum of individual deviations is minimized. This means when p = ∞, only the largest deviations are considered. The value of the parameter p reflects the importance attached to the deviation of each objective from its ideal value.

The L_1 and L_∞ metrics define a subset of the efficient set or the best-compromise set (Zeleny 1974). The entire best-compromise set or solutions fall between the solutions corresponding to L_1 and L_∞ metrics (Romero, Amador and Barco 1987). In essence, therefore, the solutions generated through two LP models represented in metrics L_1 and L_∞ characterize the bounds of the compromise set i.e. $1 < x < \infty$ for d_x. For measuring the distances between each of the solutions and the *ideal point*, CP uses the following distance function:

$$L_p(\delta,k) = [\ \Sigma(w_j d_j(x)^p]^{1/p} \qquad [2.50]$$

where w_j are the weights subjectively assigned to different objectives based on the experience of the researcher to reflect their relative importance, d_j, x and p remain as previously defined.

Another feature of compromise programming technique is the generation of a pay-off matrix. The elements of this matrix are obtained by optimizing a single objective under consideration and computing corresponding values of other objectives. As an illustration consider a MOP problem with two objectives, i.e. maximization of net cash income and minimization of total absolute deviations i.e. risk minimization. A pay-off matrix for the problem can be presented as shown in Table 2.2.

Table 2.2 A pay-off matrix for a MOP problem with two objectives

	Maximization of net cash income (TAS)	Minimization of risk (TAS)
Maximization of net cash income	<u>894416</u>	400971
Minimization of risk	0.0	<u>54234</u>

The elements in the first row in Table 2.2 represent the maximum net cash income of TAS 894,416 corresponding to risk level of TAS 400,971. The values in the second row indicate that, with a minimum risk of TAS 54,234, it is not possible to generate any net cash income. From the results in Table 2.2 two aspects can be gleaned. First, the two solutions in rows one and two are extreme cases. Secondly, the results indicate the conflict between the two objectives. That is, the objective of maximization of net cash income conflicts with that of risk minimization. In fact that is why they are called non-dominated or Pareto optimal solution points. Thus, there is always a trade-off in such a MOP problem. The decision maker has to decide as to how much of net cash income has to be sacrificed in favour of low risk levels using the guiding criterion of $\delta E^2/\delta V^2 > 0$ (in case a farmer is risk averter).

The ideal point is represented by the elements lying on the main diagonal of the pay-off matrix. In the example shown in Table 2.2, the ideal point corresponds to TAS 894,416 and TAS 54,234 representing maximum net cash income and minimum risk respectively. Such a solution, however, is infeasible to the extent that the two objectives are in conflict. Therefore, a decision maker will attempt to generate a compromise solution which is as close to the ideal point as possible. And that is where the CP technique becomes a useful tool of analysis.

Finally in order to reflect individual preference on the compromise set generated, decision makers assign "subjective" weights to the objective functions. For instance, a farmer who prefers high cash income will tend to assign high weights to maximization of net cash income. The tendency is that most (if not all) farmers would like to have stable income from agriculture over time. Hence, as a second priority, farmers aim at minimizing risk or variance associated with net cash income. Therefore, the two objectives are "compromised" using the CP technique.

Suppose the compromise set corresponding to the ideal point shown in Table 2.2 is the same as the one presented in Table 2.3 for the L_1 and L_∞ metrics (assuming $\delta_1 = \delta_2$).

Table 2.3 A compromise solution set for L_1 and L_∞ metrics

Metric	Maximization of net cash income (TAS)	Minimization of risk (TAS)
L_1	835328	367316
⋮	⋮	⋮
L_x	------compromise set------	⋮
⋮	⋮	⋮
L_∞	455873	224243

It can be observed from Table 2.3 that all other compromise solutions lie between L_1 and L_∞ metrics and are represented by L_x. The choice of x reflects or is influenced by the intent of making the maximal deviation from the ideal as small as possible (Zeleny 1974). The trade-off between the two objectives can be represented by way of a "trade-off curve" (Romero, Amador and Barco 1987). An example of a trade-off curve (based on the data from Tables 2.2 and 2.3) is illustrated in Figure 2.11. The curve AE represents a Pareto-optimal frontier. The ideal point is I whereas points O and Y represent solutions corresponding to L_1 and L_∞ metrics respectively.

Notice that points O and Y (L_1 and L_∞) represent the bounds of the compromise set for maximization of net cash income and risk minimization objectives. In order to check the stability (or conversely flexibility) of the solution set and the range defining the compromise set, a sensitivity analysis can be conducted using different weights (subjectively decided).

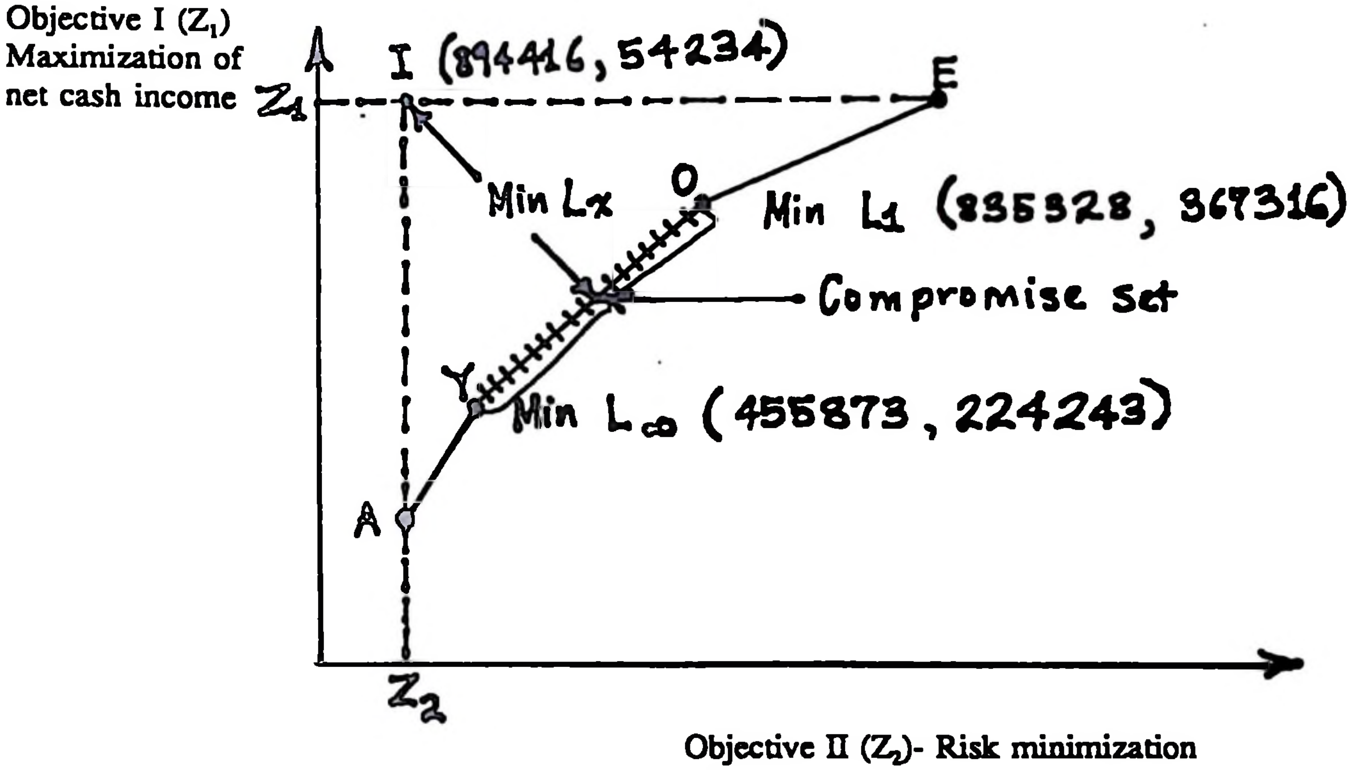


Figure 2.11 Trade-off curve for two objective functions: maximization of net cash income and risk minimization

The main advantage of best-compromise set is that it does not require *a priori* specification of preferences, although value judgement is still needed (*ibid*). That is, once the compromise set of solutions is generated, by assigning different values to weights and metrics, the choice is referred to the decision maker as there is no *a priori* a justification for choosing a particular solution (Sankhayan, Prihar and Cheema 1988). Also the approach is flexible to the extent that it precludes a rigid specification of a full utility function, as a decision maker or farmer considers only that part of a utility function represented by the best-compromise solution set lying between the L_1 and L_∞ metrics (Hazell 1971).

The extent of value judgement embodied in the solution relies, *inter alia*, on the ability of the decision maker to interpret the L_1 and L_∞ metrics. The choice of a solution set or metric between 1 and ∞, such as x is fairly difficult (Cohon 1978). In the absence of an objective measure, it becomes necessary for the decision maker to discharge subjective value judgement.

The theoretical review presented in this chapter will be used as a basis for developing a compromise programming (CP) model for analyzing peasant farming systems in Lukozi Village.

CHAPTER 3 METHODOLOGY

3.1 Biophysical and socio-economic aspects of the study area

3.1.1 Location

Data for the case study were obtained from Lukozi Village which is located in the West Usambara Mountains, Lushoto District situated in the North-East corner of Tanzania (see Map 3.1). The village lies on the foothills of the West Usambara Mountains, North of the Shume Magamba Forest Project. The total land area of Lukozi Village is 650 ha of which approximately 450 ha (about 70%) is under agriculture and the rest is either unproductive or is allocated for settlement and infrastructure. About 5% of the village land is rocky and therefore unsuitable for agriculture production.

The soil of Lukozi Village has a textural class of sand-clay-loam with poor to moderate nutrient availability. The color of the soil changes according to the presence of various minerals such as iron, magnesium and manganese. The elevation of the area ranges between 1650 and 1750 m above sea level.

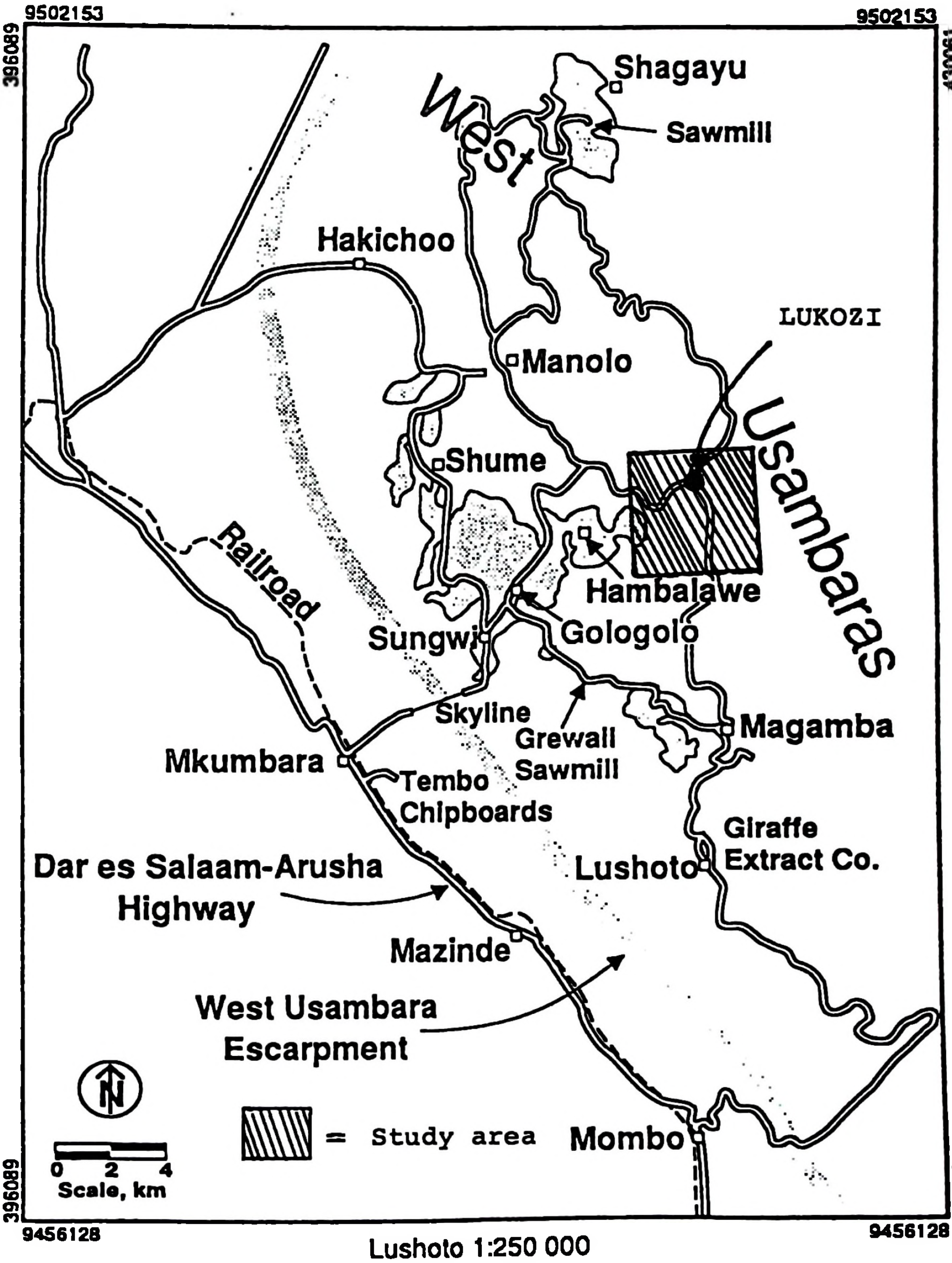
3.1.2 Climate

Lukozi Village, like most parts of Tanzania, receives bimodal type of rainfall. The long rains fall between March and May whereas the short rains fall between October and December. On an average the area receives a little over 1000 mm of rain annually. The distribution of rainfall determines the growing seasons for the farm crops. Deviations of over 100% in the mean monthly precipitation are not unusual, leading to "serious problems in planning agriculture" (Baum *et al.*1983). The rainfall intensity can be very high especially during rainstorms thereby causing extensive soil erosion on fields without tree cover. The period between June and mid-September is the coldest time of the year; misty weather is common during these months although rainfall is rare. It is a period of limited farm activities due to frequent occurrence of frost.

Temperatures in the area are relatively cool, generally in the range of 18^{0}C (June to mid-September) to 23^{0}C (rest of the year). The lowest temperature ever recorded was in 1974 when a low of 5^{0}C occurred. The wind speeds are low to moderate. Mean monthly relative humidity is highest in April at about 85% and lowest in February at about 77%.

3.1.3 Local administration

Administratively, the village has its own Local Government subordinated to Lushoto District Council. The Local Government is responsible for planning of various socio-economic development activities undertaken by the village, maintenance of law and order and resolving conflicts through the "mediation body or council" (locally known as "*Baraza la Usuluhishi*"). The Village or Local Government is divided into a number of committees as a way of delegating responsibilities. These include committees for economic planning, social and



Map 3.1 Location of Lukozi Village in the West Usambaras

welfare services, security and "*militia*" (*militia* is no longer as strong as it was in the 1970s), finance and marketing and a special group composed of distinguished elders. The top leaders are the village chairman and secretary. They are followed by the ten-cell leaders who lead the "*kayas*" (a *kaya* is made up of ten or more households).

3.1.4 Demography

Lukozi Village has a population of 4500 people in a total of 500 households (a household is not synonymous to family because a Shambaa man may have more than one wife to the extent that the Shambaa people are polygamous. The average size of a household is 7.5 persons. About 65% of the population comproses young individuals in the age of between 15 and 25 years, 25% are adults over 25 years and 15% are children under 15 years. The population grows at a rate of 2.1% per annum (GTZ 1992). The tribes living at Lukozi Village are Shambaa, Pare and Mbugu accounting for 80%, 15% and 5% respectively (*ibid*). The tendency of Shambaa people towards polygamy is attributed to the fact that children are considered to be the source of family labour as well as social security during old age (per. exp.).

3.1.5 Land use patterns

There are essentially three types of land use patterns at Lukozi Village. First is the natural forest (part of Shume-Magamba forest reserves) and pure stands of forest plantation established in the village or adjacent to the village. Second is the traditional intercropping system of maize, beans and potatoes. Occasionally banana is included. Third are the valley floors (beds) which are largely used for growing vegetables. In drought years potatoes and maize are grown as well because of the possibility for "low cost" irrigation. Another system besides the traditional system is the monocropping farming system. In essence therefore there are two farming systems at Lukozi Village, monocropping and intercropping systems. Agroforestry will be introduced as an alternative farming system.

3.2 Methods of data collection

3.2.1 Source of data

Data for the case study were obtained from both the primary and secondary sources. Data from the primary source were obtained through structured and semi-structured interviews, informal discussion with village elders, local government leaders and direct observations. Field surveys were also conducted in part of the Shume Magamba Forest Project which borders (lies adjacent to) Lukozi Village. Specimen from various tree species considered important to the villagers were collected for identification by Forest Silviculture Station situated in Lushoto town. The purpose of collecting tree/plant specimen was two-fold, to elucidate the end-use and to estimate the density of the various species (only a crude estimate was the object).

Ground survey of the village boundaries was conducted in collaboration with SECAP personnel and local government leaders. Market surveys were conducted in three different periods, just before and after Christmas (1991); in January 1993 and during the Holy Month of *Ramadhan* (the month of fasting for Muslims) to track "price movements". Soil samples were collected and analyzed at the Department of Soil Science, Sokoine University of Agriculture (Tanzania).

Secondary data sources includes Lushoto District Agricultural Development Office, SECAP, GTZ-Lushoto Station, Forest Silviculture Station, (Shume) Magamba Forest Projet, RTC-Lushoto Branch, TARECU-Lushoto Branch, Tanga Regional Forest Office, Division of Forestry and Beekeeping Planning and Catchment Management Sections in Dar es Salaam. Also wherever necessary informal discussions were conducted with the relevant authorities.

3.2.2 Techniques for data collection

The techniques used to acquire data from primary sources were administering both structured and semi-structured questionnaire (the structure of questionnaires used is given in appendix 3); direct observation and collection of field samples especially those for botanical and soil analysis. Due to time limitations and to minimize possible errors enumerators were picked from Lukozi Village. Local enumerators were preferred also because during the peak of the farming season it was difficult to interview the peasants during the day time. Thus evening and night sessions were necessary. The education level of the enumerators were Form VI leavers and were supervised largely by the local government leaders. The month of December 1991 was used mainly to conduct seminars regarding the purpose and *modus operandi* of the field work. The local government leaders took interest in the research itself for a couple of reasons. First it was possible for some of their children to get "temporary employment". Second they were eager to "see light at the end of the tunnel" (as the Village Secretary put it) emanating from the research to the extent that it "deals with land use planning". They were partly motivated by high expectations. The surveys were supplemented by direct observations.

Data from secondary sources were obtained largely through the analysis of various documents and records. The analysis was supplemented by informal discussions. The use of a combination of techniques in data collection was necessary due to the existence of variations among the data components and the village households.

3.2.3 Type of data

This study followed closely the "*micro diagnosis and design*" (Micro D & D) technique proposed by International Council for Research in Agroforestry (see Marcelino & Minae 1991). The micro D & D was developed as an approach to study land uses at the micro level. Since the studies of Lukozi village were done at the micro level, therefore, the technique was considered relevant. Modifications were made in relation to data types in order to accommodate the aims of the current study. The data collected from the study area includes;

(a)<u>Wood products</u>:
- (i) fuelwood, m^3
- (ii) poles

(b)<u>Farm crops, kg</u>:
- (i) maize
- (ii) beans
- (iii) potatoes

(iv) vegetables

The common unit of measurement for the farm crops at the village was a *bag*. The following conversion parameters were used:

maize 1 bag = 90 kg
beans 1 bag = 90 kg (elsewhere it is 100 kg)
vegetable (cabbage) 1 bag = 30 kg
potatoes 1 bag = 70 kg.

These conversion weights were based on market surveys at Lukozi village and compared well with those in Kwemakame village and Lushoto town markets.

(c)<u>Physical and soil data</u>:
- (i) slope
- (ii) soil-type, texture, pH reaction and nutrient status.
- (iii) topography
- (iv) altitude
- (v) border forest vegetation
- (vi) growing season, months, number of days

(d)<u>Basic climatic data</u>:
- (i) rainfall (amount and distribution)
- (ii) temperature, minimum, maximum and seasonal variation
- (iv) wind situation

(e)<u>Demographic data</u>:
- (i) population size
- (ii) population density
- (iii) population growth rate
- (iv) age distribution
- (v) tribes, ethnic groups
- (vi) marriage pattern; monogamy versus polygamy

(f)<u>Socio-economic assessment</u>:
- (i) annual income
- (ii) income per capita
- (iii) seasonal labour supply
- (iv) size of household
- (v) off-farm activities

(g)<u>Land use</u>:
- (i) source of land (inheritance, purchase, village)
- (ii) land tenure system and ownership
- (iii) size of holdings, average, range, distribution
- (iv) spatial arrangement, homestead, crops, trees
- (v) crop production (main crops, land preparation, planting, inputs, weeding,

harvesting, pesticide spraying and storage
(vi) tree growing, species, uses
(vii) Qualitative assessment of risk factors
(viii) Ecological assessment of the West Usambara natural forest reserves. Species diversity and end-uses[1].

(j)<u>Infra-structure and social services:</u>
(i) road network
(ii) medical services
(iii) schools
(iv) shops

3.2.4 Selection of sample village and detailed surveys

3.2.4.1 Reconnaissance survey

A reconnaissance survey of the Shume-Magamba Forest Project was conducted in November 1991. Post survey discussions revealed the following:

(a) The natural forest reserves, as they are today, were protected by law such that extractions are not allowed. Thus it was envisaged that any change thereof has to relate to changes in forest management policy. In the Tanzanian context, a policy change takes relatively long time to accomplish. In the short-run therefore, the forest reserves were considered stable, in that no meaningful change can take place without changing the structure of the management.

(b) Encroachment to the forest reserves was more conspicuous in those areas where proper boundary is lacking. Proper boundary in this regard is a line plantation of *Eucalyptus spp.* which separates the forest reserves from "public" land. Similar trends/situation was observed in the Uluguru mountains where encroachment was serious in areas without clear demarcation or boundary (Pocs 1988).

The level of encroachment was serious in the north-east side of the Shume-Magamba forest reserve bordering Ndabwa kaya in the Lukozi village. Low levels of encroachment were also noted in the adjacent villages including Viti, Manolo and Shume. Villagers also strips trees of their bark for use as a roofing material (the same was reported by Chemi Che-Mponda in Daily News of 5th May 1992). The stripping causes stunted tree growth and sometimes the tree dies off. The most severely damaged tree is cedar (*Juniperus procera*).

(d) The villages surrounding the forest reserve have well established subsistence farming system. However, according to SECAP's assessment, the system is hardly sustaining due to population growth and bad farmland management practises.

Note: [1] This part of field data was incorporated in report 2 (*see* Kaoneka 1993(b))

3.2.4.2 Diagnostic views

On the basis of the observations made during the reconnaissance survey augmented by discussion with the SECAP leader the following "diagnostic" views were expressed:

(a) Changing the management situation of the Shume-Magamba Forest Project is a long-term oriented solution.

(b) The encroachment of forest reserves is a symptom and not the cause. It is a manifestation of problems associated with subsistence form of agriculture and general bad farmland management practises.

(c) It was envisaged that a meaningful approach would be to analyze the peasant sector and use agroforestry as a bridge between "pure" forestry and "pure" agriculture.

(d) Serious encroachment occurs in *kayas* belonging to Lukozi village especially those which border the forest reserves.

3.2.4.3 Selection of Lukozi village as a study area

The selection of Lukozi village as a study area was based on the diagnostic views as well as the following reasons:

(a) In light of time limitations and possible problems with data availability it was considered appropriate to limit the case study to one village only.

(b) The case study requires somewhat detailed data which means high time demand. One village would thus allow the acquisition of somewhat detailed data in relation to the available time schedule.

(c) The socio-economic development of the Lukozi village is relatively high with fairly high level of literacy. This was considered to be a characteristic that would lessen problems of data availability. Also Lukozi village is one of the pilot areas where SECAP has been conducting field trials (though with minimal practical success). Thus local people were used to being interviews. Ostensibly the Shambaa people are averse to interviews because they liken it to "interrogation".

(d) Lukozi village is accessible with an all weather road going to Mlalo town. This aspect was important especially taking into account that part of the field work was to be done during the long rains in March through May.

(e) It is said that land use pattern is influenced *inter alia* by cultural and traditional values. The dominant tribe of the West Usambaras is the Shambaa tribe. Lukozi village is seen as a representative of the Shambaa culture because 80% of its inhabitants belong to the Shambaa tribe. Therefore a study of the Lukozi village was envisaged to elucidate some Shambaa cultural behaviour which in one way or the other influences the existing land use pattern.

3.2.5 Detailed field surveys

3.2.5.1 Selection of households for interviews

Selection of households for field interviews was based on the village register. The houses were picked at random using the village register. In due course some kayas received more interviews than others. However since subsequent analysis was intended to cover the entire village this was not considered a handicap.

Preliminary random household surveys conducted in December 1991 revealed low level of inter-household variation, for instance of income, farming techniques, dietary behaviour and land use pattern. Therefore stratification based on these parameters was not considered to be necessary. However, there existed some inter-house variations such as male/female ratio and old/young ratio which might affect labour availability. In fact it would have been of technical advantage to stratify households along these factors. Nevertheless this could not be done due to limitations of time and other resources.

3.2.5.2 Mode of interviews

The interviews were conducted at three levels, *viz*, household, *kaya* and village. At the household level the head of the family (in our case all households were male-headed) was interviewed. The purpose of those interviews was to obtain basic household data. At the *kaya* level the ten cell leaders (locally known as "*balozi*") were interviewed. These interviews were conducted for two reasons, to cross-check household data and to obtain aggregated data for the entire *kaya*. The third level of interview was conducted by interviewing either the village chairman or secretary or both (in this case both were interviewed by the author). The main purpose of the interviews at this level was two-fold, to obtain aggregated data for the entire village and elucidate the political arrangements and some policy issues related to the village administration.

In addition to the formal interviews, a wide range of informal interviews were conducted with the village extension workers, *viz*, the agriculture extension worker (*Bwana Shamba*) and the village forester (*Bwana Miti*). The village had no livestock extension staff. These interviews were intended to gather information about farming practises, extent of using market inputs such as chemical fertilizers, improved seeds and pesticides; the type and extent of extension services rendered and the practises of tree planting (village afforestation) programmes.

3.3 An overview of techniques used for data analysis

The analysis of the data from this case study was done in three steps as outlined under sections 3.3.1, 3.3.2 and 3.3.3.

3.3.1 Microeconomic analysis

The microeconomic analysis was conducted for the peasant household farm with essentially three objectives;

(i) Analysis of labour demand and supply

(ii) Assessment of the economic profitability of the farming systems at Lukozi Village
(iii) Comparison of the farming systems from socio-economical point of view.

3.3.2 Mathematical modelling

Mathematical modelling was used to develop linear programming (LP) and compromise programming (CP) models. These techniques have already been described in Chapter 2.

3.3.3 Assessment of soil productivity

The assessment of soil productivity was conducted with the objective of examining the following aspects;
(i) soil nutrient status/content;
(ii) soil nutrient removal in each cropping system;
(iii) assessment for sustainability and potential for improvement of the farming systems.

The soil nutrient budget approach (Stoorvogel & Smaling 1990; Mnkeni 1992; pers. comm.) was used for the assessment. The approach is described further in Chapter 4.

3.4 Development and application of models

3.4.1 Analysis of the existing farming systems using LP model

3.4.1.1 Introduction

Linear programming technique has found wide application in land use planning as discussed in Chapter 2. The wide use of linear programming technique indicates its usefulness as an analytical tool for decision making process related to resource allocation and general resource planning. Due to its strength in dealing with resource allocation, the present study proposed the application of linear programming technique in developing farm land use plans at the village level in Lukozi area, West Usambaras. The general theory on linear programming technique relevant to this case study was reviewed in Chapter 2. The farming systems that were modelled are monocropping and intercropping farming systems.

The main objective of applying linear programming technique in this case study was to map out what a peasant farmer is capable of producing within the existing resource limitations or conditions referred to as available resources in this study. As a starting point two normative static linear programming (LP) models were developed to determine the optimal land allocation among the various crops, one model with the objective of maximizing total net income and the other with the objective of maximizing net cash income, while meeting the subsistence requirements of the peasant household at Lukozi Village.

Sensitivity analyses were conducted in order to elucidate the effect of farm-gate (producer) price movements. This experiment was based on normative and positive economic principles with the aim of exploring the concequences of a particular policy (pricing policy) and the responsive behaviour of the peasant farmer to price changes. The results were used to estimate a "step" supply function. The term "step supply function" is used bacause the response on supply quantities is observed after a series of simulated changes. The supply function obtained was used to estimate the price elasticity of maize supply. Maize is not only a staple grain for most parts of Tanzania, but also has high potential as a tradeable crop. Thus, it was assumed to respond to price variation more significantly than potatoes and beans. Another sensitivity analysis was carried out to determine the effect of changes in the land area constraint. In the extended model further analyses were carried on the effect of population growth over time on per capita income and food consumption from own farm. The object was to elucidate the sustainability pf the present farming systems given population growth trends. Another objective was to examine the pressure on forest lands emanating from population growth.

3.4.1.2 Household farm data

The data material used to build, parameterize and run the LP models were obtained during field surveys and from secondary data sources. A detailed analysis of the field data is presented in Chapter 4. However, for the purpose of adding clarity, a summary of the base input-output materials for the LP models are presented in Table 3.1.

Table 3.1 A summary of production activities on per ha basis for farmer at Lukozi Village

Production Resources	Monoculture cropping				Intercropping			
					System I		System II	
	Maize X_1	Beans X_2	Potatoes X_3	Vegetables X_4	Maize/Beans X_5	Beans X_6	Maize X_7	Beans X_8
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Land area (ha):								
Lowland	0	0	0	1	0	0	0	0
Highland	1	1	1	0	1	1	1	1
Human labour (man-days):								
January	0	0	0	0	0	0	0	0
February	4	4	8	10	4	0	4	0
March	8	5	11	11	7	0	8	0
April	2	0	0	8	0	0	2	0
May	0	5	6	3	5	0	0	0
June	5	0	0	0	5	0	5	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	4	8	10	0	4	0	4
October	0	5	11	11	0	5	0	5
November	0	0	0	8	0	0	0	0
December	0	4	6	3	0	5	0	5
Fertilizer nutrients (kg):								
Phosphorous	25	0	50	50	0	0	25	0
Nitrogen	42	0	0	168	0	0	42	0
Manure (t):	0	5	5	5	5	0	0	5
Working capital (TAS) [1]	10525	23350	20550	57150	27725	8600	10525	8600
Total cost (TAS):	27033	25850	27266	92666	30225	8600	27033	11100
Yield (kg)	1340	1206	2000	20000	(1206 543)	603	1340	603
Price (TAS/kg)	48	68	40	22	48 68	68	48	68
Gross Returns (TAS)	64320	82008	80000	440000	94812	41004	64320	41004
Gross Margin (TAS) [2]	53795	58658	59450	382850	64587	32404	53795	32404

Note: (1) Working capital is the money set aside for purchasing seeds/seedlings, chemicals and hand tools
(2) Obtained as a difference between gross returns less working capital

3.4.1.3 Underlying assumptions in developing the LP models

In developing the linear programming (LP) models the general assumptions as described in Chapter 2 were taken into consideration. In addition the following assumptions were made regarding household farming systems:

(a) There is no purchase or sale of land.

(b) No labour hiring during the period of analysis. Farmer households rely solely on family labour.

(c) No change in farming technology over the period under analysis. Thus farm resources are assumed to be fixed in both supply and use.

(d) The total amount of available labour for farming activities in each calendar month was assumed to represent a proportion of 75%. A margin of 25% was considered to represent the time spent by the farmer household on off-farm activities such as prayers (Fridays and Sundays), cultural ceremonies and religions festivals (Id el Fitr, Id el Haj and Maulid for Muslims; Christmas and Easter for Christians). This assumption was based on own experience and Sankhayan (1992; pers. comm.).

(e) Working capital can be borrowed at the existing rate of interest up to the level it is profitable.

3.4.1.4 Mathematical formulation of the LP models

3.4.1.4.1 Definition of decision variables or real activities

3.4.1.4.1.1 Production activities

The symbols used to represent production activities are defined as follows:

X_i = hectares of land allocated to crop i where i = 1, 2, ..., 7, 8 representing

1 = maize planted in monoculture farming system
2 = beans planted in monoculture farming system
3 = potatoes planted in monoculture farming system
4 = vegetable planted in monoculture farming system
5 = maize planted in intercropping farming system
6 = beans planted in intercropping farming system
7 = maize alternately intercropped with beans
8 = beans alternately intercropped with maize

3.4.1.4.1.2 Purchase activities

The symbols used to represent purchase activities are defined as follows:
X_p = kilogrammes of phosphorous fertilizer purchased per year
X_n = kilogrammes of nitrogen fertilizer purchased per year
X_k = tanzanian shillings borrowed as working capital per year

3.4.1.4.1.3 Crop sale activities

The symbols used to represent crop sale activities are defined as follows:
S_i = kilogrammes of crop i sold by the household to earn cash income per year

3.4.1.4.1.4 Crop consumptions activities

The symbols used to represent crop consumption are defined as follows:
C_i = kilogrammes of crop i consumed by the household per year

3.4.1.4.2 Right hand side (RHS) values

The symbols used to represent the values of the right hand side (RHS) for each constraint (row) are defined as follows:

A_{lr} = hectares of land available for planting crops during long-rain (lr) season
A_{sr} = hectares of land available for planting crops short-rain (sr) season
A_v = hectares of land available for planting vegetables (v) during both long- and short-rain seasons
L_t = mandays of available labour during month t where t = 1, ...,12 and 1 = January, ... 12 = December
M = tonnes of farm yard manure available for plant crops on the farmer household farms
K = total capital available for farming activities (TAS)

3.4.1.4.3 Technical coefficients

The symbols used to represent technical coefficients are defined as follows:

l_{ti} = mandays of household labour required during month t to plant a hectare of crop i
p_i = kilogrammes of phosphorous fertilizer required to plant a hectare of crop i
n_i = kilogrammes of nitrogen fertilizer to plant a hectare of crop i
k_i = tanzanian shillings of working capital required to plant a hectare of crop i
m_i = tonnes of farm yard manure required to plant a hectare of crop i
q_i = kilogrammes per hectare produced by crop i
f_p = market price for phosphorous fertilizer, TAS kg^{-1}
f_n = market price for nitrogen fertilizer, TAS kg^{-1}
f_i = farm-gate price for crop i, TAS kg^{-1}
gr_i = gross return at farm gate prices obtained by planting crop i, TAS ha^{-1}
r = interest rate per annum (%)

3.4.1.4.4 Generalized detached coefficient matrix

The generalized detached coefficient matrix for the LP models is presented in Table 3.2.

Table 3.2 A generalized detached coeffizient matrix for the LP models

Row identity	Decision variables						Sign	RHS
	Crop Production	Input purchase			Crop Sale	Household Consumption		
		Phosphorous	Nitrogen	Working capital				
	X_{ij}	X_p	X_n	X_k	S_i	C_i		
Land area (ha):								
Long rains							≤	A_{lr}
Short rains	+1	0	0	0	0	0	≤	A_{sr}
Vegetable land							≤	A_v
Household labour (mandays):								
January . . . December	$+l_{ij}$	0	0	0	0	0	≤	L_t
Fertilizer nutrients (kg):								
Phosphorous	$+p_i$	-1	0	0	0	0	≤	0
Nutrients	$+n_i$	0	-1	0	0	0	≤	0
Manure (tonnes):	$+m_i$	0	0	0	0	0	≤	M
Working capital (TAS):	$+k_i$	0	0	-1	0	0	≤	0
Working capital limit (TAS):	0	$+f_p$	$+f_n$	+1	0	0	≤	K
Output allocation (kg):								
Maize, Beans, Potatoes, Vegetables	$+q_i$	0	0	0	-1	-1	≥	0
Objective function:								
Gross return	$+gr_i$	$-f_p(1+r)$	$-f_n(1+r)$	$-(1+r)$	0	0	Maximiz	Model I
Net cash income	0	$-f_p(1+r)$	$-f_n(1+r)$	$-(1+r)$	$+f_{ij}$	0	Maximiz	Model II

3.4.1.5 Description of the LP models

3.4.1.5.1 General overview

The development of the linear programming models for the farm household farming systems in this case study was based on traditional linear prgramming (Dykstra 1984; Sankhayan and Cheema 1991) and compromise programming (Hazell 1971: Romero and Rehman 1984; Romero, Amador and Barco 1987; Sankhayan, Prihar and Cheema 1988; Boisvert and McCarl 1990). General micro-economic theory with relevance to farming systems, household economic theory (Low 1986; Nakajima 1986 and Holden 1991), the satisficing principle (Simon 1979) and linear programming theory were used in designing the conceptual framework of the model, specification of model parameters, definition of underlying assumptions and logic; as well as discussing the results obtained from the models.

As a starting point two models were developed in relation to the farming systems analyzed commensurate with the objectives described in Chapter 1. The two models were maximization of total net income using gross returns as "prices" or coefficients in the objective function (Model I) and maximization of net cash income using farm-gate prices as coefficients for crop sale activities in the objective function (Model II). The two models were considered relevant for representing the situation faced by the farmers in their struggle for survival. The models are described fully in the following sections.

3.4.1.5.2 Model I - maximization of total net income using market prices

In developing Model I, gross returns (gri) were used as prices on coefficients for production activities (decision variables) in the objective function. Other activities included in the objective function were phosphorous and nitrogen fertilizer purchase activities using their respective market prices as coefficients and working capital borrowing activity at the prevailing rate of interest. The coefficient of fertilizer purchase and working capital borrowing included the principal and interest rate. In the output allocation a minimum subsistence requirement for the household was specified for each crop. The allocation is based on the premise that the strategy of the farmer is to produce to the level such that the subsistence needs of the family are met, and the rest of the crop is sold to earn cash income for purchasing market goods. In fact, this is the typical behaviour of a farmer farmers (see Holden 1991). Also, such a behaviour may be explained using Maslow's hierarchy of needs (see Kaoneka 1987) whereby the physiological needs, including food and cultural needs, must be satisfied first before an individual proceeds to "higher" needs such as earning cash income. In model I, crop sale activities were not included as they are incorporated into the gross returns exogeneously.

3.4.1.5.2.1 Objective function

The objective function of Model I is to maximize total net income obtained from planting maize, beans, potatoes and vegetables in monocropping and intercropping farming systems. It was assumed that whenever opportunities are available, a farmer may borrow working capital from money lending institutions such as the Cooperative and Rural Development Bank (CRDB) which at present levies an interest rate of 28% per annum on such loans. Such an interest rate embodies inflation, thus in the analysis the real rate of discount (RRD) which is about 10% (EIU 1992) will be applied. Furthermore it is assumed that working capital is used for purchase of seeds, handtools and chemicals. When the RRD is included, the objective function may now be written down as:

$$Maximize\ Z = \sum_{i=1}^{8} gr_i\, X_i - f_p(1+r)X_p - f_n(1+r) - (1+r)X_k \qquad [3.3]$$

3.4.1.5.2.2 Labour constraint

Labour supply in any calendar month must not exceed the total amount of available effective working days. Further more, labour used to plant a hectare of any crop must not exceed the total amount of effective household family labour which participate in farming activities to the extent that there is no labour hiring. The average household size is 7.5 persons (own field data). In each calendar month 75% of the days are assumed available for farming activities. Also in each household, members of the family below 15 years, who constitute an average of 10% by proportion are exempted from farming activities because they spend most of their time at school. In essence, therefore, the average household adult labour available for farming activities is:

$$(0.9 \times 7.5\ \frac{persons}{household}) = 6.8\ persons/household$$

Also in each calendar month the available working days are computed as;

$$(0.75 \times 30/31\ \frac{days}{month}) = 23\ working\ days/month$$

Thus, on average each household will have;

$$23 \times 6.8 = 156\ mandays\ per\ month$$

Furthermore, it is assumed that each member of the household spends the same length of time on the farm each day. Based on these facts, the labour constraints can be written down as:

$$\sum_{t=1}^{12} \sum_{i=1}^{8} l_{ti} X_i \leq 156 \qquad [9.2]$$

Finally, only peak months, February, March, May, September, October and December, were used as constraints because it is during such months that labour could be limiting.

3.4.1.5.2.3 Phosphorous nutrient requirement

Phosphorous is one of the macronutrients required for crop growth and is applied during planting. The fertilization regime currently precticed in Lukozi Village, applies 124 kg ha^{-1} of triple super phosphate (tsp), a commercial mineral fertilizer. The phosphorous nutrient content in triple superphosphate is 20% by weight. This proportion translates into phosphorous content of:

(0.2 x 124 kg ha^{-1}) = 25 kg ha^{-1} of phosphorous nutrient

The crops which need phosphorous fertilizer are maize, potatoes and vegetables requiring 25, 50 and 50 kg respectively. Considering these facts the phosphorous nutrient contraint can be written down as:

$$\sum_{i=1}^{8} p_i X_i - X_p \leq 0 \qquad [3.3]$$

The specification of equation [3.3] indicates that the amount of P fertilizer purchased must not exceed that required by the allocated farming systems.

3.4.1.5.2.4 Nitrogen nutrient requirement

Nitrogen, like phosphorous, falls in the category of macronutrients required for crop growth and is applied as top dressing. The present rate of application is 200 kg ha^{-1} of sulphate of ammonia (sa), a commercial mineral fertilizer which supplies nitrogen nutrient. The nitrogen nutrient content in sulphate of ammonia is 21% by weight. This proportion translates into:

(0.21 x 200 kg ha^{-1}) = 42 kg ha^{-1} of nitrogen nutrient

The crops which need N fertilizer are maize and vegetables requiring 42 and 168 kg respectively. Based on the above information the nitrogen nutrient constraint can be written as:

$$\sum_{i=1}^{8} n_i X_i - X_n \leq 0 \qquad [3.4]$$

Equation [3.4] indicates that the amount of N fertilizer purchased must not exceed that required by the allocated farming systems.

3.4.1.5.2.5 Manure requirement consraint

Traditionally farm yard manure is a long term land maintenance practise. Farm yard manure is very important because it adds both nutrients and organic matter which provides cation exchange sites and influences the physical properties of the soil. The application regime of farm yard manure in Lukozi village is 2 t per acre or 5 t ha^{-1} (DADO 1991). A household can obtain a maximum of 25 t of manure per year (based on SECAP and DADO surveys). Thus the manure requirement constraint can be written down as:

$$\sum_{i=1}^{8} m_i X_i \leq 25 \qquad [3.5]$$

The logic embodied in constraint [3.5] is that the total amount of farm yard manure applied must not exceed the maximum amount which a household can obtain annually for the farming systems.

3.4.1.5.2.6 Working capital constraint

A narrow definition used here is that the working capital represents the sum of cash set aside for purchasing of seeds, handtools and chemicals. The amount of working capital varies with crop type and farming system. A borrowing activity is included such that when opportunity is available, the farmer will borrow at the existing interest rate to the extent it is profitable. Therefore the working capital constraint can be written down as:

$$\sum_{i=1}^{8} k_i X_i - X_k \leq 0 \qquad [3.6]$$

3.4.1.5.2.7 Capital limit constraint

The capital limit constraint is included in the model with the aim of setting a ceiling for the use of borrowed working capital. The maximum capital limit represents the combined amount of working capital plus costs of purchasing mineral fertilizers. The capital limit can be written down as;

Total capital = Working capital + Cost of mineral fertilizer

Thus the capital limit constraint can be written down as

$$X_p + X_n + X_k \leq K \qquad [3.7]$$

K = total capital available for farming activities. Initially K is assumed to be TAS 241173 (based on own field surveys).

3.4.1.5.2.8 Consumption requirement constraints

3.4.1.5.2.8.1 Maize (*Zea mays*)

About 80% of the maize produced is set aside to meet household subsistence requirement. The present production level in Lukozi area is 1340 kg ha^{-1} (based on field survey and own experience). The average household size is 7.5 persons. Thus, the amount set aside for household subsistence requirement is taken as 143 kg per person. Therefore total household requirement can be estimated as

$$(143\ kg/person)\ x\ 7.5\frac{persons}{household}) = 1072\ kg\ per\ household/year$$

Thus the output allocation for maize can be written down as:

$$\sum_{i=1,5,7} q_i X_i - \sum_{i=1,5,7} S_i X_i \geq 1072 \qquad [3.8]$$

Implied in constraint equation [3.8] is the fact that maize produced in all systems must at least meet subsistence requirements.

3.4.1.5.2.8.2 Beans (*Phaseolus vulgaris*)

About 45% of the bean production is used to meet consumption requirement for the household and is a basic source of protein. The average yield of beans is 603 kg ha^{-1} (based on own survey and experience). The average amount set aside to meet subsistence requirements was found to be 36 kg per person. Therefore total household consumption requirement can be worked out as;

$$(\frac{36\ kg}{person})\ x\ (\frac{7.5\ persons}{household}) = 270\ kg\ per\ household/year$$

The output allocation for beans can be written down as;

$$\sum_{i=2,5,6,8} q_i X_i - \sum_{i=2,5,6,8} S_i X_i \geq 270 \qquad [3.9]$$

Equation [3.9] implies that beans produced in all farming systems must at least meet the household subsistence requirements.

3.4.1.5.2.8.3 Potatoes (***Solanum tuberosum***)

About 50% of the potatoes produced is consumed by the household (based on own survey and experience). With a crop turnover of 1000 kg ha^{-1}, potato consumption was found to be 67 kg per person. Thus total household consumption is estimated as;

$$\left(\frac{67\ kg}{person}\right)\ x\ \left(\frac{7.5\ persons}{household}\right) = 502\ kg\ per\ household/year$$

Thus the output allocation for potatoes can be written down as:

$$q_3X_3 - S_3X_3 \geq 502 \qquad [3.10]$$

3.4.1.5.2.8.4 Vegetables (***Brassica oleracea***)

The amount of vegetable set aside for household consumption is about 10% of the total crop turnover of 10,000 kg ha^{-1} (wet weight) (based on own survey and experience). Thus the household consumption was found to be 133 kg per person. The total household consumption is estimated as:

$$\left(\frac{133\ kg}{person}\right)\ x\ \left(\frac{7.5\ persons}{household}\right) = 998\ kg\ per\ household/year$$

The output allocation for vegetable crop can be written down as:

$$q_4X_4 - q_4S_4 \geq 998 \qquad [3.11]$$

3.4.1.5.2.9 Land area constraint

The total land area under agriculture was divided into two broad categories, based on field survey regarding the actual utilization of farmlands by the farmers:

a) Lowland: representing the land under agriculture with a slope of <10% used for planting vegetables (hence to be referred to as vegetable land). The vegetable land was estimated to represent about one third of the total household farmlands (based on own field survey and SECAP 1991).

b) Highland: representing the land under agriculture with a slope of >10% used for planting maize, beans and potatoes (based on own field survey and SECAP 1991).

Since beans and potatoes are planted twice each year during long- and short-rain seasons respectively, the highland was further classified into long- and short-rain land. The highland zone was estimated to represent about two thirds of the total household area under agriculture. Based on an average farm size of 2.5 ha per household, the land area distribution is 0.8 ha lowland per household and 1.7 ha highland per household.

Vegetables, which grows in lowland zone, are planted twice each year, during long- and short- rain season respectively. Thus the total cropped land area under vegetable is 1.6 ha per year. Beans and potatoes which grow in the highland zone, is planted twice each year, during long- and short- rain seasons respectively. Maize is planted once in each year. However under monocropping system, once maize is planted in essence it occupies a hectare of land for the whole year. Thus the land area available in each season for planting maize, beans and potatoes is 1.7 ha. Based on the above information, the land area constraints can be written down as:

Long-rain land area constraint

$$\sum X_i \leq 1.7 \qquad [3.12]$$

i = all crops (except vegetables) planted during the long-rain season.

Short-rain land area constriant

$$\sum X_i \leq 1.7 \qquad [3.13]$$

i = all crops (except vegetable) planted during the short-rain season.

Since vegetable is planted twice each year, the vegetable land area constraint can be written down as;

$$X_4 \leq 1.6 \qquad [3.14]$$

3.4.1.5.2.10 Nonnegativity conditions

$X_i \geq 0$, i = 1,2,...,8 [3.15]
$X_n \geq 0$ [3.16]
$X_p \geq 0$ [3.17]
$X_k \geq 0$ [3.18]
$S_i \geq 0$ i = 1,...,4 [3.19]
$C_i \geq 0$ i = 1,...,4 [3.20]

3.4.1.5.2.11 Detached coefficient matrix

Omitting the non negative conditions, the detached coefficient matrix for model I, in numerical format, is presented in Table 3.3.

3.4.1.5.3 Model II - Maximization of net cash income for farm household

Model II seeks to maximize net cash income obtained from the sale of crops while meeting the subsistence requirements of the farm household. In this formulation sale activities are included. Farm-gate prices were used as coefficients of the sale activities in the objective function. The farm-gate prices used were 48, 68, 40 and 22 TAS kg^{-1} for maize, beans, potatoes and vegetables respectively (based on field survey). The basic nature of this model necessitated to assign zero prices to the production activities. Other features of model I remain unchanged. Therefore, the objective function can be written down as:

$$Maximize\ z = -(1+r) f_p X_p - (1+r) f_n X_n - (1+r) X_k + \sum_{i=1}^{4} f_i S_i \qquad [3.21]$$

With the introduction of these changes, the detached coefficient matrix for model II is presented in Table 3.4.

The two matrices for models I and II were subjected to the simplex algorithm in LINDO package. Several runs were conducted for each model. The results obtained from the two models will be presented in Chapter 4.

3.4.1.5.4 Sensitivity analysis

Model I was used to conduct a "What if" the farm-gate prices for the crops increase and use the results to elucidate the reaction of the farmer.

Whereas the positive economic principles were used to analyze the effects of changes (What if question), normative theory was used to explain how the farmers react to the changes on the assumption that they maximize the defined objective functions under the stated constraints.

Table 3.3 A detached coefficient matrix for the LP model I - Maximization of net income

	Hectares of crops planted under different cropping systems								Input purchase activities			Type	RHS
	Monocropping system				Intercropping system				Phosphorous	Nitrogen	Working capital		
	Maize	Beans	Potatoes	Vegetables	System 1		System 2						
					Maize/Beans	Beans	Maize	Beans					
Row identy	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_P	X_N	X_K		
Objective function:	64320	82008	80000	440000	94812	41004	64320	41004	-18.7	-39.6	-1.1	z	Maximize
Household labour (mandays)(1):													
February	4	4	8	10	4	0	4	0	0	0	0	≤	156
March	8	5	11	11	7	0	8	0	0	0	0	≤	156
May	0	5	6	3	5	0	0	0	0	0	0	≤	156
September	0	4	8	10	0	4	0	4	0	0	0	≤	156
October	0	5	11	11	0	5	0	5	0	0	0	≤	156
December	0	5	6	3	0	5	0	5	0	0	0	≤	156
Fertilizer nutrients (kg):													
Phosphorous	25	0	50	50	0	0	25	0	-1	0	0	≤	0
Nitrogen	42	0	0	168	0	0	42	0	0	-1	0	≤	0
Farm yard manure (ton):	0	5	5	5	5	0	0	5	0	0	0	≤	25
Working capital (TAS):	10525	23350	20550	57150	27725	8600	10525	8600	0	0	-1	≤	0
Limit on total capital (TAS)(2):	0	0	0	0	0	0	0	0	17	36	1	≤	241175
Crop output allocation (kg):													
Maize	1340	0	0	0	1206	0	1340	0	0	0	0	≥	1072
Beans	0	1206	0	0	543	603	0	603	0	0	0	≥	270
Potatoes	0	0	2000	0	0	0	0	0	0	0	0	≥	502
Vegetables	0	0	0	20000	0	0	0	0	0	0	0	≥	998
Land area (ha):													
Long rain area	1	1	1	0	1	0	1	0	0	0	0	≤	1.7
Short rain area	1	1	1	0	0	1	0	1	0	0	0	≤	1.7
Vegetable area	0	0	0	1	0	0	0	0	0	0	0	≤	1.6

Note: (1) Labour constraints are limited to peak months when labour demand is especially high
(2) The limit on working capital includes all costs i.e. working capital plus cost of fertilizers

Table 3.4 A detached coefficient matrix for the LP model II - Maximization of net cash income

	Hectares of crops planted under different cropping systems								Purchase activities			Sale activities				Type	RHS
	Monocropping system				Intercropping				Phosph.	Nitrog.	W.capital						
					System 1		System 2										
	M	B	P	V	M/B	B	M	B				M	B	P	V		
Row identy	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_P	X_N	X_K	S_1	S_2	S_3	S_4		
Objective function:	0	0	0	0	0	0	0	0	-18.7	-39.6	-1.1	48	68	40	22	z	Maxim
Labour (mandays):																	
February	4	4	8	10	4	0	4(a)	0	0	0	0	0	0	0	0	≤	156
March	8	5	11	11	7	0	8	0	0	0	0	0	0	0	0	≤	156
May	0	5	6	3	5	0	0	0	0	0	0	0	0	0	0	≤	156
September	0	4	8	10	0	4	0	4	0	0	0	0	0	0	0	≤	156
October	0	5	11	11	0	5	0	5	0	0	0	0	0	0	0	≤	156
December	0	5	6	3	0	5	0	5	0	0	0	0	0	0	0	≤	156
Fertilizer (kg):																	
Phosphorous	25	0	50	50	0	0	25	0	-1	0	0	0	0	0	0	≤	0
Nitrogen	48	0	0	168	0	0	42	0	0	-1	0	0	0	0	0	≤	0
Manure (tonne):	0	5	5	5	5	0	0	5	0	0	0	0	0	0	0	≤	25
W. capital (TAS):	10525	23350	20550	57150	27725	8600	10525	8600	0	0	-1	0	0	0	0	≤	0
Lim.total capital	0	0	0	0	0	0	0	0	17	36	1	0	0	0	0	≤	241173
Output (kg):																	
Maize	1340	0	0	0	1206	0	1340	0	0	0	0	-1	0	0	0	≥	1072
Beans	0	1206	0	0	543	603	0	603	0	0	0	0	-1	0	0	≥	270
Potatoes	0	0	2000	0	0	0	0	0	0	0	0	0	0	-1	0	≥	502
Vegetables	0	0	0	20000	0	0	0	0	0	0	0	0	0	0	-1	≥	998
Land area (ha):																	
Long rain area	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	≤	1.7
Short rain area	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	≤	1.7
Vegetable area	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	≤	1.6

Key: M = Maize, B = beans, P = potatoes, V = vegetables

3.4.2 Analysis of agriculture/forestry relations

3.4.2.1 Introduction

As described by Kaoneka (1993(b)) deforestation is a strong issue in the Usambaras. Virtually all the land available in Lukozi Village is under agriculture and human settlements. In the immediate environs to the village lies a natural forest reserve managed by Shume-Magamba Forest Project. Thus any expansion of the farmlands has to occur by way of clearing the natural forest reserve or more precisely deforestation.

The results generated via the Village I.LP model indicated that the present farming systems in Lukozi village could be sustainable given the present trends. However, if the population grows fairly fast, such a stable condition is likely to be disturbed. The most likely scenario is that population growth will increase pressure on farmlands. Such a pressure is attributed to an increase in the derived demand for food in the short-run and both food and human settlement in the long run. The model did not include provision for land clearing. Therefore it was found relevant to expand the model by incorporating land clearing activities. The aim was that the model should be able to accommodate the need for expanding farmlands as a result of population growth. The dynamic aspect included in the extended model is the population growth over time which introduces periodic changes in model parameters.

In expanding the model, the underlying hypothesis was that fast population growth increases the level of deforestation due, primarily, to a rising derived demand for food and income per household. Hence the primary aim of the analysis was to use the model to examine the effect of population growth and assumption of non-declining per capita and food consumption and income on land use pattern, in particular in relation to deforestation pressure over time. An additional aim was to examine the sustainability of the farming systems over time in light of an assumed population growth rate and constant farming technology.

3.4.2.2 Model development and application

The new model, to be referred to as Village II.LP, was developed by incorporating land clearing activities such that at any given year, the total cropped land is the sum of available land plus cleared land in the previous period. This condition can be stated mathematically as:

$$L_c = L_{t-1} + L_t \qquad [3.22]$$

where L_c = total cropped land in year t, where t = 5, 15, 25, 35
L_{t-1} = existing land area in the previous period/year
L_t = new cleared land

The new clearing activities that were incorporated into Village II.LP model are defined as follows:

VL_t = vegetable land cleared in year t, where t = 5, 15, 25, 35
LR_t = long-rain land cleared in year t
SR_t = short-rain land cleared in year t

such that in any given period the total cleared land is represented by:

$$CL_t = VL_t + LR_t + SR_t \qquad [3.23]$$

where CL_t = total cleared land in year t and other symbols remain as previously defined.

The development and subsequent experimentation of the model assumed certain aspects of importance. First it assumes that the same farming technology will be used over time. The second assumption is that clearing of new land will be done using family labour only. That is, there is no provision for hired labour to clear forests. However, it is considered appropriate that unnecessary deforestation does not occur in the sense that clearing of new land should be done only when the demand for it rises. In fact clearing of new land *per se* is not desirable unless it is found necessary under the model conditions assumed. Labour needed to clear forest land was assumed to be 75 mandays per hectare to reflect the ardous work involved. Also an additional average working capital requirement of 15,000 TAS ha^{-1} was assumed for clearing land. This amount was considered relevant for purchasing additional handtools, such as, cross-cut saws, axes and pangas. The estimates were based on Shume-Magamba Forest Project management plan (1991/96).

Population growth increases the demand for food. Thus household consumption was expected to increase as the household size increases. In this analysis, household consumption was estimated exogeneously. The basic premise was that population growth rate could be used as a proxy for estimating the increase in household consumption. Furthermore, it was assumed (though not necessarily realistically) that the per capita consumption will remain unchanged over time. Based on this framework, household consumption over time was estimated using the following equation:

$$C_t = C_0\,(1 + r)^t \qquad [3.24]$$

where C_t = household consumption in year t, *where t = 5, 10, 15, 20, 25, 30, 35 years.*
C_0 = household consumption in the base year (kg/household)
r = population growth rate (%)
t = time horizon i.e. 5, 10, 15, 20, 25, 30, 35 years.

Base year values used to compute future household consumption for each crop were those contained in the existing farm plan.

In addition to clearing activities, labour, working capital and land area constraints (row) were adjusted to reflect the changes made. Also two more rows were included representing accounting equations for total land clearing and the objective function such that per capita income and food consumption (from own farm) kept non-declining over time. The purpose of this provision is that per capita income should not fall below a certain minimum if the welfare level is to be sustained (or increased) over time. The accounting equation for total land clearing was incorporated such that the model computes value of cleared land in each period. After making the necessary adjustments, a detached coefficient matrix for Village II.LP model was drawn and is presented in Table 3.5.

The model was run using two alternatives. The first alternative represented an average farmer, i.e., a farmer with average land holding of 2.5 ha. The second alternative involved a smallholder farmer, i.e. a farmer with average land holding of 1.6 ha. The smallholder farmers constituted a proportion of 33% of the total households at Lukozi village. It was hypothesized that farmers with small land holdings have a motive for more land clearing and hence increased deforestation.

Model runs in the first alternative were conducted using three scenarios. These are summarized as follows:

<u>Scenario 1</u>: Assuming a population growth rate of 2.1% over a period of 35 years, while holding per capita cash income and food consumption from own farm non-declining.

<u>Scenario 2</u>: Population growth rate of 3% over a period of 35 years while holding per capita cash income and food consumption from farm non-declining.

<u>Scenario 3</u>: Population growth rate of 2.1% and an increase in per capita cash income of 2% p.a. over a period of 35 five years while holding per capita food consumption non-declining.

The term per capita income is used here to connote net cash income per capita to the household family obtained solely from agricultural activities. The baseline value used in scenarios 1 and 2, and allowed to increase by 2% p.a. in scenarios 3, was 603,607 TAS/yr based on the results of Village I.LP model. The value was chosen because the average income level for the village which was calculated on the basis of field data was assumed to be too low to represent the real or actual socio-economic situations in Lukozi village.

Model runs using the second alternative were conducted by making a number of assumptions and changes. It was assumed that the same farming technology is used by the smallholder as well as the average farmer. An average family size for the smallholder farmer was 6.5 persons/household compared to 7.5 persons/household for the average farmer. Thus the right-hand side (RHS) values were adjusted for family labour available in a given month, basic food requirements for the household and land area constraints. The monthly availability of family labour was calculated at 131 mandays. Subsistence requirements were calculated at 929, 234, 435 and 865 kg per household for maize, beans, potatoes and vegetables respectively. Land area was calculated to be 0.8 ha in each case, representing vegetable, long- and short-rain lands respectively for two seasons per year. Two scenarios were simulated in the model runs. These are summarized as follows:

<u>Scenario 1</u>: Population growth of 2.1% p.a. over a period of 35 years while keeping per capita cash income and food consumption from own farm non-declining.

<u>Scenario 2</u>: Population growth of 3% p.a. over a period of 35 years while keeping per capita cash income and food consumption from own farm non-declining.

The use of the same income level was based on the premise that people in the same village strive to maintain the same or uniform welfare standard.

...ities		Land clearing activities			Crop sales activities				SIGN	RHS
0	X11	X12	X13	X14	X15	X16	X17	X18		
.6	-1.1	0	0	0	40	60	40	22		MAXIMIZE
	0	75	75						<=	150
	0	0							<=	170
	0	0							<=	150
	0	75		75					<=	150
	0	0							<=	150
	0	0							<=	170
									<=	0
									<=	0
									<=	25
	-1	15000	15000	15000					<=	0
	1								<=	241170
					-1				>=	1072
						1			>=	270
							-1		>=	502
								-1	>=	993
		-1							<=	1.6
			-1						<=	1.7
				-1					<=	1.7
									>=	0
		1	1	1					>=	0
.6	-1.1	0	0	0	40	60	40	22	>=	0

Table 3.5 Detached coefficient matrix for Village11.LP

Row identity	Crop production activities								Purchase a…
	X1	X2	X3	X4	X5	X6	X7	X8	X9
Objective	0	0	0	0	0	0	0	0	-18.7
Labour (mandays):									
February	1	4	8	10	4	0	4	0	0
March	3	7	11	11	7	0	8	0	0
May	0	3	8	0	3	0	0	0	0
September	0	4	0	10	0	1	0	4	0
October	0	5	11	11	0	4	[illegible]	[illegible]	0
November	0	4	0	0	0	4	0	5	0
Fertilizer (kg):									
Phosphorous	23	0	30	30	0	0	23	0	-1
Nitrogen	42	0	0	160	0	0	42	0	0
Farmyard manure (t).	0	3	3	3	0	0	0	5	0
Work. capital (TAS):	10525	20330	20330	57150	27725	8000	10525	8000	0
W.capital limit(TAS)	0	0	0	0	0	0	0	0	17
Output allocation (kg).									
Maize	1040	0	0	0	1200	0	1040	0	
Beans	0	1200	0	0	540	600	0	600	
Potatoes	0	0	2000	0	0	0	0	0	
Vegetables	0	0	0	20000	0	0	0	0	
Land allocation (ha):									
Vegetable land				1					
Long-rain land	1	1	1		1		1		
Short-rain land	1	1	1			1		1	
Accounting equations.									
Total land area (ha)	1	1	1	1	1	1	1	1	
Total cleared land(ha)									
Net cash income (TAS)	0	0	0	0	0	0	0	0	-18.7

3.4.3 Stochastic analysis of farming systems using MOP approach

3.4.3.1 Procedure

Based on the theoretical background regarding multiobjective programming (MOP) presented in Chapter 2, a compromise programming (CP) model was developed and applied to analyze farming systems in Lukozi Village. The MOP problem consisted of two objectives: maximization of net cash income and risk minimization, i.e., MOTAD. The risk elements considered were those related to crop yield and market prices, i.e., gross returns. The use of net rather than gross returns would have presented a more appealing approach. However, in the absence of input costs for previous years it was deemed necessary to use gross returns, with the view that such a measure would adequately capture the main components of risk in the village. The underlying hypothesis is that, farmer farmers are risk averters. They aim not only at maximizing net cash income but also at keeping it stable or less fluctuating over time i.e. with as little risk as possible. A five year period was considered, that is, 1988 through 1992. This is the period for which the data could be obtained. It would have been desirable to consider more years (and hence more constraints) for capturing the gross revenue variability, but experience elsewhere has shown that a five-year period could represent reasonably well the variability in yields and product prices (Sankhayan and Øygard 1993). Further, a five-year period represents a short-run planning horizon over which farm overhead costs are assumed to be constant and thus the income distribution of a farm plan can be specified by the total gross margin distribution (Hazell 1971). The risk elements were measured as total absolute deviations (TAD).

The MOTAD approach (*op. cit.*) was used to compute the relevant technical coefficients as well as specifying the objective function decision variables. Yields were measured in terms of kg ha^{-1} in each of the five years considered. Yearly prices, measured as TAS kg^{-1}, were adjusted using consumer price indices as published in EIU (1992)

3.4.3.2 Estimation of total absolute deviations

The absolute deviations were estimated using crop yield and product prices. A detailed account of the calculations is presented in Appendices 3(a) and 3(b). However, a summary of the deviations used as coefficients in the CP model are summarized in Tables 3.6 and 3.7

Table 3.6 Deviations associated with crop yield and market prices for crops grown under monocropping farming system

Year	Deviations for each crop, TAS ha^{-1}			
	Maize	Beans	Potatoes	Vegetables
1992	+12338	+9411	+8960	+53800
1991	+ 2408	+2067	+3060	+ 9800
1990	- 3382	- 993	-1040	- 8900
1989	+ 1418	-3593	-3740	-19900
1988	-12782	-6953	-7240	-34800

representing monocropping and intercropping farming systems respectively.

Table 3.7 Deviations associated with crop yield and market prices for crops grown under intercropping farming system

Year	Deviations for each crop, TASha^{-1}	
	Maize	Beans
1992	+12802	+8597
1991	+3754	+1763
1990	-1586	-1027
1989	-5086	-3126
1988	-9884	-6207

3.4.3.3 Objective function

There were two objective functions in a MOP framework used in the CP model: maximization of net cash income and minimization of TAD, i.e. risk. The maximization of net cash income was defined using market prices as in models I and II. The risk minimization objective function was defined using the MOTAD approach. In mathematical terms the two objective functions can be presented as follows:

Objective I: Maximization of net cash income

Maximize $Z_1 = -18.7X_p - 39.6X_n - 1.1X_k + 48S_1 + 68S_2 + 40S_3 + 22S_4$ [3.24]

Objective II: Minimization of TAD

Minimize $Z_2 = D_1 + ... + D_{10}$ [3.25]

where variables in objective I remain as previously defined

D_1, D_2 = positive and negative deviations associated with cash income in year 1992

D_3, D_4 = positive and negative deviations associated with cash income in year 1991

D_5, D_6 = positive and negative deviations associated with cash income in year 1990

D_7, D_8 = positive and negative deviations associated with cash income in year 1989

D_9, D_{10} = positive and negative deviations associated with cash income in year 1988

3.4.3.4 Constraints of the CP model

The constraints in the CP model were the same as those in models I and II, plus five rows which were added to represent the individual yearly deviations for the period 1988-1992. The values shown in Tables 3.6 and 3.7 were used as technical coefficients.

3.4.3.5 Detached coefficient matrix for the CP model

Omitting the nonnegativity restrictions, the detached coefficient matrix representing the CP model is shown in Table 3.8. The CP model has a total of 32 activities and 27 constraints.

Table 3.8 Detached coefficient matrix for the Village.CP model

Row identity	Crop production activities				
	X1	X2	X3	X4	X5
Objective I	0	0	0	0	0
Objective II	0	0	0	0	0
Labour (mandays):					
February	4	4	8	10	4
March	8	5	11	11	7
May	0	5	6	3	5
September	0	4	8	10	6
October	0	5	11	11	0
November	0	4	6	3	0
Fertilizer (kg):					
Phosphorous	25	0	50	50	0
Nitrogen	42	0	0	168	0
Farmyard manure (t):	0	5	5	5	0
Working capital (TAS)	10525	23350	20550	57150	27725
W.capital limit(TAS):	0	0	0	0	0
Output allocation (kg):					
Maize	1840	0	0	0	1206
Beans	0	1206	0	0	548
Potatoes	0	0	2000	0	0
Vegetables	0	0	0	20000	0
Risk min (TAS):					
1992	12838	9411	8960	53800	12802
1991	2408	2067	3060	9800	3754
1990	-3882	-933	-1040	-8900	-1586
1989	1418	-3593	-3740	-19900	-5086
1988	-12782	-6953	-7240	-34800	-9884
Land allocation (ha):					
Vegetable land				1	
Long-rain land	1	1	1		1
Short-rain land	1	1	1		
Accounting equations:					
Total land area (ha)	1	1	1	1	1
Total cleared land(ha)					
Net cash income (TAS)	0	0	0	0	0

Note: Objective I. maximization of net cash income
Objective II: risk minimization (MOTAD)

ss revenues activites

X22	X23	X24	X25	X26	X27	X28	SIGN	RHS
0	0	0	0	0	0	0		MAXIMIZE
1	1	1	1	1	1	1		MINIMIZE
							<=	136
							<=	156
							<=	136
							<=	156
							<=	136
							<=	156
							<=	0
							<=	0
							<=	25
							<=	0
							<=	241173
							>=	1072
							>=	270
							>=	502
							>=	933
1							=	0
	-1	1					=	0
			-1	1			=	0
					-1	1	=	0
							=	0
							<=	1.6
							<=	3.7
							<=	3.7
							>=	0
0	0	0	0	0	0	0	>=	0
							>=	0

3.4.3.6 Compromise programming model experimentation and sensitivity analysis

The detached coefficient matrix (Table 3.8) was subjected to a CP algorithm developed by Harjinder Cheema and Prem L. Sankhayan at the Department of Mathematics and Statistics, Punjab Agricultural University, Ludhiana, India and described in Sankhayan, Prihar and Cheema (1988). The package was provided by Prem L. Sankhayan, a Senior Economist with the Centre for Sustainable Development, Agricultural University of Norway, Aas. The reliability of the model results were checked using LINDO algorithm. During the first run with LINDO, a single objective: maximization of net cash income was used whereas risk minimization (MOTAD) was formulated as a constraint or as an accounting equation. In the second run with LINDO, a single objective: risk minimization (MOTAD) was used whereas maximization of net cash income was formulated as a constraint (an accounting equation). Except for the decimal places, the results generated via the CP and LINDO algorithms were similar in every respect. Testing against LINDO was considered appropriate because, as a commercial optimization package, LINDO has been extensively tested (Schrage 1991). A series of sensitivity analyses were conducted using various subjective weights shown in Table 3.9.

Table 3.9 Subjective weights used in the sensitivity analysis with the CP algorithm

Scenario	Subjective weights	
	Maximization of net cash income (δ_1)	Risk minimization (MOTAD)(δ_2)
1[(1)]	1	1
2[(2)]	2	1
3	5	1
4	1	2
5	1	5

Note: [(1)] Scenario 1 represents a situation where equal weights are given to the two objectives. That is, $\delta_1 = \delta_2$ meaning that the two objectives are of equal importance to the farmer. It was a starting point for subsequent sensitivity or "what if" analyses.

[(2)] (a) Scenarios 2 and 3 depict a situation whereby the decision maker (farmer in this case) puts more weight on maximization of net cash income generated through agricultural activities.

(b) Scenarios 4 and 5 depict a situation whereby the decision maker (farmer) assigns greater weight to risk minimization.

3.5 Limitations of the study

This study is limited in terms of scope and detail due to time limitations. The time allocated for field work was six months only. This limited the possibility of conducting time series studies to elucidate the *actual* time allocated to various activities. Hence it was necessary to rely on farmers information. At the same time data collection was limited to one village only. Also it was not possible to make preliminary field data coding and analysis in order to determine the level of accuracy.

Some information depended on the farmers' capacity to recollect past events which may embody any element of error. The field work began during the harvesting period of the second season for 1991. Therefore the researcher was unable to follow the cropping pattern closely.

Although an effort was taken to indoctrinate the enumerators certain elements of subjective estimates and bias may not be ruled out completely. Therefore it is necessary to take into account these limitations when interpreting the results of this study. Finally the study results are based on certain main assumptions which are outlined in the respective sections in chapter 4. All the limitations of linear programming, such as, linearity, single outcome expectations, fully apply here.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Analysis of village survey data

The data coding and analysis was conducted in order to elucidate the adequacy, relevancy and pattern of the household data for subsequent analyses. The purpose of this section is to present the results from village surveys.

4.1.1 Description of the land uses in Lukozi Village

4.1.1.1 Agriculture

The inhabitants of Lukozi Village are peasants farmers or simply farmers. They depend mostly on agriculture for food and household cash income. The major factors of production are labour or time and land. Typically, there are two major growing seasons in Lukozi Village, and indeed for the rest of West Usambaras. The first season falls between February and May corresponding to long-rains (*masika*). February is a fairly dry month and is utilized by the peasants for land preparation. Crop sowing/planting takes place in March at the onset of long rains. The peak of the growing season is approximately 90-100 days. At the end of May the rainfall trails off while crops are maturing. Therefore, the labour is employed in farm activities for a successive period of about 80 days during the first growing season. The second growing season falls between October-December following short rains (*vuli*). During the second season only fast maturing crops such as beans are grown. The growing period is approximately 70 days. Labour employment is about 50-55 days.

The major crops grown in Lukozi Village are maize, beans, potatoes (both irish and sweet potatoes) and vegetables (including tomatoes, cabbages and spinach). The main potatoes grown are irish potatoes and major vegetables grown are the cabbages. Therefore in our analysis we shall refer to potatoes to mean irish potatoes and vegetables to mean cabbages.

4.1.1.2 Forestry

Lukozi Village is bordered by a forest corridor of about 380 ha which is part of Magamba Forest Project. The corridor is a mixture of conifers and natural forests. It is heavily encroached upon by the villagers in the form of expanding farm lands. There are no settlements in the forest corridor. The only excuse the villagers have is the absence of legal boundary. Traditionally the forest reserves are separated from the public or village land by a line plantation of *Eucalyptus spp*. Thus in areas where such boundary is marked by other means, villagers consider it as being lacking or invalid. It is not decided in this manner out of sheer ignorance, rather it is a strategy designed to gain portion of forest reserves without facing legal proceedings (Lubango 1992; pers. comm.).

The Magamba Forest Project Manager observed that it would be important to keep the corridor under complete or total forest cover in order to protect water streams and minimize soil erosion (Lubango 1992; pers. comm.). However, since the corridor is heavily encroached, it will be necessary to reafforest the area. The proposed species are *Grevilla robusta* and *Acacia mearnsii* (Back Wattle), which are considered to be "crop friendly".

Data available from an adjacent area to the village under Magamba Forest Project show management regimes for the tree species as summarized in Table 4.1.

Table 4.1 Extraction and management regimes for *Grevillea robusta* and *Acacia mearnsii.*

Tree species	1st Thinning		2nd Thinning		3rd Thinning		Final harvesting	
	Year	Volume m^3ha^{-1}	Year	Volume m^3ha^{-1}	Year	Volume m^3ha^{-1}	Year	Volume m^3ha^{-1}
G.robusta	10	50	14	90	18	130	25	355
A. mearnsii	4	60	6	90	-	-	10	150

Source: Magamba Forest Project Management Plan 1991-1996/97

Microsite effect is ignored due to the proximity of the two areas. The rotation age for *Grevillea robusta* is 25 years whereas that of *Acacia mearnsii* is 10 years. *Grevillea robusta* can produce timber, poles and fuelwood. *Acacia mearnsii* produces bark as the main product which is used to extract tannin and fuelwood as a by-product.

4.1.2 Land tenure and ownership

The pattern of land ownership and inheritance is characteristically patrilineal. Seldom does a Shambaa household be headed by a female. Most often a widower is inherited. This is a tradition widely held by the Shambaa tribe. The inherent deficiency in the Shambaa customary arrangement is that female children are not allowed to inherit land. The basic premise is that upon marriage, a female becomes a member of another family or clan. In case of unmarried or divorced females, they can use family land on a temporary land lease basis. Despite the disruption of the Shambaa cultural heritage or values especially during the colonial rule, todate the land inheritance and ownership is strictly observed.

There are three types of land ownership in Lukozi Village, private (individual), lease and village land. Sources of land include inheritance, purchase and village land. The land tenure and sources are presented in Table 4.2. On an average each household owns about 2.5 ha parcel of land.

It can be seen from Table 4.2 that the main form of land ownership is private (or individual) ownership which consists of 95% of the households interviewed and the main source to acquire land is through inheritance which accounts for 78% of the households interviewed.

Table 4.2 Ownership and source of land in Lukozi Village

Category	Percentage of respondents[1] (%)
Land ownership:	
Private ownership	95
Leased	1
Village land	4
Source of land:	
Inherited	78
Bought	15
Village land[2]	7

Source: Own field data

Note: [1]Percentage based on a detailed survey for 74 households
[2]Village land refers to the land which are used for community activities or allocated to the "landless".

4.1.3 Classification of land under agriculture by the Washambaa

The consumers of research results are many. But perhaps the most important *clientele*, from the practical point of view, are those people who constitute the "sample or research unit". In the regard it is envisaged that the immediate consumers of this research are the extension staff and the farmers of Lukozi Village. Furthermore the use of common terminolgy is considered to enhance not only clarity but also two-way communication. The retention of local names has been also practised by Mlambiti (1982) and Holden (1991) when studying peasant farming systems in Kilimanjaro Region and Northern Zambia respectively. Based on this background it was considered appropriate to outline the land as classified by the Washambaa people in Lukozi Village and indeed in the entire Lushoto District. The Washambaa people classify land under agriculture into four categories, "*kishumu*", "*shamba*", "*mghunda*" and "*kitivo*", which are described in sections 4.1.3.1, 4.1.3.2, 4.1.3.3 and 4.1.3.4.

4.1.3.1 Kishumu

"Kishumu" is a name given to the land which lies in the immediate environs of homesteads. Such land is often "manured" through dumping household wastes, chicken droppings and animal dung. The major use of "kishumu" is to establish "home gardens". Crops that are planted range from green vegetables to banana and fruit trees. In terms of land ownership, "kishumu" is a fixed household private property which under any circumstances shall not be sold.

4.1.3.2 Shamba

"Shamba" is considered to be the main farm for a farm household. On the shamba households grow both food and cash crops. Also some households establish "line" tree plantations or hedgerows and fruit trees. The type and extent of crop activities is dependent *inter alia* on the available land and amount of household family labour.

4.1.3.3 Mghunda

"Mghunda" is typically a "pure" banana plantation. Although the dominant crop is banana, often trees of *Albizzia spp.* and coffee are found interspaced. Traditionally, banana is grown as a famine "security" crop. Normally Shambaa people eat banana as a ripe fruit only. Tending of "mghunda" farms is treated as off-season activity. In fact until recently it was usual to find mghunda as "wild stands" of plants because they were never tended properly. However in the advent of climatic changes and scarcity of farmlands more attention is given to mghunda nowadays. In some cases banana plants are thinned to accomodate food crops such as maize, potatoes and beans. Also banana crop is sometimes sold as kind of "petty business" to supplement ordinary farm income.

4.1.3.4 Kitivo

"Kitivo" is a local name for valley floor or flood plains. The area in the immediate proximity to rivers and water streams. The main use of kitivo is to plant vegetables. Most often vegetables require consistent and adequate supply of water. Therefore the proximity to water sources facilitates irrigation regimes. Moreover in case of serious drought kitivo is used to plant maize.

Traditionally foor beds were used only as pastures for cattle. For instance in the early sixties (pers. exp.) there were virtually no farming activities in the floor beds. The probable reason was the frequence of flooding which rendered farming virtually impossible. At the time rainfall was both reliable and consistent. The general weather in most parts was overcast, misty and cool throughout the year. However the climate began to change drastically in the late sixties, more precisely in 1968 (pers. exp.) and early seventies. In fact there was severe drought in 1974. Although not specific to the West Usambaras the drought caused a change in the climatic situation such that it is believed (based on discussion with old folks) that the initial conditions were never restored.

Vegetable growing in the valley floors at commercial level began in 1970. Two factors gave rise to the impetus for extensive vegetable growing. First the inception of Lushoto Intergrated Rural Development Project (LIDEP) in 1970 with emphasis on vegetable planting as an "economic activity". A commercial nursery was established at Mabughai Village situated about 9 km north of Lushoto town. Later on a Vocational Training Unit was opened at the same locality. The objective was to meet the growing demand for vegetables in both Tanga Municipality and Dar es Salaam City. The second reason was the arrival of Japanese volunteers who introduced a new variety of cabbage simply (and even nowadays) referred to as "chinese cabbage" which was not only fast growing but also had high per hectare crop turnover. Moreover the introduction of chinese cabbage coincided with the arrival of Chinese technical team for the construction of the Tanzania Zambia Railway (TAZARA) also referred to as "*Reli ya Uhuru*" (a Swahili phrase for "Independence railway" because it was built after both Tanzania and Zambia became independent). The Chinese team provided a ready market for *chinese cabbage.*

Chinese cabbage is no longer grown in the West Usambaras and the Japanese volunteers have left long ago. However, the tempo of vegetable growing at commercial level that was initiated by the Japanese volunteers has been maintained or even increased in some areas such as Lukozi Village where it is considered to be a cash crop. Moreover young people find "self employment" in vegetable trading with the main market outlets like Tanga municipality and Dar es Salaam city.

4.1.4 Assessment of crop production patterns

4.1.4.1 Description of farming systems

4.1.4.1.1 Monocropping system

Under the monocropping system, pure stands of maize (*Zea mays*), beans (*Phaseolus vulgaris*), potatoes (*Solanum tuberosum*) and vegetables (the only vegetable considered in this case study is cabbage, (*Brassica oleracea*) are planted. In practise maize, beans and potatoes are planted on "highlands" which fall in areas with an average slope of more than 10%. Vegetables are commonly planted on valley floors with an average slope of less than 10%. The major advantage of growing vegetables on valley floors is to facilitate irrigation especially during drought or seasons with limited rainfall. Potatoes and maize may also be planted in valley floors particularly when there is severe drought, otherwise they are normally confined to the highlands.

Due to cold weather climate in the West Usambaras, maize takes fairly long time (up to 210 days or 7 months) to reach maturity stage depending on the variety and rainfall situation. "Katumani" variety takes shorter time to mature, about 90 days or 3 months. Maize is planted only during the long rains (*masika*) season which fall between March and June (both March and June are inclusive) each year. Timely planting of maize is very crucial. When planted at the onset of rain, maize outgrows weeds and minimizes the possibility of pest and disease attack. In the recent times, beginning in the 1980's, there has been some efforts to improve maize production, notably through the introduction of improved maize (*hybrid*) seeds and the use of fertilizers. The adoption of these new techniques was, however, slow mainly due to two reasons. First maize was considered less tasteful compared to the local maize varieties. Ostensibly improved maize seeds have high per hectare turnover. For instance yield level of improved maize seeds can be as high as 3367 kg ha^{-1} (Nkonya 1989) compared to 1340 kg ha^{-1} (field data) produced from local variety. Second fertilizers are considered fairly expensive relative to the economic level of the peasant farmers.

At present, however, there is a fair majority of farmers who use fertilizers prompted by a gradual decline in crop yield levels. Major fertilizers used are triple super phosphate (phosphorous, P) which is applied during planting and sulphate of ammonia (nitrogen, N) which is applied as top dressing. Also there is an increasing trend towards adopting improved maize varieties, *viz*, *hybrid* and *composite*. The *hybrid* seeds cannot be recycled. On the other hand, *composite* seeds may be recycled provided adequate care is taken to select good maize cobs soon after harvesting. Recycling is, nevertheless, limited to three years only of the original maize seeds. In general maize is classified as a heavy feeder crop demanding and using a substantial amount of nutrients during the growing cycle. Soil nutrient status may be maintained by applying adequate amounts of farm yard manure (FYM). Maize requires well drained deep loam, good aeration and high amount of organic matter (Scheinmann 1986).

Beans and potatoes are planted twice each year. Both are short-time growing crops, requiring 70-90 days to reach the level of maturity. They are planted during both the long-rains (*masika*) and the short-rains (*vuli*) seasons. Beans require moderate rainfall throughout the growing season and well drained soils with average fertility. Early planting is not as critical as is the case with maize. Potatoes grow well under cool moist conditions, but too much rainfall is apt to cause potato blight, a fungal disease. They require soils which are friable, well drained loam and rich in organic matter content. Best planting time is at the end of long rains (Scheinmann 1986).

Vegetables (cabbages) are also planted twice a year. Because of its importance as cash-income earning crop and the possibility of irrigation, vegetable planting may not follow, strictly, the seasonal pattern. An exception is made for the period between July and August, when vegetable cannot be planted due to the possibility of frost occurrence. In areas where irrigation is not possible, vegetables are planted at the onset of long or short rains. Vegetables require cool, moist climate or higher altitudes (about 1200 m above sea level), moderate rainfall throughout the growing period and sandy loam soil with adequate organic matter content. The duration of maturity depends on the variety. *Glory of ekhuizar* variety takes 90 days whereas *Prize drum head* variety takes about 120 days to reach maturity stage (Scheinmann 1986). These are the two varieties of cabbage planted in the West Usambara. The variety that is widely grown in the Lukozi village is the *Glory of ekhuizar*.

The sustainability of the monocropping system depends primarily on the type of existing land management practises. In this regard there are two aspects worth examining, soil erosion control measures and fertilization regime. The soil erosion control measures practised in the West Usambaras are planting of guatemala grass (*Tripsacum laxum*) and *Canna edulis* as contour plants, which is the widely applied measure, and the construction of macro-contour lines (mcl) introduced by SECAP (see Woytek *et al.* 1987). Preliminary results of an evaluative study by Shenkalwa (1989) indicated that the two measures reduced soil erosion considerably.

Second, sustainability of the monocropping system depends on fertilization regimes. The peasants in West Usambara, for instance of Lukozi Village, apply 25 kg ha^{-1} and 42 kg ha^{-1} of phosphorous (P) and nitrogen (N) fertilizers respectively (based on own field data). This rate of fertilizer application is below the recommended levels of 60 kg ha^{-1} and 80 kg ha^{-1} of phosphorus and nitrogen fertilizers respectively (Mnkeni 1992). On the understanding that these recommended rates are based on soil types and type of cropping system, there is reason to believe that the monocropping system will not be sustainable.

4.1.4.1.2 Intercropping maize/beans system

Under this system maize and beans are intercropped. During *masika* season peasants intercrop maize and beans and during the *vuli* season beans are planted as monoculture because they mature relatively fast. There are essentially two practical advantages of the maize/beans intercropping system. Beans are nitrogen fixing plants. Therefore, by intercropping beans and maize, the rate of applying fertilizers is reduced. Further, beans are cover crops and suppress the growth of certain types of weeds, thereby minimizing the arduous task of weeding. However, due to competition and spacing effects, the intercopping practise causes a decline in the per hectare turnover of both maize and beans. In fact an earlier study in Kilimanjaro region by Mlambiti (1982) showed a 10% decline in maize and bean yields when intercropped.

The recommended fertilizer application rates for the maize/beans intercropping system is 50 kg ha^{-1} and 20 kg ha^{-1} of nitrogen and phosphorous for maize and 30 kg ha^{-1} of phosphorous for beans (Mnkeni 1992). However farmers in West Usambara apply manure only in the maize/beans intercropping system. Consequently the yield level is 1,206 kg ha^{-1} and 543 kg ha^{-1} of maize and beans respectively (based on own field data) compared to yield levels of up to 3367 kg ha^{-1} of maize (Nkonya 1989). Bean yield level is, however, superior compared to 506 $kgha^{-1}$ reported by Nkonya (1989).

Soil erosion is a serious threat to the maize/beans intercropping system. Soil erosion results into a loss of soil fertility as top soil rich in nutrients and organic matter is eroded. For instance a removal of 2.5 cm of top soil could result into a yield loss of 40-50% (Lal 1979). In essence, therefore, the soil erosion processes are a significant threat to the sustainability of the maize/beans intercropping system.

4.1.4.1.3 Agroforestry system

Agroforestry may be looked upon as a type of land use system in which trees (or shrubs) are mixed together with farm crops, pastures or livestock, and in which there is ecological and economic linkage between the trees and the non-tree components of the system. Young (1989) defines agroforestry as "a collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) and/or livestock in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the trees and non-tree components of the system".

The origin of both indigenous agroforestry practises and research agroforestry techniques can be found in tropical Africa (Young 1989). There are several agroforestry systems in the region, many of which evolved from the adaptive strategies of local farmers to changing socio-economic conditions such as the multistorey tree gardens (O'kting'ati and Kessy 1991). Such systems include agrosilviculture where trees are mixed with farm crops, silvipastoral whereby trees are mixed with pastures and livestock, taungya where the wood component is dominant for multipurpose woodlots and reclamation of forestry leading to multiple use (Young 1989).

An agroforestry ecosystem is composed of both biotic and abiotic components. The main biotic components are trees and shrubs, crops, pastures and livestock. The abiotic components include environmental factors like climate, soils and land forms. The utility of agroforestry is ecological as well as socio-economic. The ecological functions of an agroforestry system include, conservation of soil, rehabilitation of degraded soils, amelioration of climatic conditions, preservation of water sources and protection of the general environment whereas the socio-economic aspects include production of timber, poles, fodder and fuelwood, medicinal products, fruits and ornamental trees (O'kting'ati 1984).

The adoption of an agroforestry system as an alternative to existing traditional farming systems is based on the belief that mixing in time and space of perennials (trees) and annuals (crops) is more profitable than growing them separately (Hoekstra 1985(b)). The term profitable here is used to imply that less resources are used to produce the required (existing) output or to produce more output using the existing resources. In economic terms the adoption of an agroforestry is based on essentially the premise of maximizing welfare.

Producers (in our case farmers) have a choice to grow the trees biologically separate from any other components (non-agroforestry land use system) or to grow them in a system in which they biologically interact with the other components (agroforestry land use system) (Hoekstra 1985(b)). For the purpose of our discussion and subsequent analyses the latter view will be applied. The working hypothesis is that the cost of production of the product mixture is lower compared to the alternative non-agroforestry land use system. Also the presence of perennials (trees) is considered to be an important component for maintaining sustainability of the system (Hoekstra 1985).

In Tanzania the main system of agroforestry practised is agrosylvicultural where trees are mixed with crops. Under this system there are three levels of classification as outlined by Young (1989). The first level classification is based on the components present; the tree component is dominant and practises involve spatial components. The second level is based on the spatial and temporal arrangement of components. Spatial practises are those in which it is primarily a combination in space while temporal arrangement means that the association between trees and crops takes place primarily over time. Spatial systems are divided into two categories, mixed and zoned. In mixed spatial practises, the trees and herbaceous plants are grown in intimate mixtures, with the trees distributed over more or less the entire land area. In zoned spatial practises, the trees are either planted in some systematic arrangement, such as rows, or are grown on some element in the farm, such as boundaries or soil conservation structures. In spatial-mixed systems, the tree-crop interface is distributed over all or much of the land management unit, whereas in spatial-zoned systems it occupies defined locations.

The main agrosylvicultural systems of relevance to Tanzania are *taungya* (rotational pattern); trees on cropland and multistorey tree gardens (spatial mixed); and boundary planting, hedgerow intercropping and trees on erosion-control structures (spatial zoned) (Young 1989; O'kting'ati and Kessy 1991).

The Shambaa tribe has a traditional system of mixing trees and farm crops, i.e., traditional agroforestry also called multi-storey agroforestry (Woytek *et al.* 1987). The system was disrupted by the introduction of monocropping farming systems by the "white settlers". The promotion of the agroforestry system is attributed to the noticeable erosion trends as well as the presence of SECAP. Moreover a widespread adoption is considered relevant because of relatively high economies of scale (Hoekstra 1985(b)).

The agroforestry systems that are relevant for application in the West Usambaras include *taungya* (mainly practised in black wattle - *Acacia mearnsii*, plantations), trees on croplands (in association with climber plants and for fuelwood), multistorey tree gardens (the traditional agroforestry practise especially in banana stands), boundary planting and the recently introduced technique by SECAP (Woytek *et al.* 1987) of planting trees on soil erosion-control structures especially the macro-contour lines (Shenkalwa 1989).

The agroforestry systems that are relevant to the study area, Lukozi Village are, trees on croplands and boundary planting. The boundary planting system is used to in limited extent only by the farmers. It is mainly used to demarcate boundaries between government controlled land, especially natural forest reserves, and the public or village land. Thus the agroforestry of significance importance to Lukozi area is the trees on croplands system. Under this system trees are spatially mixed with crops. There are essentially two "potential" farming systems that can be practised under the crop on land agroforestry system, that of mixing trees with maize and beans; and trees mixed with maize and potatoes. Maize crop is included in both cases because it is staple cereal for the people of Lukozi area. The tree considered for wide adoption in the agroforestry system is *Grevillea robusta* based on the peasant's preference (own field data).

4.1.4.2 Types of farm crops

The major crops that are grown in Lukozi Village are maize, beans, potatoes and vegetables. Vegetables are planted mainly in the valley floors, typical of lowlands with a slope of less than 10%. The main reason is that vegetables require irrigation regimes especially during the dry season. In the valley floors there are located more or less permanent water streams which make the irrigation task rather easy. Also valley floors are relatively fertile due to the deposition of silt material form uplands. The crop that is depended for income generation are the vegetables. On the highlands (land with slope > 10%) other crops are planted. These include maize, beans and potatoes. Minor crops grown are banana, sugar cane and sweet potatoes.

The farmers use mainly hand tools for cultivating and tending of crops. Other inputs used include improved seeds (hybrids), fertilizers, manure and pesticides (sometimes referred to as chemicals in this report). Because of low level of economic development the use of market inputs is lower than the recommended levels. The use of mechanized systems is limited by both physical and socio-economic factors. Lukozi village is located in an area with steep slopes, rolling hills and deep and narrow valley floors. The peasants are semi-literate with limited technical know-how and have limited cash income. Moreover the rather small household land holdings have low economies of scale hence fairly limited investments.

A summary of the amount, price and proportion of households growing the various crops is shown in Table 4.3. The production level of vegetables is amazingly high. This may be attributed to the relatively high management intensity afforded to vegetables to the extent that they are used as a cash crop. The fact that the inhabitants of Lukozi Village prefer vegetables, a seasonal (short term) crop, to coffee, a perennial (long term) crop does show that they are "averse" to risk in relation to both cash income (because they rely on farm crops for income) and crop production *per se* because perennial crops embody higher risk than seasonal crops especially due to variable weather.

Table 4.3 Output and prices of farm crops grown at Lukozi Village for 1991/92 season

Type of crop	% of households	Price (TAS kg^{-1})	Production (kg ha^{-1})
Maize	100	48	1340
Beans	99	68	603
Potatoes	99	40	1000
Vegetables	91	22	10000

Source: Own field data

4.1.4.3 Land management practises

The inhabitants of Lukozi Village use a number of practises to maintain soil conditions in terms of soil fertility and reduce soil erosion. These include terracing, planting of contour crops, such as, *Tripsacum laxum* and *Canna edulis* and application of manure and fertilizers. A summary of the land management practises is given in Table 4.4.

Table 4.4 Land management practises at Lukozi Village

Type of practise	% of households	
	Yes	No
Terracing	15	85
Guatemala and cana planting	90	10
Manuring	91	9
Mineral fertilizers	61	39

Source: Own field data

The majority of farmers plant planting guatemala grass (*Tripsacum laxum*) across the contour to reduce soil erosion. The amazing part is that since the early 1980s SECAP has been urging people to use terracing without significant effect. It is said that when the technique was introduced it was not preceded by extension education. Thus improper methods were used in the construction of terraces which removed top soil resulting in a serious drop in crop production (Woytek *et al.* 1987). Moreover construction of terraces involves an ardous task of removing earth, the very task that is highly resented by the local people (pers. obsev.).

4.1.5 Fuelwood survey

The purpose of the fuelwood survey was to estimate the fuelwood consumption, to determine the reliance of villagers on the natural forest reserves as a source of fuelwood and estimate the relative scarcity. Distance was used as a rough indicator of relative scarcity. It is argued that short distances ($\leq$ 5 km) indicates relatively favourable fuelwood supply whereas distances > 5 km indicate unfavourable fuelwood supply (O'kting'ati 1984). The results of the fuelwood survey are shown in Table 4.5.

Table 4.5 Fuelwood source and distance travelled by the inhabitants of Lukozi Village

Source/distance	% of sampled households
Source of fuelwood:	
Natural forest reserves	58
Forest plantation	74
Border (farm) plantations	68
Distance travelled:	
< 2 km	47
2-5 km	38
> 5 km	15

Source: Own field data

The results in Table 4.5 show that the inhabitants of Lukozi Village depend mainly on plantations as a source of fuelwood. About 81% of the households obtain fuelwood from within a distance of 5 km. Thus it can be observed that Lukozi Village faces low relative fuelwood scarcity. The average consumption is two loads (approximately 0.02 m^3) per household per week. Generally the people of Lushoto District do not face serious fuelwood shortage (based on own experience) as has been reported in other studies (see for instance O'kting'ati 1984).

4.1.6 Microeconomic assessment

4.1.6.1 Type of economic activities

The economic activities undertaken by the Lukozi Village are farming, petty business and livestock keeping. There were no households that admitted on pitsawing but field visits showed that some pitsawing was taking place in both natural forest reserves (illegal) and on forest plantation (allowed by the management of Magamba forest project). A summary of the economic activities along with the income obtained is shown in Table 4.6. The results show that the main source of income for the people of Lukozi Village is from farming which accounts for 91% of the total income generated per annum. The per capita income is estimated at TAS 14,000 per year. The average annual expenditure per household (mainly spent on school fees, taxes and development levy) is estimated at TAS 61,800 per year or TAS 8,240 per capita per year.

The income figures were obtained in two ways, from the recollection of farmers (i.e. asking them how much they earn per annum) and by derivative technique from crop sales in the open markets. The figures reported in Table 4.6 are averages. Both methods embody an element of error. The recollection technique relied on the ability of the farmers' memory which if fallible and of their interest to give true answers. The derivative technique embody error from a couple of sources. Crop prices are so seasonal that they may not reflect the true value of the crop when extrapolated to yearly estimates. Another error arises from biased

Table 4.6 Economic activities and average income per household
at Lukozi Village

Activity	Average income (TAS/yr)	Contribution (%)
Farming	97500	91
Petty business	6450	6
Livestock keeping	3470	3
Total	107420	100

Source: Own field data

estimates of the interviewers. However we decided that it was not possible to improve the accuracy of the estimates especially taking into account that most farmerss are either semi-literate or illiterate and actual tracking of price movement was not possible under the available time schedule.

On the expenditure side, it was evident that quite a substantial amount of money is spent on other family needs such as purchase of meat, clothes and housing. However the peasants were unable to quantify the cost of these needs. In fact those needs may demand a substantial proportion of the household cash income. Thus the expenditures mentioned here apply to money spent on items with fixed rates, school fees, development levy and taxes. Therefore, the estimated expenditure in this case study may be lower than the actual amount a household spends.

4.1.6.2 Labour analysis

4.1.6.2.1 Timing of operations and labour requirements

The major farming operations/activities considered in this analysis are land preparation (cultivation), planting, weeding, fertilizer and manure application, chemical spraying and harvesting. In Lukozi Village, and indeed in most parts of Lushoto District, farming activities constitute more or less a continuous process. Thus land preparation, unlike in the semi- arid and southern highlands, is an activity done mainly in the form of cultivation.

Timing of operations, among other things, depends on the size of the farm relative to the availability of family labour. Table 4.7 shows the timing and labour demand for major farming activities in Lukozi Village. Land preparation is normally carried out prior to the actual growing season. During masika season land preparation is carried out in February, whereas during *vuli* season land preparation is carried out in September. There is variation in the amount of labour required depending on the type of crop. For instance, whereas both maize and beans require four mandays per ha for land preparation, potatoes and vegetables requires eight and 10 mandays per ha respectively for the same activity. It may be pointed out that, although an average of eight hours per manday was used in labour calculations, personal experience has shown that certain families may spend as much as 10 hrs per manday on farming activities, especially during the peak season.

Table 4.8 summarizes labour requirements for each crop in terms of man days and man hours per hectare. It can be observed from table 4.8 that the highest labour demand is associated with planting vegetable crop which required a total labour input of 42 mandays per ha per season or 84 mandays per hectare per year. This is equivalent to 336 manhours ha during the season or 672 manhours per hectare per year. Notice that maize is grown only once during masika season whereas beans, potatoes and vegetables are planted in both *masika* and *vuli* season.

Table 4.7 Timing of operations by months and labour required for crops grown in Lukozi Village.

Operation	Types of crops and timing of operations							
	Maize [1]		Beans [2]		Potatoes [3]		Vegetables	
	Timing	Mandaysha^{-1}	Timing	Mandaysha^{-1}	Timing	Mandaysha^{-1}	Timing	Mandaysha^{-1}
Land preparation	Once in February	range 4 (3-5)*	Twice in February, September	8 (8-11)	Early May September	16 (14-18)	February September	20 (18-22)
Planting	Once in March	2 (2-3)	Twice in March-October	4 (3-6)	Twice in May, October	12 (10-12)	Twice in March, October	20 (18-22)
1st Weeding	Once in March	3 (2-4)	Twice in March, October	6 (4-8)	Twice in May, October	10 /8-12)	Twice in March, October	12 (10-14)
Fertilizer application	Twice in March, May [4]	3 (3-5)					Twice in March, November	10 (10-12)
Manure			Twice in February, September	4 (4-6)				
Chemical Spraying							Twice in April, November	8 (6-9)
2nd Weeding	Once in April	2 (1-3)					Twice in April, November	8 (6-9)
Harvesting	Once in June	3 (3-5)	Twice in May, December	10 (9-12)	Twice in June, December	12 (10-14)	Twice in May, December	6 (4-8)
Total		17		32		50		84

Source: Own sample survey (Field data)

Notes:

(1) Maize is grown/planted only once during the long rains season (*masika*) because it demands adequate moisture throughout its growth period which is relatively long compared to other crops.

(2) Beans, potatoes and vegetables are planted twice each year; once in each season.

(3) During *masika* season potatoes are grown close to the end of long rains, because during the heavy rains potatoes are prone to attack by diseases especially "potato blight" (a fungal disease)

(4) The second fertilization regime for maize is an "optional" activity to most households.

* Figures in brackets indicate a range representing minimum and maximum values respectively.

Table 4.8 Labour demand per activity on seasonal basis for crops in Lukozi Village [1]

Major activity	Labour requirements during "masika" season							
	Maize		Beans		Potatoes[3]		Vegetables	
	Mandays ha^{-1}	Man-hrs ha^{-1} [2]	Mandays ha^{-1}	Man-hrs ha^{-1}	Mandays ha^{-1}	Man-hrs ha^{-1}	Mandays ha^{-1}	Man-hrs ha^{-1}
Land preparation	4	32	4	32	8	64	10	80
Planting	2	16	2	16	6	48	10	80
1st Weeding	3	24	3	24	5	40	6	48
Fertilizer application	3	24	-	-	-	-	5	40
Manure application	-	-	2	16	-	-	-	-
Chemical spraying	-	-	-	-	-	-	4	32
2nd Weeding	2	16	-	-	-	-	4	32
Harvesting	3	24	5	40	6	48	3	24
Total	17	136	16	128	25	200	42	336

Source: Own field survey

Notes:
(1) These data and calculations are based on the "monoculture cropping system".
(2) Computations were based on an "average" working day of 8 hours long.
(3) For potato planting manure is applied during land preparation operations.

The results obtained in this study compare rather well with those found by Mlambiti (1982 and 1992), in the Pare District, Kilimanjaro Region and Ulanga District, Morogoro Region. It was earlier observed that activities conducted outside the indicated periods in Table 4.7 tend to have a "strong downward effect on the average yield under normal weather conditions" (Mlambiti 1982 and 1992). The impression here is that liming of farming activities is an important aspect in order to enhance yield output.

4.1.6.2.2 Monthly labour demand and availability

4.1.6.2.2.1 Labour availability and utilization

In traditional or peasant farming, labour is frequently a limiting resource, especially during peak periods (Collinson 1963; Mlambiti 1992). Therefore, measures of its availability and requirements are critical in planning farming activities. The availability of labour governs not only the size of farms for a particular area but also the scope of the improvements which can be introduced and successfully implemented (Mlambiti 1982 and 1992).

In order to ensure successful planning, labour availability must be estimated realistically, allowing for both other work the family may be committed to and for the willingness of the family to supply labour from the nominal labour force especially at the seasonal peaks.

Labour availability may be high on average but the actual supply for it may be limited due to other factors such as rain and social events. The social events that are likely to interfere with labour supply are weddings, festivals and funerals. Mlambiti (1992) observed that "some societies spend so much of their time on festivals that their agricultural production is adversely affected".

4.1.6.2.2.2 Calculations of mandays

The calculations of the effective mandays of labour on an average peasant household farm was based on the average adult equivalent farm labour available per family. A simplifying assumption used was that the average household size represents adult equivalent manpower per family less the proportion of children ≤ 15 yrs old. The total labour demand was computed on the basis of the data obtained during sample survey. The results of these calculations are shown in Table 4.9. Seasonal peaks occur in March and May during masika season and September, October and November during vuli season (see also Figure 4.1). In fact during the month of March and May, labour demand is higher than the supply for it. The monthly labour demand for each crop is shown in Table 4.10.

Table 4.9 Effective adult equivalent labour demand and availability per month for farm work

Month	Calculated labour demand			Estimated labour availability		
	No of days	Man-days per month	Man hours per month	No of days	Man-days per Month	Man-Hrs per month
January	0	0	0	24	163	1304
February	18	122	979	21	143	1144
March	31	211	1688	24	163	1304
April	12	82	656	23	156	1298
May	30	204	1632	24	163	1304
June	11	75	600	23	156	1248
July	0	0	0	24	163	1304
August	0	0	0	24	163	1304
September	22	150	1200	23	156	1248
October	18	122	976	24	163	1304
November	19	129	1032	23	156	1248
December	14	95	646	24	163	1304

<u>Source:</u> Own sample survey (field data)

Table 4.10 Monthly labour demand for each crop planted by peasant farmers in Lukozi Village

Month	Labour demand, mandays ha^{-1}			
	Maize	Beans	Potatoes	Vegetables
January	-	-	-	-
February	4	6	-	10
March	8	5	-	21
April	2	-	-	8
May	-	5	19	3
June	3	-	6	-
July	-	-	-	-
August	-	-	-	-
September	-	6	8	10
October	-	5	11	16
November	-	-	-	13
December	-	5	6	3

Source: Table 4.7

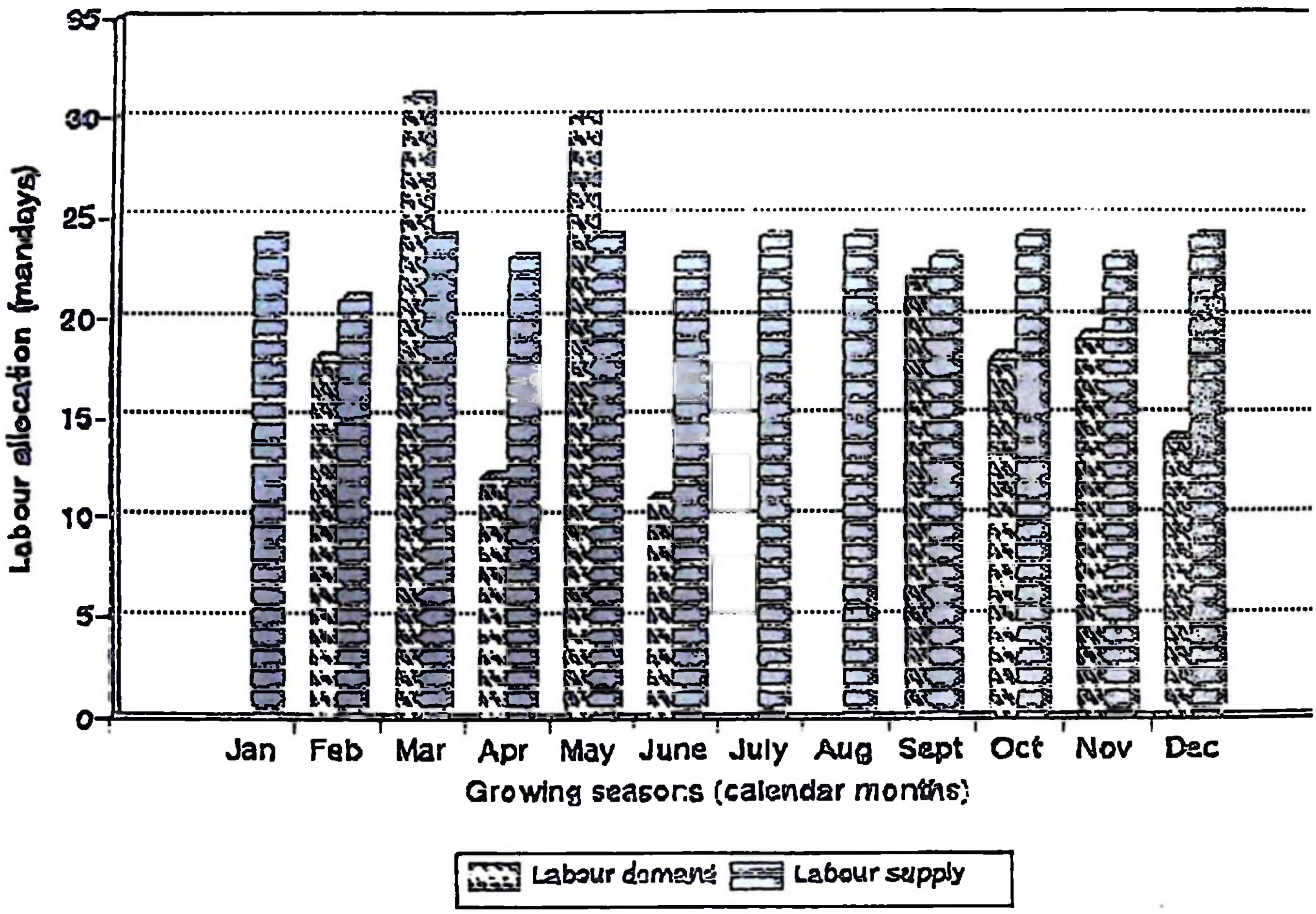


Figure 4.1 Annual distribution of household labour

4.1.6.2.2.3 Yield levels from household farm

The average yield levels for the major crops grown by the peasants at Lukozi Village are shown in Table 4.11. The contents of the table include also the farm-gate price for various crops. It can be seen from the table that vegetables have the highest production turnover of 10,000 kg (10 t) ha^{-1} (wet weight). Maize and potatoes gave a turnover of 1,340 and 1,000 kg ha^{-1} respectively whereas beans yield 603 kg ha^{-1}. There is a slight decrease in maize and beans when intercropped.

The official (government) estimates of production levels are shown in Table 4.12. There are some variations between actual (based on own field surveys) and official production levels. Perhaps one reason is that official figures are mere estimates. It is seldom that a thorough field survey is conducted prior to releasing the official figures. The same trend is observed between actual (based on field survey) and official (government controlled) prices. For the purpose of this analysis, actual yield and price data are used which are considered to reflect more realistically the situation faced by the peasant farmers.

Table 4.11 Average crop yield and farm-gate prices for major crops by peasant farmers in Lukozi Village

Crops	Crop yields, kg ha^{-1}		Farm-gate prices, TAS kg^{-1}
	Monoculture	Intercropping	
Maize	1,340	1206	48
Beans	603	543	68
Potatoes	1,000	-	40
Vegetables	10,000	-	22

Source: Own field survey

Table 4.12 Official estimates of crop yield and prices for crops grown in Lushoto District

Crops	Crop yields, kg ha^{-1}	Crop prices TAS kg^{-1}
Maize	1,200	16
Beans	1,000	40
Potatoes	1,500	40
Vegetables	10,000	22

Source: District Agriculture Development Office, Lushoto (1991/92).

4.1.6.2.2.4 Gross returns and margins for peasant farms

The gross returns and margins were calculated in order to determine the relative profitability of the major crops grown by peasant farmers in Lukozi Village. The main premise is that land is a limiting factor of production. Moreover in the face of high population density and growth rate, land is scarce relative to the demand for it. In economic terms, then the opportunity cost of land rises with increased population. The index of such an increase can be measured when trend data are available. Most often however data is lacking in peasantry farming systems or peasant societies. A proxy is then computed in terms of the relative variation in the gross margins generated by putting a given parcel of land under a particular crop. (See Collinson

1963, Mlambiti 1982 and 1992). This approach is used in this study to calculate the gross margin generated by maize, beans, potatoes and vegetable crops. Gross margin is considered to measure the relative profitability of crops.

The procedure used to compute gross returns and finally gross margin is summarized in Table 4.13. A summary of the results is given in Tables 4.14 and 4.15.

4.1.6.2.2.5 Labour returns

The relative returns to labour were computed to determine the relative profitability of the major crops grown by peasant farmers in Lukozi. The underlying assumption is that labour is a limiting factor especially during peaks of the growing season. The procedure for calculating relative returns to labour is summarized in Table 4.13 whereas a summary of the results is shown in Tables 4.14 and 4.15 for monoculture and intercropping systems respectively.

Table 4.13 Calculations of gross margins and returns to labour for major crops grown by peasant farmers at Lukozi Village[1]

Item	Monoculture cropping system				Intercropping systems			
					Intercropping system I		Intercropping system II	
	Maize	Beans	Potatoes	Vegetables	Maize/Beans	Beans	Maize	Beans
Revenues:								
Yield [1] (kg ha^{-1})	1340	1206	2000	20000	1206 543	603	1340	603
Price (TAS kg^{-1})	48	68	40	22	48 68	68	48	68
Total reveres (TAS ha^{-1})	64320	82008	80000	440000	94812	41004	64320	41004
Costs:								
1. Seeds (kg ha^{-1})	25	80	72	-	25 80	40	25	40
Unit cost (TAS kg^{-1})	175	215	200	-	175 215	215	175	215
Total cost (TAS ha^{-1})	4375	17200	14400	11000	21575	8600	4375	8600
2. Fertilizer:								
2.1 TSP (kg ha^{-1})	124	-	248	248	-	-	124	-
Unit cost (TAS kg^{-1})	17	-	17	17	-	-	17	-
Total cost (TAS ha^{-1})	2108	-	4216	4216	-	-	2108	-
2.2 SA (kg ha^{-1})	400	-	-	800	-	-	400	-
Unit cost (TAS kg^{-1})	36	-	-	36	-	-	36	-
Total cost (TAS ha^{-1})	14400	-	-	28800	-	-	14400	-
3. Manure (kg ha^{-1})	-	5000	5000	5000	5000	-	-	5000
Unit cost (TAS kg^{-1})	-	0.50	0.50	0.50	0.50	-	-	0.50
Total cost (TAS ha^{-1})	-	2500	2500	2500	2500	-	-	2500
4. Hand tools (TAS)	6150	6150	6150	37150	6150	-	6150	-
5. Chemicals (TAS)	-	-	-	9000	-	-	-	-
Total cost (1+...+5)	27033	25850	27266	92666	30225	8600	27033	11100
Gross margin (TAS ha^{-1})	37287	56150	52734	347334	64587	32404	37287	29904
Labour inout (mandays ha^{-1} p.a.)	17	32	50	84	32	16	17	16
Returns to labour (TASMand^{-1})	2193	1755	1055	4135	2018	2025	2193	1869

Source: Field data [1]Based on sample survey of 74 households SA = Sulphate of ammonia TSP = Triple super phosphate

Table 4.14 Summary of gross margins and returns in labour for crop grown under monoculture

Type of crop	Gross margins(1) (TAS ha^{-1})	Labour input(2) (Mand ha^{-1})	Labour returns(3) (TAS $Mand^{-1}$)
Maize	37287	17	2193
Beans	56150	32	1755
Potatoes	52734	50	1055
Vegetables	347334	84	4135

Notes: (1) Gross margin = Gross returns - Total input costs
(2) Labour input = Total number of man-days per hectare per year
(3) Labour returns = $\frac{\text{Gross margin}}{\text{Labour input}}$

Table 4.15 Summary of gross margins and returns to labour for crops planted under intercropping system.

	Intercropping system I			Intercropping system II		
	Gross margins(1)	Labour input(2)	Labour returns(3)	Gross margins(4)	Labour input(5)	Labour returns(6)
Maize/Beans	64587	32	2018	-	-	-
Beans	32404	16	2025	-	-	-
Maize	-	-	-	37287	17	2193
Beans	-	-	-	29904	16	1869
Total	96991	48	4043	67191	33	4062

Note: (1), (2), (3) and (4), (5), (6) were computed as in Table 4.13

4.1.6.2.3 Discussion of the results

4.1.6.2.3.1 Monoculture farming system

The gross margin analysis was carried on the premise that land is a limiting factor of production to the extent that it is scarce relative to the demand for it. The results (Table 4.14) showed that vegetable crop had the highest gross margin of 34,7344 TAS ha^{-1} followed by bean, potato and maize crops with gross margins of 56,150 TAS ha^{-1}, 52,734 TAS ha^{-1} and 37,287 TAS ha^{-1} respectively. The high gross margin generated by the vegetable crop may be attributed to the relatively high output turnover of 10,000 kg ha^{-1} (10 t ha^{-1}). However, such a turnover is not without cost. In fact the peasant farmers use more time and effort, in addition to market inputs on vegetable growing than other crops. For instance a total of 84 mandays are needed to raise vegetables compared to 50 and 32 mandays needed to raise potato and beans respectively (although both are raised in two seasons). Maize has the lowest gross margin basically due to low per hectare yields coupled with moderately low product price and expensive inputs like fertilizer. Based on the micro-level analysis, particularly when land is scarce, it is economical to maximize the growth of vegetable crop by raising the other crops just at the subsistence level. Most likely that is why the people of Lukozi village have chosen vegetable growing for cash income generation.

Analysis of returns to labour was carried on the premise that "labour is a limiting factor of production in most peasant farmer households" (Mlambiti 1982 and 1992). The results (Table 4.14) showed that vegetable crop generates the highest returns to labour of 4,135 TAS per manday. It is followed by maize with a return to labour of 2,193 TAS per manday. Beans and potatoes have 1,755 and 1,055 TAS per manday respectively as returns to labour. Despite having a higher labour input of 84 mandays per year (two seasons) vegetables generate higher returns to labour. Maize also has higher returns to labour compared to beans and potatoes. One reason is that maize required lower labour input of 17 mandays per annum (one season) compared to 32 and 50 mandays p.a. for beans and potatoes respectively.

If labour is limiting one would advise the farmer to plant vegetables as a commercial crop, maize as a staple cereal (which is the case at present) and plant beans and potatoes at the subsistence level. Such a proposal is likely to compromise the interests of the farmers because while they treat vegetable as a commercial crop and maize as a staple cereal, they have varied interests when it comes to beans and potatoes.

4.1.6.2.3.2 Intercropping systems

In this case two intercropping patterns were considered. The first one is called "maize/beans and beans". That is on the same hectare of land maize and beans are interplanted during the *masika* season followed by monoculture beans during *vuli* season. The practical advantage of such a system is two-fold. Beans are nitrogen fixing plants, thus when intercropped with maize (a nitrogen demander) is likely to benefit the latter. The shading effect of maize on beans is considered minimal. Also beans are cover plants which they suppress weed growth thereby minimizing the arduous task of weeding. Finally the system minimizes costs of other inputs such as fertilizers and handtools. When interplanted maize does not require the application of nitrogen fertilizer. On the other hand it has been shown by studies elsewhere (for instance Mlambiti 1982 and 1992) that intercropping reduces the per hectare production of individual crops. The second system may not be classified as being intercropping *per se*. In this system, maize is grown as monoculture during *masika* season and beans is planted as monoculture during *vuli* season on the same hectare of land. The only advantage here is that the land is not left unutilized in any of the two seasons and that investments made on handtools during the first season are used in the second season as well.

When interplanted maize and bean mixture produces a total gross margin of 96,991 TAS ha^{-1} where in the alternate monoculture cropping two crops produce a total gross margin of 67,191 TAS ha^{-1} (Table 4.15). Based on these results peasant farmers are better off if they interplant maize and beans than if they grow the two crops as alternate monoculture cropping especially when land is scarce. Personal experience has shown that the peasant farmers practise the maize/bean intercropping system rather than the alternate monoculture cropping. Household families have high dependance on beans as a source of protein. Therefore it would seem an unwise to advice the farmers that during the *masika* season, beans should not be grown until the *vuli* season which comes at the end of the year. Also the maize/bean mixture is beneficial to the soil to the extent that bean is a nitrogen fixing crop.

The results presented in Table 4.15 shows that intercropping beans and maize generates a total return to labour of 4,043 TAS per manday compared to a alternate monoculture cropping which produces 4,062 TAS per manday. The absolute difference in returns to labour is not substantial high due to the high labour input of 48 mandays p.a. for interplanting beans and maize compared to 33 mandays demanded in the alternate monoculture cropping (Table 8.9). Therefore, by way of advice, a peasant farmer may adopt intercropping beans and maize rather than planting alternating monoculture.

4.1.6.3 Concluding remarks

The overall micro-level analysis of the peasant farming system has shown that vegetable crop is profitable. It has both high gross margin as well as return to labour. A peasant farmer may, thus, be advised to optimize the production of vegetables in order to maximize both gross margins and return to labour. In the case of subsistence crop, the analysis has shown that intercropping system, especially that between maize and beans is more beneficial compared to pure and alternating intercropping. Therefore, it will be more economical and practical to adopt the maize/beans and beans intercropping system and plant potatoes as a monoculture crop.

These pieces of advice may elicit disagreements not only with the farmers but also with economists because the analysis has not indicated the optimal product mixture neither has it said anything about the sustainability of the system. These issues are so important that they merit further exploration. Hence the analysis is extended to include mathematical programming formulations with the objective of analyzing the existing farming systems, agriculture/forestry relations and risk associated with yields and prices.

4.1.7 Measurable land parameters

4.1.7.1 Physical characteristics of land

The land slope of the Lukozi Village was measured using clinometer and was found to average 10-15%. However a questionnaire was also include to determine the proportion of farms falling on each slope category. The question was rather difficult (based on pilot survey), but due to the presence of SECAP personnel it was possible to get some responses albeit in relative terms (Table 4.16)

Table 4.16 Terrain situation for various farm areas in Lukozi village

Slope (%)	Classification[1]
0-10	gentle slope
10-15	moderately steep
15-30	steep
> 30	very steep

Source: Own field data Note:[1] This is a "relative" classification based on local conditions.

Over 80% of the households with farms falling in the slope class > 30% do not practise tree planting. This means soil erosion from such farms is relatively high. It was not surprising, therefore, that over 81% of the households interviewed pointed to an observed declining trend in productivity.

4.1.7.2 Soil assessment

Soil samples were collected from Lukozi village as well as adjacent village for analysis by the Department of Soil Science, SUA, Morogoro . Soil nutrients were classified into two broad classes, macronutrients and micronutrients. The macronutrients were further subdivided into primary and secondary macronutrients. Primary macronutrients consisted of nitrogen (N), phosphorous (P) and potassium (K). Secondary macronutrients comprised of calcium (Ca), magnesium (Mg), sodium (Na), sulphur (S) and iron (Fe). The micronutrients consists of zinc (Zn), copper (Cu), Boron (B), manganese (Mn) and molybdenum (Mo). The basis for such a classification is the relative importance of a nutrient element to crop growth. Finally a textural class of sand-clay-loam (SCL) was given for the soil samples from Lukozi Village. The soil analysis data are presented in Tables 4.17, 4.18 and 4.19.

Table 4.17 Macronutrients status for the soil samples from Lukozi Village

Nutrient element	Exchangeable cation, me/100g	Available (ppm)	Critical me/100g
Nitrogen (%)	-	0.3	-
Potassium (K^+)	0.5	-	0.2
Phosphorous,Bray(ppm)	-	4.2	15.0
Calcium (Ca^{2+})	15.6	-	4.5
Magnesium (Mg^{3+})	2.7	-	2.0
Sodium (Na^+)	0.3	-	-
Iron (Fe^{2+}), ppm	-	24.0	-
Hydrogen (H^+)	0.2	-	-

Source: Own field data

Notes:

m.e. = milligramme-equivalent

c.e.c = cation exchange capacity

ppm = parts per million

Bray = standard procedure for analysing phosphorous content in a given soil sample

The average pH_w (pH of soil in water suspension) level of the soil in Lukozi Village is 7.1, close to alkaline condition, which makes the application of fertilizer, especially sulphate of ammonia, appropriate.

Table 4.18 Micronutrient status of soil samples from Lukozi Village

Nutrient element	Available (ppm)
Manganese (Mn^{2+})	33.0
Copper (Cu^{2+})	1.2
Zinc (Zn^{2+})	5.8

Source: Own field data

It can be inferred from Tables 4.17 and 4.18 that although the soil from Lukozi Village contains most nutrients above the "critical levels", it has deficience in phosphorous (P) element. The available phosphorous was 4.20 ppm whereas the critical level is 15.0 ppm. A critical level may be looked upon as a kind of minimum amount a nutrient element is needed to support crop growth (Mnkeni 1992, pers. comm.).

Other soil properties are summarized in Table 4.19. These included organic carbon (OC), cation exchange capacity (c.e.c), soil particle size and textural class. Organic carbon content is a *proxy* for organic matter content of the soil. Organic matter content influences to a great extent the physical properties of the soil, it provides the cation exchange sites and determines the availability of other nutrients especially phosphorous (P), sulphur (S), magnesium (Mg) and calcium (Ca). Organic matter (OM) is computed as (based on Mnkeni 1987);

$$OM = OC \times 2.72 \qquad [4.1]$$

where

OM = organic matter content
OC = organic carbon content

The cation exchange capacity (c.e.c) is a measure of the extent of negative charges or cation exchange sites available in a given soil. The main function of the cation exchange sites is to "attract" the positively charged cation nutrient elements. This follows the law of physics which states that "like poles repel, whereas unlike poles attract". The main utility of the cation exchange sites is to keep nutrient elements bound to the soil. Therefore, the higher the cation exchange capacity, the more is the ability of the soil to bind nutrient elements, which probably means high fertility (not necessarily so). The soil particle size determines the porosity of the soil of a given site. Also they influence the structure of the soil, i.e., whether it is coarse (which means big particle size) or smooth (which means small size). The textural class of the soil from Lukozi Village is sand-clay-loam (scl).

This classification falls closely into the one given by the peasants during field surveys when they described the soil as being "*tifutifu*" and "*kichanga*", which literally implies a soil with high content of loam/silt/humus (*tifutifu*) and sand content (*kichanga*).

Table 4.19 Other properties of soil samples from Lukozi Village

Properties	Value
Cation exchange capacity	19.30
Organic carbon (%)	6.28
Particle sizes (%)	
sand	65.20
silt	13.20
clay	21.60
Texural class	SCL[1]

Source: Own field data
Note: [1]SCL = sand-clay-loam

4.1.7.3 Tree planting effort

The inhabitants of Lukozi Village also engage themselves in tree planting activities. The proportion of households and amount of trees planted per household over a period of four years are shown in Table 4.20. It can be seen from the table that the preferred tree type is *Grevillea*.

Table 4.20 Tree planting effort at Lukozi Village

Tree type	% of household planting trees	Average number of trees planted/year[1]
Albizzia	8	18
Grevillea	86	174
Eucalypt	11	5
Wattle	20	136
Fruits	5	48

Source: Own field data
Note: [1] Figures rounded up to the nearest figure (an optimistic view).

4.2 Analysis of existing farming systems from Village I.LP model solutions

4.2.1 Comparative analysis of model solutions

One main objective of generating basic solutions was to compare the optimum farm plans obtained by the two alternately formulated linear programming models, Models I and II. The results generated by the models are summarized in Table 4.21. It can be inferred from the results that the optimum farm plans generated by the models were virtually alike. The values of the objective function representing total net income produced by models I and II were 744,346 and 632,494 TAS yr^{-1}. The difference between the value of the objective functions of models I and II is ascribed to the fact that model II penalizes the household consumption at market prices. Notice here that model I presupposes that all farm output produced by a peasant household is sold at market prices. Such presupposition deviates from household economic theory (Low 1986; Holden 1991), that a peasant farmer normally produces to meet at least household subsistence requirements, before selling the surplus to earn cash income. Model II on the other hand penalizes output consumed by the household directly. Although penalizing consumption represents a real market situation facing the peasant farmer, it is seldom that the farmer costs out such allocation. In fact the part of output consumed by the household family is likely to have higher social value compared to that part which is sold at market prices (Low 1986). But on the margin they should be equal, i.e., the last kg consumed and the first kg sold should give the same contribution to the farmer's welfare.

Land allocation was 0.25 and 1.60 ha for potatoes and vegetables respectively planted under monocropping system; and 1.45 ha each for maize and beans respectively planted under maize/beans intercropping system (Table 4.21). There was no land allocation for maize alternately planted with beans (intercropping system II). This is logical, at least, intuitively because people depend largely on beans as a source of protein, thus omitting its planting during the long rain season may not be acceptable to the farmers.

Fertilizer used amounted tos 93 and 269 kg for phosphorous and nitrogen nutrients respectively, whereas the amount of working capital used was TAS 149,233 (Table 4.21). The crops sold amounted to 675, 1,390 and 31,002 kg of maize, beans and vegetables respectively (Table 4.21). There was no sale allocation for potatoes. The land area allocated, allowed the production of potato at the subsistence level only. Large amount of sale allocated for vegetables is of practical advantage to the farmers for essentially two reasons. First it satisfies their choice/preference of vegetables as a cash crop. Second, the relatively low farm-gate price, i.e., 22 TAS kg^{-1}, implies that large volume of vegetable crop must be sold in order to obtain substantial cash income for the peasant farmer.

Table 4.21 Numerical solutions generated by the LP model

		Model I	Model II
Net/Cash income (TASy^{-1}):		744,346	632494
Land allocation (ha):[1]			
Moncropping -	Maize	0.00	0.00
	Beans	0.00	0.00
	Potatoes	0.25	0.25
	Vegetables	1.60	1.60
Intercropping -	Maize	1.45	1.45
	Beans	1.45	1.45
Total cultivated land		4.75	4.75
Fertilizer nutrients used (kg):			
	Phosphorous	93	93
	Nitrogen	269	269
Working capital used (TAS):		149233	149233
Sales activities (kg):			
	Maize	-[2]	675
	Beans	-	1390
	Potatoes	-	0.0
	Vegetables	-	31002
Consumption allocation (kg):			
	Maize	1072	1072
	Beans	270	270
	Potatoes	502	502
	Vegetables	998	998

Note: [1]Land allocation values are given in two decimal points. The object is not to claim precision but because truncating the solution may give "exagerated" value.
[2] All farm produce is assumed sold at the prevailing market prices

Another set of results obtained in the optimal solution was that of dual (shadow) prices (Table 4.22). The dual prices produced by the two models are identical. This is considered logical, from economic point of view, to the extent that they related to virtually identical optimum farm plans. Perhaps of particular interest to a land use planner (and economist) is the shadow price of land. The shadow prices of land worked at 369,547, 64,314 and 31,544 TAS ha^{-1} yr^{-1} for vegetable, long- and short-rain lands respectively. Notice the relatively high shadow price of vegetable land. In economic terms the high shadow price implies high marginal value. That means expansion of vegetable land by one hecttare will produce an increase of TAS 369,547 in the value of the objective function (net cash income). The same logic can be followed in intepreting the shadow prices of long- and short-rain lands respectively. The substantially high marginal value of vegetable land implies that the expansion of vegetable area is likely to produce high economic returns to a farmer *ceteris paribus*.

Table 4.22 Dual or shadow prices generated by the LP models for various resources

Row/Resource	Shadow price	
	Model I	Model II
Phosphorous fertilizer (TAS kg^{-1})	18.70	18.70
Nitrogen fertilizer (TAS kg^{-1})	39.60	39.60
Total capital (TAS)	1.10	1.10
Vegetable land (TAS ha^{-1})	369547.19	369547.19
Long-rain land (TAS ha^{-1})	64314.50	64314.50
Short-rain land (TAS ha^{-1})	31544.00	31544.00

It can be observed from Table 4.21 that the contribution of potato crop to cash income is zero because the land allocated to potato allowed the production of potato for household consumption only. It might be more economical to allocate potato resource to vegetable production and use the extra cash obtained to purchase that amount of potato needed for family consumption. Such an arrangement may also be a saving in terms of utilizing family labour.

Based on the basic results (Table 4.21), the two models produced virtually identical farm plans. Comparable results using the same paradigm was reported by Sankhayan and Cheema (1991). Despite the similarity of results, model I suffers from one serious deficiency, that is, it presupposes that all farm produce is sold, which in essence deviates from the real situation facing a Tanzanian farmer. On the other hand the matrix of model II includes production activities, input purchase activities, sale activities and consumption activities, which are representative of a household farming system. In addition the inclusion of farm-gate and market prices of crops and fertilizer respectively was important for analyzing the effect of price changes which can influence farm production. Therefore model II was selected for subsequent analyses under the name Village I.LP model.

4.2.2 Sensitivity analysis using Village I.LP model

4.2.2.1 Range value analysis

The range value analysis (Table 4.23) is a part of an optimum solution generated by LP models running on LINDO. Some useful information can be gleaned from the results. The range analysis gives two columns, allowable increase and allowable decrease. The values under allowable increase, represent the level at which the coefficients of the respective variables (activities) can be increased without changing the optimum mix of activities. Conversely, the values under allowable decrease implies that the coefficients of the variables may be decreased by the magnitude indicated without changing the optimum activity mix. With respect to decision making process, the range values give a farmer, or any other decision maker, the region within which to vary the real activities without affecting optimum activity mix. The term "INFINITY" on the range analysis results (Table 4.23) indicates that increasing an activity by any positive amount (or conversely decreasing an activity by any negative amount) does not affect the optimum activity mix (Schrage 1991).

Table 4.23 Range analysis report generated by the LP model

Variable[1]	Ranges of objective function coefficients		
	Current coefficient	Allowable increase	Allowable decrease
X_p	-18.70	18.70	7390.94
X_n	-39.60	39.60	2199.68
X_k	-1.10	1.10	0.79
S_1	48.00	102.25	32.66
S_2	68.00	658.92	25.23
S_3	40.00	19.69	infinity
S_4	22.00	infinity	18.47
X_1	0.00	45246.69	infinity
X_2	0.00	39535.50	infinity
X_3	0.00	39398.49	infinity
X_4	0.00	infinity	369547.18
X_5	0.00	infinity	13702.69
X_7	0.00	13702.69	infinity
X_8	0.00	0.00	infinity
X_6	0.00	infinity	0.00
Resource	**Right hand side ranges**		
	Current RHS	Allowably increase	Allowable decrease
Labour Feb.	156.00	infinity	132.19
March	156.00	infinity	125.49
May	156.00	infinity	142.44
September	156.00	infinity	132.19
October	156.00	infinity	128.39
December	156.00	infinity	142.44
Phosphorous	0.00	92.55	4746.13
Nitrogen	0.00	268.80	2241.38
Manure	25.00	infinity	8.50
W.capital	0.00	149232.98	80689.87
Cap. limit	241173.00	infinity	80689.87
Maize	1072.00	675.49	infinity
Beans	270.00	1390.55	infinity
Potato	502.00	1120.22	501.99
Vegetable	998.00	31002.00	infinity
Veg. land	1.60	1.25	1.55
Longrain land	1.70	1.70	0.56
Shortrain land	1.70	9.38	1.44

Note: [1] Variable names remain as previously defined (Chapter 3)

In the objective coefficient ranges, the coefficients for production activities of maize, beans and potatoes can be increased by a margin of 45,246, 39,535 and 39,398 TAS ha^{-1} respectively with infinite decrease levels, and vegetable has an increase and decrease levels of ∞ and 36,9547 TAS ha^{-1} respectively without changing the optimum activity mix (Table 4.23). These gross values are controlled by price levels. Thus it is considered more appropriate to make practical implication of range analysis from the price levels. The allowable increases in price were 102.26, 658.92, 19.70 and ∞ TAS kg^{-1} for maize, beans, potatoes and vegetables respectively (Table 4.22). Maize, beans and potato farm-gate prices can be increased by a maximum of values indicated, without altering the optimum activity mix. The indicated allowable increase of "infinity" for vegetable, implies that the price of vegetable may be increased by a large positive value without affecting the optimum solution. On the other hand the allowable decreases were considerably low/small, 32.67, 25.23 and 18.45 TAS kg^{-1} for maize, beans and vegetables respectively. Potato has an allowable decrease of ∞ kg ha basically because, as indicated in section 4.2.1 potatoes are produced to meet subsistence requirements only. Thus a fall in the price of potatoes is unlikely to affect the optimum solution.

In the right hand side (RHS) part of the analysis report, there is an allowable increase and decrease in land allocation for crops. This indicates that land is sensitive to changes given the available resources.

4.2.2.2 The effect of changes of farm-gate prices

It has been observed that the producer prices paid to farmers in Tanzania are very low (see Somogyi 1989; Gibbon, Havnevik and Hermelle 1992). Ostensibly producer price is an economic incentive to the farmers (Kaoneka 1993(b)). If the two observation hold true, then an increase in producer (farm-gate) prices should stimulate increased production of tradeable crops. Based on this premise a sensitivity analysis was conducted to elucidate the effect of change in farm-gate prices on optimum farm plan.

In conducting sensitivity analysis on the effect of changing producer prices on optimum farm plans, the partial equilibrium principle is applied. The principle is that "the change in maize price can take place without causing significant change in the price of other products" (Mansfield 1988). The analysis was conducted with two objectives, to elucidate the farmer's response to changes in producer price and to estimate price elasticity of maize supply. In this analysis only maize crop was considered for two reasons. First, maize is not only a staple cereal but also a crop of high commercial value, meaning that it is a tradeable crop likely to be affected by changes in farm-gate prices. Second, government pricing policies have more effect on the production and consumption of maize compared to beans, potatoes and vegetables. In fact, even subsidy provision before the adoption of Structural Adjustment Programmes and stand-by agreement with the International Monetary Fund (EIU 1992), was directed more to Ruvuma, Mbeya, Rukwa and Iringa, the four major maize producing regions (Somogyi 1989). This policy orientation shows that maize is a crop of high value at the national level. Vegetable is a cash or tradeable crop for farmers in Lukozi Village. However sensitivity analysis on the price of vegetable crop is not relevant because the allowable increase indicated on the range report was "infinity" (Table 4.23) meaning that the price of vegetable can be increased by any positive value without affecting the optimum farm plan.

Based on the range report (Table 4.23), the allowable increase for maize was 102.26 TAS kg^{-1}, then the maximum price that can be paid for maize without affecting the optimum farm plan is 150.26 TAS kg^{-1} (i.e. 48.00 + 102.26 = 150.26 TAS kg^{-1}). Thus in order to alter the existing optimum farm plan, a small increase of 0.01 TAS kg^{-1} was added to the maximum price level of 150.26 TAS kg^{-1} to obtain a new price value of 150.27 TAS kg^{-1}. The new price value of 150.27 TAS kg^{-1} was used instead of 48.00 TAS kg^{-1} in the maize sale activity (S_1) in Village I.LP model.

The results from the analysis are presented in Table 4.24. For purpose of comparison both existing and alternative optimum farm plans are included. The results show a significant difference between the existing and alternative optimum farm plans. The value of the objective function increased from 632,494 to 701,579 TAS ha^{-1} for the existing and alternative optimum farm plans respectively, representing an increase of 11%. The alternative optimum farm plan entail the use of 129 and 330 kg of phosphorous and nitrogen fertilizers respectively and a working capital of TAS 154,310. Land allocation was 0.25 and 1.60 ha of potatoes and vegetables respectively planted under monocropping farming system and 1.45 ha each for maize and beans planted in the intercropping farming system. The variation in this case is caused by the allocation of maize to alternating maize and beans intercropping pattern which means production of more maize sold at higher than the existing market price. This partly explains the increase in the use of phosphorous and nitrogen mineral fertilizers. The shadow price of long-rain land where maize is planted increased from 59,324 to 157,927 TAS ha^{-1} in the basic and alternate optimum farm farm plans respectively. The increase in marginal value of long-rain land implies that it is profitable to expand farmland under maize crop. This is logical from economic point of view because a rise in farm-gate price for maize implies increased returns for the farmer who plants maize. The response of the farmer will, however, depend on the avilability of arable land given a certain level of farming technology.

The range analysis report (Table 4.25) showed that after the first iteration the allowable increase on maize farm-gate price assumed the "infinity" value meaning that further price increases are not likely to alter the alternative optimum farm plan. In essence, therefore, there was only one "step" analysis to elucidate the effect of an increase in the fam-gate price for maize. The results gave an indication on the possible response of maize supply caused by price increases. In addition, the results were used to compute the price elasticity of maize supply.

Table 4.24 Optimum farm plans showing the effects of change of farm-gate price for maize

	Initial price (48 TAS kg^{-1})	Alternative price (150.27 TAS kg^{-1})
Cash income (TAS yr^{-1}):	632494	701579
Land allocation (ha):		
Monocropping - Maize	0	0
Beans	0	0
Potatoes	0.25	0.25
Vegetables	1.60	1.60
Intercropping I- Maize[1]	1.45	1.45
Beans	0	0
IntercroppingII- Maize	0	0
Beans	1.45	1.45
Total cultivated land	4.75	4.75
Fertilizer nutrient used (kg):		
Phosphorous	93	129
Nitrogen	269	330
Working capital used (TAS):	149233	154310
Sales activities (kg):		
Maize	675	870
Beans	1390	604
Potatoes	0	0
Vegetables	31002	31002
Consumption activities (kg):		
Maize	1072	1072
Beans	270	270
Potatoes	502	502
Vegetables	998	998

Note: [1] Maize is allocated under "alternating" maize and beans intercropping pattern in the alternative optimum farm plan (at price = 150.27 TAS kg^{-1}).

Table 4.25 Range analysis report for the alternative optimal farm plan

Variables[1]	Ranges of objective function coeficients		
	Current coeffient	Allowable increase	Allowable decrease
X_p	-18.70	18.70	0.05
X_n	-39.60	39.59	0.03
X_k	-1.10	0.00	3.66
S_1	150.27	infinity	0.01
S_2	68.00	0.00	52.31
S_3	40.00	81.36	infinity
S_4	22.00	infinity	18.47
X_1	0.00	31544.00	infinity
X_2	0.00	162874.60	infinity
X_3	0.00	162737.60	infinity
X_4	0.00	infinity	369547.18
X_5	0.00	1.48	infinity
X_7	0.00	infinity	1.48
X_8	0.00	0.00	infinity
X_6	0.00	infinity	0.00
Resource	**Right hand side ranges**		
	Current RHS	**Allowable increase**	**Allowable decrease**
Labour Feb.	156.00	infinity	132.19
March	156.00	infinity	124.04
May	156.00	infinity	149.69
September	156.00	infinity	132.19
October	156.00	infinity	128.39
December	156.00	infinity	142.44
Phosphorous	0.00	128.77	2944.08
Nitrogen	0.00	329.65	1390.26
Manure	25.00	infinity	15.74
W.capital	0.00	124310.17	50049.37
Capital limit	241173.00	infinity	64063.19
Maize	1072.00	869.66	infinity
Beans	270.00	603.74	infinity
Potato	502.00	1298.00	501.99
Vegetable	998.00	31002.00	infinity
Veg. land	1.60	1.60	1.55
Longrain land	1.70	8.24	0.64
Shortrain land	1.70	11.95	1.00

Note:[1] variables remain as previously defined

The price arc elasticity of maize supply can be computed using the following procedure (Mansfield 1988):

$$\eta_s = \frac{\Delta Q_s}{(Q_{s1} + Q_{s2})/2} \div \frac{\Delta P}{(P_1 + P_2)/2} \qquad [4.2]$$

where,

η_s	=	price elasticity of supply
ΔQ_s	=	change in quantity of supply (kg)
Q_{s1}	=	quantity of maize supply at the existing price level (kg)
Q_{s2}	=	quantity of maize supply at the alternative price level (kg)
ΔP	=	change in farm-gate price (TAS kg^{-1})
P_1	=	farm-gate price in the existing optimum farm plan (TAS kg^{-1})
P_2	=	farm-gate price in the alternative optimum farm plan

Notice that arc price elasticity of supply (equation 4.2) is used because the price change was substantial, i.e., from 48.00 TAS kg^{-1} to 150.27 TAS kg^{-1}.

From table 4.24

Q_{s1}	= 676 kg
Q_{s2}	= 870 kg
ΔQ_s	= $Q_{s2} - Q_{s1}$ = 870 - 676 = 194 kg
P_1	= 48.00 TAS kg^{-1}
P_2	= 150.27 TAS kg^{-1}
ΔP	= $P_2 - P_1$ = 150.27 - 48.00 = 102.27TAS kg^{-1}

Thus,

$$\eta_s = [\frac{\Delta Q_s}{(Q_{s1} + Q_{s2})/2}] \div [\frac{\Delta P}{(P_1 + P_2)/2}]$$

$$= [\frac{194}{(676 + 870)/2}] \div [\frac{102.27}{(48.00 + 150.27)/2}] = 0.24$$

Therefore the price elasticity of supply is 0.24 meaning that the supply curve for maize is "inelastic" which is consistent with the logic because "the supply curve for basic farm products is relatively inelastic in the short-run" (Mansfield 1988). This observation seems relevant to average farmers who, because of limited resources, are not able to expand farm production to increase maize supply in the short-run. The results indicate, however, that maize supply can be increased marginally by changing the cropping pattern to alternating cropping system from maize/beans intercropping system. In so doing the peasant farmer should be able to sell 870 kg compared to 676 kg thereby increasing the amount of net cash income earned.

4.3 Analysis of agriculture/forestry relations

4.3.1 The effect of population growth

The purpose of this section is to present an analysis of the pressure on forest lands as a result of population growth. The analysis is based on the results obtained from Village II.LP model. The results generated by simulating the first alternative with Village II.LP are presented in Tables 4.27, 4.28 and 4.29 representing scenarios 1, 2, and 3 respectively. The results in Table 4.27 show a declining trend in net cash income over time. The decline could be attributed to a decrease in vegetable sale, the only cash crop sold over the period corresponding to a decline in vegetable land. This trend could be ascribed to the fact that more family labour is diverted to subsistence food crops, maize, beans and potatoes in order to satisfy household demand for food.

This seems logical as the model assumes that any rational farmer would secure subsistence needs before selling farm crops. Further, as long as the farmer relies on family labour for agriculture, any diversion of it to food crop production will decrease the labour available for cash crop production.

Another feature of interest of the results obtained via the first alternative is land clearing and the resulting deforestation. A total of 1.38 ha was cleared in year 5 to compensate for 2.98 ha allocated to vegetable production. The logic of such clearing is based on the premise that vegetable land was restricted to 1.6 ha of land confined to valley floor. Therefore, any optimum farm plan that allocates more than 1.6 ha to vegetable production is likely to cause land clearing through deforestation. There was no provision for taking long- and short-rain lands because such areas are unsuitable for vegetable production.

The results representing the second scenario, i.e. population growth rate of 3% p.a. over a period of 35 years (Table 4.27), indicate a different set of outcome especially with respect to a decline in cash income. The results show a more dramatic decline in net cash income generated over time than that indicated by scenario 1 (Table 4.27). This trend could be attributed to fast population growth of 3% p.a. hence increased household demand for food. As more family labour is allocated to food crop production, land for vegetable, the only cash crop, declines. This decline causes a corresponding decrease in vegetable sales hence the decline in net cash income.

Table 4.27 Optimum farm plans generated over time for an average farmer with a population growth rate of 2.1% p.a. over a period of 35 years[1] (all figures per household)

Component	Basic plan[2]	Optimum farm plans during the year			
		5	15	25	> 30
Cash income					
TAS:	632494	1114044	1077210	1032295	INFEASIBLE
Land allocation, ha:					
Monocropping:					
Maize	0.00	0.00	0.00	0.00	
Beans	0.00	0.00	0.00	0.00	
Potatoes	0.25	0.28	0.34	0.42	
Vegetables	1.60	2.98	2.94	2.88	
Intercropping:					
Maize	1.45	0.89	1.09	1.34	
Beans	1.45	1.42	1.36	1.28	
Total land	4.75	5.57	5.73	5.92	
Cleared land, ha:					
Vegetable land	0.00	1.38	1.34	1.28	
Long-rain land	0.00	0.00	0.00	0.07	
Shortrain land	0.00	0.00	0.00	0.00	
Total cl. land	0.00	1.38	1.34	1.35	
Fertilizer use, kg:					
Phosphorous,kg	93	185	191	198	
Nitrogen, kg	269	539	540	539	
W.Capital, TAS	149233	218629	218473	218366	
Sales, kg:					
Maize	675	0.00	0.00	0.00	
Beans	1390	1390	1148	1011	
Potatoes	0.00	0.00	0.00	0.00	
Vegetables	31002	58586	57474	55854	
Consumption, kg:					
Maize	1072	1189	1464	1802	
Beans	270	299	407	453	
Potatoes	502	557	686	844	
Vegetables	998	1107	1363	1678	

Note: [1] Assuming same level of technology, thus input remain the same.
[2] Optimum farm plan developed by Village I.LP with the existing resources

The results representing scenario 3 are summarized in Table 4.29. The results indicate a declining trend in cash income produced. That means it is not possible to achieve the projected increase in per capita income of 2%. In fact the declining trend means a deterioration rather than an improment of welfare situation of an average farmer.

Based on the analysis the following observations can be made. With the present population growth rate in Lukozi Village of 2.1% p.a., the farming systems of an average farmer are sustainable for at least 25 years but not more than 30 years (both 30 and 35 years gave an infeasible solution) at the existing level of technology. The cut-off year lies between 25 and 30 years. With a population growth of 3% p.a. (close to the national average of 2.8% p.a. according to the 1988 census), the farming systems of an average farmer are sustainable for a period of at least 15 years but not more than 20 year (periods ≥ 20 years gave infeasible solution). The cut-off year lies between 15 and 20 years. With a population growth rate of 2.1% p.a. and an expected increase in per capita cash income of 2% p.a., the farming systems are sustainable for a period of 10 years but below 15 years (periods ≥ 15 years gave infeasible solutions). The cut- off year lies between 10 and 15 years.

Table 4.28 Optimum farm plans generated over time for an average farmer with a population growth rate of 3% p.a. over a period of 35 years[1] (all figures per household)

Component	Basic plan[2]	Optimum farm plans during the year		
		5	15	> 20
Cash income				
TAS:	632494	1107332	1054278	INFEASIBLE
Land allocation, ha:				
Monocropping:				
Maize	0.00	0.00	0.00	
Beans	0.00	0.00	0.00	
Potatoes	0.25	0.29	0.39	
Vegetables	1.60	2.98	2.91	
Intercropping:				
Maize	1.45	0.93	1.25	
Beans	1.45	1.41	1.31	
Total land	4.75	5.60	5.86	
Cleared land, ha:				
Vegetable land	0.00	1.38	1.31	
Long-rain land	0.00	0.00	0.00	
Short-rain land	0.00	0.00	0.00	
Total cl. land	0.00	1.38	1.31	
Fertilizer use, kg:				
Phosphorous,kg	93	187	196	
Nitrogen, kg	269	539	541	
W.Capital, TAS	149233	218598	218354	
Sales, kg:				
Maize	675	0.00	0.00	
Beans	1390	1301	1080	
Potatoes	0.0	0.00	0.00	
Vegetables	31002	58368	56641	
Consumption, kg:				
Maize	1072	1243	1670	
Beans	270	313	420	
Potatoes	502	582	782	
Vegetables	998	1157	1555	

Note: [1] Assuming same level of technology, thus input remain the same.
[2] Optimum farm plan developed by Village I.LP with existing resources

Table 4.29 Optimum farm plans generated over time for an average farmer with a population growth rate of 2.1% and increase in cash income of 2% p.a. over a period of 35 years[(1)] (all figures per household)

Component	Basic plan[(2)]	Optimum farm plans during the year		
		5	10	> 15
Cash income				
TAS:	632494	1144044	1097806	INFEASIBLE
Land allocation, ha:				
Monocropping:				
Maize	0.00	0.00	0.00	
Beans	0.00	0.00	0.00	
Potatoes	0.25	0.28	0.31	
Vegetables	1.60	2.98	2.96	
Intercropping:				
Maize	1.45	0.89	0.98	
Beans	1.45	1.42	1.39	
Total land	4.75	5.57	5.65	
Cleared land, ha:				
Vegetable land	0.00	1.38	1.36	
Long-rain land	0.00	0.00	0.00	
Short-rain land	0.00	0.00	0.00	
Total cl. land	0.00	1.38	1.36	
Fertilizer use, kg:				
Phosphorous,kg	93	185	188	
Nitrogen, kg	269	539	539	
W.Capital, TAS	149233	218629	218554	
Sales, kg:				
Maize	675	0.00	0.00	
Beans	1390	1330	1262	
Potatoes	0.0	0.00	0.00	
Vegetables	31002	58586	58058	
Consumption, kg:				
Maize	1072	1189	1320	
Beans	270	299	332	
Potatoes	502	557	618	
Vegetables	998	1107	1228	

Note: [(1)] Assuming same level of technology, thus input remain the same.
[(2)] Optimum farm plan developed by Village I.LP with existing resources

Model results representing a smallholder farmer, alternative 2, are shown in Table 4.30. Scenario 2 was not conducted because a population increase of 3% p.a. was found to be even more restrictive than 2.1% p.a. used in scenario 1. The results indicated that between years 1 and 5 there was a decrease in cash income produced (Table 4.30) and hence decline in per capita income. The farming systems are sustainable for at least 5 years but not beyond 10 years (periods ≥ 10 years gave infeasible solutions). Thus the cut-off year lies between 5 and 10 years. Land clearing increased from 1.52 in year 1 to 1.60 ha in year 5. The increase may be attributed to the rise in household demand for food.

The scenarios selected were found to be very restrictive to both the average and smallholder farmers. A couple of observations could be relevant. First, in real life situation farmers do not consider cash income as the overriding goal. In most cases priority is give to food production and cultural needs before the goal for cash income is pursued (c.f. Maslow's hierarchy of needs, Kaoneka 1987). Second, in the rural sector of Tanzania seldom, if ever, is the population growth matched to increase in per capita income. The declining living conditions of the rural populace is an indication of this disparity.

Table 4.30 Optimum farm plans generated over time for farmers with land areas < 2.0 ha with population growth rate of 2.1% p.a.[1]

Component	Year 1	Year 5	Years > 10
Cash income			
TAS:	747508	718583	INFEASIBLE
Land allocation, ha:			
Monocropping:			
Maize	0.00	0.00	
Beans	0.00	0.00	
Potatoes	0.22	0.24	
Vegetables	2.10	2.02	
Intercropping:			
Maize	0.69	0.75	
Beans	0.69	0.75	
Total land	3.70	3.76	
Cleared land, ha:			
Vegetable land	1.30	1.22	
Long-rain land	0.11	0.19	
Short-rain land	0.11	0.19	
Total cl. land	1.52	1.60	
New land	1.52	0.08	
Fertilizer use, kg:			
Phosphorous, kg	133	131	
Nitrogen, kg	381	371	
W.Capital, TAS	160294	158845	
Sales, kg:			
Maize	0.00	0.00	
Beans	560	608	
Potatoes	0.00	0.00	
Vegetables	41059	39503	
Consumption, kg:			
Maize	1030	1269	
Beans	260	320	
Potatoes	483	594	
Vegetables	963	1186	

Note: [1] Assuming same level of technology, thus input remain the same except RHS values for labour, food requirements and land area were revised.

On the basis of the results presented in this section, some concluding remarks can be made. The farming systems analyzed are not sustainable in the long run. A maximum period of between 25 and 30 years is too short to support even one human generation. Therefore, there is a need to chart out strategies for improving farming technology. This could be enhanced crop production hence an increase in per unit land productivity, agroforestry activities or increased off-farm income from forest industrial activities. Finally if the welfare of an ordinary farmer is to be improved, even more needs to be done to boost up economic production.

The analysis was based on the premise that the existing technology continues over time. Further it was assumed that both average and smallholder farmers have limited financial working capital. Thus the next step is to analyze the responsive behaviour of a farmer when a credit facility is available such that working capital is increased. In particular, the analysis is intended to determine whether or not availability of capital influence land clearing or deforestation and use of market inputs. This analysis is presented in section 4.3.2.

4.3.2 Effect of changes in total capital on deforestation

The purpose of this analysis was to investigate the effect of changes in total capital on land use pattern and deforestation. An additional aim was to elucidate the effect of total capital availability on the derived intensity for the use of market inputs *viz* phosphorous and nitrogen fertilizers. The analysis was conducted for an average farmer only. Three alternatives (Table 4.31) were simulated. The alternatives are outlined as follows:

Alternative 1: No land clearing and unrestricted working capital.

Alternative 2: Land clearing allowed and restricted working capital.

Alternative 3: Land clearing allowed and unrestricted working capital.

Table 4.31 A summary of alternatives used to analyze the effect of changes in total capital

Alternatives	Land clearing	Working capital	
		Restricted	Unrestricted
Alternative 1	No	-	Yes
Alternative 2	Yes	Yes	-
Alternative 3	Yes	-	Yes

The results obtained from the analysis are summarised in Table 4.32. The net cash income generated are 63,2494, 1,128,573 and 1,215,217 TAS/yr representing alternatives 1, 2 and 3 respectively (Table 4.32). The impact of changes in working capital are observed in alternatives 2 and 3. There was a substantial increase in net cash income when the relaxation of working capital constraint was associated with provision for land clearing (alternative 3). Alternatives 2 and 3 produced more cash income resulting from expanded farmland through forest clearing. Alternatives 2 and 3 gave net cash income of 1,128,572 and 1,215,217 TAS/yr respectively. The combination of increase in working capital and provision for land clearing produced the highest net cash earnings per annum (alternative 3). It can be said therefore that given the fixed resources endowed to an average farmer, provision of a credit facility is likely to stimulate expansion of farmlands. Labour, however becomes a limiting factor especially during the peak seasons (observed via shadow prices).

Land allocation changed considerably when land clearing was permitted (alternatives 2 and 3). An extra 1.4 ha of land was added from land clearing activities. There was no land clearing for short- and long-rain land categories as the demand is satisfied by the available land.

In alternative 3, vegetable land increased further to 3.15 ha corresponding to a land clearing of 1.55 ha. These results indicated that all land cleared is allocated to crops. More vegetable land is cleared because it has high marginal value (determined via shadow prices) compared to other land categories. The high marginal value indicates that it was profitable to expand vegetable land *ceteris paribus*. Generally the analysis indicated that working capital is an important farm input and determined to some extent the size of farmland a farmer was willing to cultivate. In the absence of surplus land, most likely the expansion of farmland will be effected by way of clearing forest reserves.

The results show a substantial increase in the use of both phosphorous and nitrogen mineral fertilizers in alternative 2 and 3 as a result of relaxing the working capital constraint. The amount of phosphorous used is 183 and 207 kg for alternatives 2 and 3 respectively compared to 93 used up in alternatives 1 (Table 4.32). The amount of nitrogen fertilizer used were 538 and 590 kg for alternatives 3 and 4 respectively compared to 269 kg for alternatives 1 (Table 4.32). The working capital for alternatives 2 and 3 amounted to 218,696 and 236,521 TAS respectively compared to TAS 149,233 for alternatives 1 (Table 4.32). Based on these results it can be inferred that provision of working capital increased the use of market inputs, ostensibly due to the expansion of farmlands *ceteris paribus*.

The results indicated a substantial increase in the sale of vegetables in alternatives 3 and 4 compared to alternative 1. The sales were 59,059 and 62,107kg of vegetables in alternatives 2 and 3 respectively compared to 31,002 kg (vegetables) in alternative 1 (Table 4.32). The increase in sales for alternative 2 and 3 is attributed to the expansion of farmland hence increase in farm outputs.

An additional sensitivity analysis was conducted on *taungya* system. Under the *taungya* system the management of Magamba Forest Project is assumed to clear a forest land and allow peasants to plant agriculture crops mixed with young trees (Alternative 4). The system has advantages to both the farmer and the forest management. The farmer is relieved of the ardous task of clearing forest trees. On the other hand the forest management benefits because farmers take care of young trees thereby cutting down the tending cost. Labour for land clearing was reduced from 75 to 25 mandays per ha required for removing debris from the cleared area. Additonal capital was reduced from 15,000 to 5,000 TASha^{-1} because farmers no longer need cross-cut saws. Such land is assumed to be added to the existing farmlands. It may be observed, however, that the input requirement for a *taungya* system is quite different from monocropping and intercropping systems. Nevertheless, for the purpose of this

Table 4.32 Optimum farm plans generated by varying working capital and land area

Component	Optimum farm plans in years			
	Altern.1	Altern.2	Altern.3	Altern.4
Cash income				
TAS:	632494	1128572	1215217	2933462
Land allocation, ha:				
Monocropping:				
Maize	0.00	0.00	0.00	12.63
Beans	0.00	0.00	0.00	0.00
Potatoes	0.25	0.25	0.25	0.25
Vegetables	1.60	3.00	3.15	4.75
Intercropping:				
Maize	1.45	0.80	1.45	0.00
Beans	1.45	1.45	1.45	20.20
Total land	4.75	5.50	6.30	37.83
Cleared land, ha:				
Vegetable land	0.00	1.40	1.55	2.15
Long-rain land	0.00	0.00	0.00	20.15
Shortrain land	0.00	0.00	0.00	10.13
Total cl. land	0.00	1.40	1.55	32.83
Fertilizer use kg:				
Phosphorous,kg	93	183	207	565
Nitrogen, kg	269	538	590	1328
W.Capital, TAS	149233	218696	236521	583161
Sales, kg:				
Maize	675	0.00	869	15845
Beans	1390	1390	1390	11910
Potatoes	0.00	0.00	0.00	0.00
Vegetables	31002	59059	62107	93982
Consumption, kg:				
Maize	1072	1072	1072	1072
Beans	270	270	270	270
Potatoes	502	502	502	502
Vegetables	998	998	998	998

Note: [1] Optimum farm plan developed by Village I.LP without provision for clearing new land.

Alternative 1: no land clearing and unrestricted working capital
Alternative 2: land clearing allowed and restricted working capital
Alternative 3: land clearing allowed and unrestricted working capital
Alternative 4: "*taungya* arrangement"

analysis such a distinction is not taken into account.

Other assumptions were the same as alternative 3. The results representing alternative 4 are quite different from the alternative 3. Land allocated to vegetables increased from 3.15 to 4.75 ha in alternatives 3 and 4 respectively. Land allocation to maize and beans increased with maize allocated to monocropping farming system. Land allocation was 12.3 and 20.2 ha for maize and beans respectively. These results obtained in alternative 4 indicated that *taungya* system, with unlimited capital increases the demand for forest land. Cash income obtained increased from 1,215,217 to 2,933,463 in alternatives 3 and 4 respectively.

The use of fertilizers increased from 207 to 565 kg of P and 590 to 1,328 kg of N as a result of shifting from alternatives 3 to 4. Total capital used increased from 236,521 to 583,165 TAS in alternatives 3 and 4 respectively. Crop sales in alternative 4 were 15,845, 11,910 and 93,982 kg of maize, beans and vegetables respectively.

4.3.2.5 Concluding remarks

Based on the results presented in this section it can be concluded that the availability of working capital is very important to an ordinary farmer. Therefore as a matter of policy issue it is important for money lending institutions to design measures of extending appropriate credit facility to the farmers. Further the results have indicated that, given the available technology, an extension of working capital will result into the expansion of farmlands. If such expansion is not possible within the available arable land, farmers will most likely clear forest lands resulting into increased deforestation.

The *taungya* system coupled with provision of capital is likely to increase the pressure on forest lands *ceteris paribus*. If proper arrangement is not made deforestation could also accelerate.

4.4 Stochastic analysis of farming systems from Village.CP model solutions

4.4.1 Analysis of the effect of risk aversion

The payoff matrix for the MOP problem is presented in Table 4.33. The figures or values on the main diagonal present the *ideal point*, i.e., TAS 1,128,572 and TAS 56,405 for maximization of net cash income and risk minimization objectives respectively. The results in Table 4.33 clearly indicate that the two objectives are in conflict, thus the *ideal* farm plan is infeasible. The degree of conflict can be observed from the solutions in rows one and two of the payoff matrix (Table 4.33). The first row shows that net maximization of cash income to a magnitude of TAS 1,128,572, the farmer must accept a risk i.e. overtime fluctuation level of TAS 470,376 which is higher than the *ideal* level of TAS 56,405. The second row shows that with a low (*ideal*) risk level of TAS 56405, the farmer must expect no cash returns from agricultural activities.

In essence, therefore, there is a trade-off to be made. In order to minimize risk level the farmer must accept a lower net cash income than the *ideal point*. Conversely, a decision maker who aims at higher net cash income must also accept higher risk level. That

Table 4.33 A payoff matrix for a MOP problem with two objectives: maximization of net cash income and risk minimization (MOTAD) given equal weights (TAS)[(1)]

Objectives	Maximization of net cash income (Z_1)	Risk minimization (MOTAD) (Z_2)
Maximization of net cash income(Z_1)	<u>1128572</u>	470376
Risk minimization (MOTAD)(Z_2)	0.00	<u>56405</u>

Note: [(1)] MOTAD = minimization of total absolute deviations

is, the farmer would prefer a strategy with higher income variance (V) only if it is coupled with an increase in the expected net cash income (E) and $\delta E^2/\delta V^2 > 0$ such that this compensation must increase at an increasing rate with increases in V (Hazell 1971). In practise the choice of any of the two alternatives are hard to make to the extent that they are extreme points. Thus the decision maker will attempt to find a compromise solution set which is as close to the *ideal point* as possible. Often a number of solution points, the Pareto-optimal or non-dominated points, are developed as a way of increasing the range of choices. These points are generated by minimizing different distance cocepts ranging from 1 to ∞. The best compromise solution set is developed upon which the decision maker or farmer can make choices which represent intent preferences. Such choices are based on subjective judgement by the decision maker or farmer to the extent that there is no *a priori* justification for choosing one solution in favour of other solutions in the CP solution set (Prem, Prihar and Cheema 1988).

The L_1 and L_∞ metrics compromise solutions are summarized in Table 4.34. The results of both L_1 and L_∞ metrics differ from the optimum plan. This observation is not surprising to the extent that the optimum plan was developed by optimizing a single objective i.e. maximization of net cash income, whereas the L_1 and L_∞ metrics solutions were generated by compromising two objectives; maximization of net cash income and risk minimization (MOTAD) in a MOP framework. However, to allow the farmer or decision maker a wide range of choices often intermediate efficient farm plans or best compromise solution set is produced. Therefore, the analysis was carried further using different weights assigned to the two objectives in form of sensitivity analysis. The procedure of assigning varying weights to δ_j generates a set of efficient farm plans which allows the decision maker to choose according to preference.

Two alternatives were conducted. The first alternative was conducted by increasing the weight of objective I (Z_1)-maximization of net cash income relative to those of objective II (Z_2)-risk minimization (MOTAD). In the second alternative the weights of objective II (Z_2) were increased relative to those of objective I (Z_1). The results generated through sensitivity analyses are presented in Tables 4.35(a), 4.35(b), 4.36(a) and 4.36(b).

Table 4.34 A compromise solution set of MOP with two objectives given equal weights

Component	Optimum plan[1]	Compromise solution set	
		L_1	L_∞
Maximization of net cash income (TAS)	1128572	633295	571500
MOTAD (TAS)	-	283071	260745
<u>Land allocation, (ha):</u>			
<u>Monocropping:</u>			
Maize	0.00	0.00	0.00
Beans	0.00	0.00	0.00
Potatoes	0.25	0.25	0.25
Vegetables	3.00	1.60	1.43
<u>Intercropping:</u>			
Maize	0.80	0.80	0.80
Beans	1.45	1.45	1.45
Total cult.land	5.50	4.00	3.93
<u>Cleared land, ha:</u>			
Vegetable land	1.40	0.00	0.00
Long-rain land	0.00	0.00	0.00
Short-rain land	0.00	0.00	0.00
Total cl. land	1.40	0.00	0.00
<u>Fertilizer use, kg:</u>			
Phosphorous	182	112	104
Nitrogen	538	302	274
W.Capital, TAS	218696	110893	107923
<u>Sales, kg:</u>			
Maize	0.00	0.00	0.00
Beans	1390	1390	1390
Potatoes	0.00	0.00	0.00
Vegetables	59059	31002	27658
<u>Consumption, kg:</u>			
Maize	1072	1072	1072
Beans	270	270	270
Potatoes	502	502	502
Vegetables	998	998	998

Note: [1]Optimum plan- the farm plan generated using the traditional LP model i.e. where only a single objective, maximization of net cash income is optimized.

The results representing the first alternative are summarized in Tables 4.35(a) and 4.35(b) representing L_1 and L_∞ metrics respectively. The results show that by increasing the weights of the first objective, Z_1, different sets of efficient farm plans can be generated. The trend indicated by the results is that there is a tendency for the CP solutions to approach the one developed by traditional LP model as the weights are increased (tables 4.35(a) and 4.35(b)). The break-even point occured between the weights 1 and 2 with solution sets of TAS 633,295 and TAS 283,071; and TAS 1,128,572 and TAS 470,376 for first and second objectives respectively in the L_1 metric. In fact the farm plans generated by giving the weights of 2 and 5 to the first objective are identical to the basic plan. These results indicated that the L_1 solutions were fairly sensitive to changes in weights assigned to the first objective (maximization of net cash income) relative to the second objective (risk minimization).

Based on these results, a couple of observations can be deduced. Assigning greater weights to the first objective results in higher net cash income and vice-versa. For example if a farmer chooses a farm plan with a weight of 2 in favour of 1 for the first objective, net cash income increases from TAS 633,295 to TAS 1,128,572 reflecting an increase of TAS 495,277. However, risk level also increases from TAS 283,071 to TAS 470,376. Hence the farmer must trade-off in terms of whether to choose low net cash income with low risk level or high net cash income with a corresponding high risk level. Another observation is that, the procedure of assigning more weights to maximization of net cash income relative to risk minimization results into increased pressure on farmlands. This in turn accelerates deforestation through clearing more land for agriculture.

The results of the second alternative are presented in Tables 4.36(a) and 4.36(b) representing L_1 and L_∞ metrics respectively. The results show that by assigning more weights to the second objective (Z_2) relative to the first objective (Z_1), the CP model produced results which were quite the opposite of the first alternative. For instance a weight of 2 produced a solution identical to the *ideal point* of zero net cash income and risk level of TAS 56,405. In simple terms it can be said that giving more weight to risk minimization reduces the pressure on farmlands hence causing less deforestation (at the expense of net cash income). The reduction of farmland area can be attributed to the fact that, assigning high weights to risk minimization the farmer perceives the situation to be risky. Thus it is not profitable to expand farmlands by clearing forestlands.

Table 4.35(a) A compromise solution set corresponding to L_1 as the weights given to objective I (Z_1) are increased in relation to that of objective II (Z_2)

Component	Optimum plan[(1)]	Compromise solution set for L_1		
		1:1	2:1	5:1
Maximization of net cash income (TAS):	1128572	633295	1128572	1128572
MOTAD (TAS):	-	283071	470376	470376
Land allocation, ha:				
Monocropping:				
Maize	0.00	0.00	0.00	0.00
Beans	0.00	0.00	0.00	0.00
Potatoes	0.25	0.25	0.25	0.25
Vegetables	3.00	3.00	3.00	3.00
Intercropping:				
Maize	0.80	0.80	0.80	0.80
Beans	1.45	1.45	1.45	1.45
Total land	5.50	4.00	5.50	5.50
Cleared land, ha:				
Vegetable land	1.40	0.00	1.40	1.40
Long-rain land	0.00	0.00	0.00	0.00
Short-rain land	0.00	0.00	0.00	0.00
Total cl. land	1.40	0.00	1.40	1.40
Fertilizer use, kg:				
Phosphorous	182	112	182	182
Nitrogen	538	302	538	538
W.Capital, TAS	218696	110893	218696	218696
Sales, kg:				
Maize	0.0	0.00	0.00	0.00
Beans	1390	1390	1390	1390
Potatoes	0.0	0.00	0.00	0.00
Vegetables	59059	31002	59059	59059
Consumption, kg:				
Maize	1072	1072	1072	1072
Beans	270	270	270	270
Potatoes	502	502	502	502
Vegetables	998	998	998	998

Note: (1) Optimum plan- the farm plan generated using the traditional LP model i.e. where only a single objective, maximization of net cash income is optimized

Table 4.35(b) A compromise solution set corresponding to L_∞ as the weights given to objective I (Z_1) is increased in relation to that of objective II (Z_2)

Component	Optimum plan[1]	Compromise solution set for L_∞		
		1:1	2:1	5:1
Maximization of net cash income (TAS):	1128572	571500	756229	941444
MOTAD (TAS):	-	260745	329562	399608
Land allocation, ha:				
Monocropping:				
Maize	0.00	0.00	0.00	0.00
Beans	0.00	0.00	0.00	0.00
Potatoes	0.25	0.25	0.25	0.25
Vegetables	3.00	1.43	1.95	2.47
Intercropping:				
Maize	0.80	0.80	0.80	0.80
Beans	1.45	1.45	1.45	1.45
Total land	5.50	3.93	4.45	4.97
Cleared land, ha:				
Vegetable land	1.40	0.00	0.35	0.87
Long-rain land	0.00	0.00	0.00	0.00
Short-rain land	0.00	0.00	0.00	0.00
Total cl. land	1.40	0.00	0.35	0.87
Fertilizer use, kg:				
Phosphorous	182	104	130	156
Nitrogen	538	274	361	449
W.Capital, TAS	218696	107923	142603	180454
Sales, kg:				
Maize	0.0	0.00	0.00	0.00
Beans	1390	1390	1390	1390
Potatoes	0.0	0.00	0.00	0.00
Vegetables	59059	27658	37966	48458
Consumption, kg:				
Maize	1072	1072	1072	1072
Beans	270	270	270	270
Potatoes	502	502	502	502
Vegetables	998	998	998	998

Note: [1] Optimum plan- the farm plan generated using the traditional LP model i.e. where only a single objective, maximization of net cash income is optimized.

Table 3.36(a) A compromise solution set corresponding to L_1 as the weights given to objective II (Z_2) is increased in relation to that of objective I (Z_1)

Component	Optimum plan[1]	Compromise solution set for L_1		
		1:1	1:2	1:5
Maximization of net cash income (TAS):	1128572	633295	0.00	0.00
MOTAD (TAS):	-	283071	56405	56405
<u>Land allocation, ha:</u>				
<u>Monocropping:</u>				
Maize	0.00	0.00	0.80	0.80
Beans	0.00	0.00	0.00	0.00
Potatoes	0.25	0.25	0.25	0.25
Vegetables	3.00	1.60	0.05	0.05
<u>Intercropping:</u>				
Maize	0.80	0.80	0.00	0.00
Beans	1.45	1.45	0.57	0.57
Total land	5.50	4.00	1.67	1.67
<u>Cleared land, ha:</u>				
Vegetable land	1.40	0.00	0.00	0.00
Long-rain land	0.00	0.00	0.00	0.00
Short-rain land	0.00	0.00	0.00	0.00
Total cl. land	1.40	0.00	0.00	0.00
<u>Fertilizer use, kg:</u>				
Phosphorous	182	112	35	35
Nitrogen	538	302	42	42
W.Capital, TAS	218696	110893	21297	21297
<u>Sales, kg:</u>				
Maize	0.0	0.00	0.00	0.00
Beans	1390	1390	0.00	0.00
Potatoes	0.0	0.00	0.00	0.00
Vegetables	59059	31002	0.00	0.00
<u>Consumption, kg:</u>				
Maize	1072	1072	1072	1072
Beans	270	270	270	270
Potatoes	502	502	502	502
Vegetables	998	998	998	998

Note: [1] Optimum plan- the farm plan generated using the traditional LP model i.e. where only a single objective, maximization of net cash income is optimized.

Table 4.36(b) A compromise solution set corresponding to L_∞ as the weights given to objective II (Z_2) is increased in relation to that of objective I (Z_1)

Component	Optimum plan[1]	Compromise solution set for L_∞		
		1:1	1:2	1:5
Maximization of net cash income (TAS):	1128572	571500	383930	195408
MOTAD (TAS):	-	260745	192976	124864
Land allocation, ha:				
Monocropping:				
Maize	0.00	0.00	0.00	0.00
Beans	0.00	0.00	0.00	0.00
Potatoes	0.25	0.25	0.25	0.25
Vegetables	3.00	1.43	0.93	0.42
Intercropping:				
Maize	0.80	0.80	0.80	0.80
Beans	1.45	1.45	1.45	1.45
Total land	5.50	3.93	3.43	2.92
Cleared land, ha:				
Vegetable land	1.40	0.00	0.00	0.00
Long-rain land	0.00	0.00	0.00	0.00
Short-rain land	0.00	0.00	0.00	0.00
Total cl. land	1.40	0.00	0.00	0.00
Fertilizer use, kg:				
Phosphorous	182	104	79	53
Nitrogen	538	274	189	103
W.Capital, TAS	218696	107923	78915	49761
Sales, kg:				
Maize	0.00	0.00	0.00	0.00
Beans	1390	1390	1390	1390
Potatoes	0.00	0.00	0.00	0.00
Vegetables	59059	27658	17506	7303
Consumption, kg:				
Maize	1072	1072	1072	1072
Beans	270	270	270	270
Potatoes	502	502	502	502
Vegetables	998	998	998	998

Note: [1] Optimum plan- the farm plan generated using the traditional LP model i.e. where only a single objective, maximization of net cash income is optimized

The choice of an efficient farm plan from the best-compromise solution set presented in Tables 4.35(a), 4.35(b), 4.36(a) and 4.36(b), is the sole responsibility of the decision maker. That is, in a given set of efficient farm plans, the acceptability of any particular solution to an individual farmer will depend on his preferences between the expected net cash income and the associated risk over time represented by his E-V utility function (Hazell 1971; Romero and Rehman 1985). For example a farmer may consider the first alternative to be more realistic because, although both the first and second alternatives satisfy household food demand, the first alternative enables the farmer to generate cash income with which to purchase marketable goods. Such an alternative, however, indicates that an increase in the expected net cash income is associated with an increase in risk level or net income variance. Further, such a choice increases pressure on farmlands with the consequence of accelerated deforestation. On the other hand a farmer who perceives the farming situation to be extremely risky, may decide to cultivate only enough to feed the family and generate cash income through other activities. Hence select the second alternative. This is especially true where seasonal employment opportunities are available. Seemingly, thus, the two solutions may be acceptable depending on the subjective preference and position of the farmer.

In real life, peasant farmers are somewhat risk takers due to limited options. They rely solely on farming activities for subsistence and cash income. There are limited opportunities for off-farm employment. Therefore, even when the situation is perceived to be risky, peasant farmers still pursue farming activities. The same line of argument was raised by Holden (1991) who observes that peasants in Northern-Zambia plant large farmlands even before they receive fertilizers which provide vital nutrient component for maize growth.

4.4.2 Concluding remarks

The results presented in this chapter have indicated that CP model can be used to produce a set of efficient farm plans using MOP framework. Unlike the traditional LP model which produces an optimum farm plan by optimizing a single objective, the CP model generates a set of efficient farm plans or best-compromise solution set which gives the decision maker a range of choices. This flexibility of choice offered by the CP model is obviously closer to reality than an optimum farm plan obtained by optimizing a single objective.

The sensitivity analyses have shown that increasing the weights, δ_j, of the net cash income maximization objective, results in the increase of net cash income as well as the associated risk or variance. Also the pressure on farmlands increases. This situation gives rise to clearing for more land hence an upsurge in the rate of deforestation. On the other hand, the results showed that an increase in the weights, δ_j, of the risk minimization (MOTAD) objective, produced the opposite effect. That is, the pressure on farmlands diminished hence the absence of deforestation. When peasant farmers assign greater weights to the second objective (risk minimization) relative to the first objective (maximization of cash income), they perceive the farming situation to be very risky. Thus the tendency is to minimize the area under crops because it is not profitable to use family labour for risky activities. In such a situation a farmer would strive to meet subsistence requirements as the overriding goal rather than attempting to maximize cash income.

The range of efficient farm plans or best-compromise solution set produced, notwithstanding, the selection of one choice in favour of the other solution is the responsibility of the decision maker based on his E-V utility function. The guiding criterion could be the weights assigned to the objectives which reflects the preference of the decision maker.

However, it may be said that the subjective weights and simulations used in the analysis were rather limited. Further, the factors influencing farmers decision and extent of deforestation are not only related to risk associated with over time variations of yield and product prices. The other risk factors are weather variability especially the amount and distribution of rainfall, unpredicted changes in government policies, such as, removal of subsidy on farm inputs and seasonal market fluctuations. Therefore it could be relevant to conduct more extensive analyses for the results to be not only conclusive but also more practical.

Finally the application of CP model in this study has indicated that risk aspects influence significantly land use and that the technique has high potential for application in land use planning due to its ability to handle multiple objectives. In fact the solutions algorithm used for solving CP model in this study is capable of compromising up to ten objectives simultaneously. Therefore, based on the performance of the technique, there is reason to encourage researchers to use compromise programming approach for land use planning problems.

4.5 An economic analysis of agroforestry farming system

The purpose of this section is to analyse agroforestry as an alternative to the existing farming systems in Lukozi Village. The main premise here is that agroforestry is more profitable in the sense that it utilizes more efficiently the available resources than the existing farming systems. Besides its high ecological value, agroforestry often has the advantage of using less resources while meeting the required level of outpu. (O'Kting'ati 1984). Further, it has been argued that agroforestry systems are less risky and less affected by variations in physical quantities compared to annual cropping systems (Arnold 1982; Harou 1983; Hoekstra 1985(b)). The analysis presented in this section relates to the economic aspects *viz* returns to labour and net present value of agroforestry system as they apply to Lukozi Village.

4.5.1 Description of potential agroforestry systems for Lukozi Village

The agroforestry system relevant for adoption in Lukozi Village is the "trees on croplands" system in which trees are spatially mixed with farm crops (Table 4.37). Under this system there are two potential farming systems that can be practised by the farmers, that of mixing trees with maize and beans; and trees mixed with maize and potatoes. Maize is included in both systems because it is an important cereal for the residents of Lukozi Village. The tree species considered for introduction in the agroforestry system is *Grevillea robusta* due to its ability to produce multiple products which include timber, poles and fuelwood, and has minimal shading effect on farm crops (own field survey and Lubango 1992; per. comm.).

Table 4.37 Possible cropping mixture under an agroforestry system.

T	M	B/P	T	B/P	M	T	B/P
B/P	T	M	B	T	B/P	M	T
M	B/P	T	M	B/P	T	B/P	M
T	M	B/P	T	M	B/P	T	B/P

Notes: T = trees
M = maize
B = beans
P = potatoes

The potential agroforestry systems for Lukozi Village are outlined as follows:

(i) *Grevillea robusta* + Maize + Beans - in which case nitrogen fertilizer application is not necessary due to the presence of beans which is a nitrogen fixing crop.

(ii) *Grevillea robusta* + Maize + Potatoes - in this case the application of fertilizer, in particular TSP is necessary. Also manure is applied during land preparation.

Trees and farm crops are grown according to an arrangement shown in Table 4.37. In both cropping mixtures beans and potatoes are planted twice each year since they are short-season growing crops. Maize is grown only once every year.

4.5.2 Cost-benefit analysis of agroforestry systems

In conducting cost benefit analysis for the agroforestry systems, there are some important aspects to consider, i.e., the choice of discount rate, pricing of family labour and land, determination of opportunity cost of other farm resources owned by the peasant household and valuation of farm outputs. A brief review of these aspects is, thus, considered appropriate before proceeding with cost benefit analysis.

For a private economic analysis, the rate of discount chosen is usually the marginal cost of money to the peasant farmer for whom the analysis is being done (Hoekstra 1985(b)). This is often the rate at which the farmer is able to borrow money. Otherwise, if the farmer uses his own capital or equity to finance the additional capital requirements the rate usually received on the equity capital may be used. Such a rate may be that made on bank deposits or on investments on or off-farm activities embodying a similar risk (*ibid*). If the alternative use of the resources results in cash or products used for family's own consumption (like on most subsistence farms), the "consumption rate of interest" is used (*ibid*). Such a rate measures the value of the farmer's willingness to forego or surrender part of the family consumption so that they can have it at some future date. The magnitude of value attached to future consumption depends on the extent of risk perceived by the farmer. There are two options to deal with risk, reducing the future net benefits (Harou 1983) and increasing the discount rate over and above the borrowing rate, rate on equity capital and rate on consumption foregone (Hoekstra 1985(a)). Some authors (Arnold 1982; Harou 1983) argue that agroforestry systems are less risky (less subject to variation in physical output) than annual cropping systems. If this view is accounted for, then the analysis of an agroforestry system could be made at a lower risk discount rate or lesser deductions from the expected future net benefits than the annual cropping system (Hoekstra 1985(a)).

For the purpose of this analysis, the private economic analysis procedure will be followed. Two discount rates will be applied. The first one is the real rate of discount (RRD) which is 10% (EIU 1992). This rate happens to fall in the range of 8 to 15% p.a. in real terms proposed by Gittinger (1982) for evaluating farming projects in developing countries. Second is the nominal discount rate which is 28% levied on borrowed capital by the Cooperative and Rural Development Bank (CRDB) [valid in 1992, Monji 1992 pers. comm.].

Another aspect is the valuation of family labour. In private economic analysis all labour which is hired is valued at its market price, while all family labour is valued at its opportunity cost (Gittinger 1982; Hoekstra 1985(a)). Such opportunity cost will differ depending on the time it is hired (i.e. peak season *vis-a-vis* off-season), the type of labour (skilled *versus* unskilled) and sex (male/female) (Hoekstra 1985(a)). For the sake of simplicity, most analysts use the hired labour wage rate as a *proxy* of the opportunity cost, increasing it by 25% under peak season and decreasing it by 25% under off-season conditions (*ibid*). In this analysis the opportunity of family labour was valued at the low wage rate paid to the employed labour force to the extent that peasant farmers are "unskilled". The rate used was 200 TAS per monday (based on the low scale wages valid in 1992).

Land is another aspect that requires attention. There are essentially two ways of valuing land in private economic analysis. In the first case land is valued at its purchase (market) price or if rented, the annual rent may be incorporated as an operating cost (Hoekstra 1985(a)). In the second case, the cost of land will depend on its productivity on its existing use. The less productive it is, the lower its cost because costs are determined by the opportunity cost principle i.e. the value foregone by the individual who uses it. The most common way of dealing with land cost if there is a change in existing land use is not to compute land cost separately, but to include it in the combined opportunity value to family resources in the non-agroforestry system (*ibid*). For the purpose of this analysis the cost of land will not be included because it is considered to be one of the "fixed family resources" and that the same land is used to evaluate all farming systems.

The formula used to compute the net present values in a private economic analysis is stated as follows (after Munasinghe 1992):

$$NPV = \sum_{t=1}^{T} \left[\frac{B_t}{(1+r)^t}\right] - \sum_{t=1}^{T} \left[\frac{C_t}{(1+r)^t}\right] \qquad [4.3]$$

where

NPV	=	net present value ($TASha^{-1}$)
B_t	=	annual returns (TAS) which accrue in year t, $t = 1,\dots,T$

r	=	discount rate (%) per annum
C_t	=	annual costs incurred in year t, $t = 1,....,T$

Other assumptions made were that of the use of constant prices, *Grevillea robusta* is used for poles thus a rotation of six years was assumed and hand tools were assumed to have a useful life of two years without scrap value. They were depreciated using the straight line method. Thus annual depreciation was computed as:

$$D = \frac{P-S}{L} \qquad [4.4]$$

where

D = annual depreciation, (TAS yr^{-1})
S = scrap value, (TAS)
P = purchase price, (TAS)
L = useful life, (TAS)

Finally it was assumed that the present cropping pattern continues over the six-year planning horizon.

The costs and revenues associated with raising *Grevillea robusta* are summarized in Tables 4.38 and 4.39. The costs and revenues for the farm crops used in the analysis were those presented in section 4.1.

Table 4.38 Costs of establishing *Grevillea robusta* (by 1990/91 prices)

Age, years	Type of activity	Costs, TASha^{-1}
0	Nursery plants	12,000
	Land preparation	2,000
	Construction of feeder tracks	5,000
	Planting	5,000
	Weeding	2,000
1	Weeding (twice)	2,000
2	Weeding (twice)	2,000
4	1st Pruning	2,000
	Construction of firelines	2,000
6	2nd Pruning	3,000
10	Marking for 1st Thinning	500
	1st Thinning	6,640
14	Marking for 2nd Thinning	500
	2nd Thinning	5,000
18	Marking for 3rd Thinning	500
	3rd Thinning	5,000
25	Clearfelling	4,000

Source: Magamba Forest Project Management Plan for 1991-1996/97

Table 4.39 Revenues generated by establishing *Grevillea robusta*

Year	Activity	Royalties[(1)] TAS/m^3	Volume m^{3}ha^{-1}	Revenues TAS ha^{-1}
10	1st Thinning	210	50	10,500
14	2nd Thinning	264	90	23,760
18	3rd Thinning	585	130	76,050
25	Clearfelling	700	355	248,500

Notes: [(1)] The royalty rates are based on The Forest Ordinance, Cap. 389, The Forest Amendment Rules ,1990, Government Notice No.399 (1990).
If a tree is sold as a pole of butt diameter > 15 cm the price is 15 TAS per pole *(ibid)*.

4.5.3 Analysis of labour returns and comparative evaluation

4.5.3.1 Returns to labour

The results of the return to labour analysis are presented in Tables 4.40 and 4.41. Return to labour criterion was used because labour is the most critical resource besides land. Therefore, a farming system can be more acceptable to a farmer if it can be accommodated by the available family labour. Based on the results, agroforestry system 1 has higher returns to labour than agroforestry system 2 in all years. If labour is the most limiting factor or resource, the returns to labour (in TAS per manday in this case) is the appropriate approach for the farmer because adoption of a farming system with higher returns to labour will most likely result in the highest cash income to the family household (Hoekstra 1985(a)). Based on this analysis, thus, agroforestry system 1 is more profitable than agroforestry system 2. Therefore, in case of labour scarcity agroforestry system 1 is most favoured by peasant farmers.

The major focus in this part of the analysis was family labour as a scarce resource. However, other factors of production such as land, working capital and market inputs may be limiting as well. At the same time, the opportunity cost of each owned farm resource in a subsistence oriented farming system may be difficult to ascertain separately (*ibid*). Thus, they are often combined by computing only the overall best net returns to family resources gross production less purchased inputs), hence referred to as family income in "without" situation (*ibid*). Also agroforestry, unlike the existing farming system is long-term oriented whereby the application of interest rate becomes necessary.

Table 4.40 Returns to labour for agroforestry farming system 1 in Lukozi village[1]

Item	Year					
	1	2	3	4	5	6
Costs:						
Cost of manure:						
Amount (kg)	5000	5000	5000	5000	5000	5000
Unit cost ($TASkg^{-1}$)	0.50	0.50	0.50	0.50	0.50	0.50
Total cost (TAS)	2500	2500	2500	2500	2500	2500
Pole harvesting cost (TAS):	-	-	-	-	-	7140
Other inputs (TAS):[2]	39725	24650	27725	24650	27725	24650
Total cost (TAS):	42225	27150	30225	27150	30225	34290
Revenues:						
Maize-Yield (kg)	600	600	600	600	600	600
Price($TASkg^{-1}$)	48	48	48	48	48	48
Returns (TAS)	28800	28800	28800	28800	28800	28800
Beans-Yield (kg)	330	330	330	330	330	330
Price($TASkg^{-1}$)	68	68	68	68	68	68
Returns (TAS)	22440	22440	22440	22440	22440	22440
Grevillea-Poles(no.)	-	-	-	-	-	672
Price(TAS/pole)	-	-	-	-	-	15
Returns (TAS)	-	-	-	-	-	10080
Gross returns(TAS)[3]:	51240	51240	51240	51240	51240	61320
Gross margins(TAS)[4]:	9015	24090	21015	24090	21015	27030
Labour (mandays:	46	29	29	29	29	49
Returns to labour (TAS/manday)	250	831	725	831	725	552

Note: [1] Agroforestry system 1: *Grevillea robusta* + maize + beans
[2] Other inputs: these are seeds/seedlings, chemicals and hand tools
[3] Gross returns = Maize returns + beans returns + tree returns
[4] Gross margins = Gross returns - total costs

Table 4.41 Returns to labour for agroforestry farming system 2 in Lukozi village[1]

Item	Year					
	1	2	3	4	5	6
Costs:						
Cost of manure:						
Amount (kg)	5000	5000	5000	5000	5000	5000
Unit cost (TAS kg^{-1})	0.50	0.50	0.50	0.50	0.50	0.50
Total cost (TAS)	2500	2500	2500	2500	2500	2500
Phosphorous:						
Amount (kg)	248	248	248	248	248	248
Price (TAS kg^{-1})	17	17	17	17	17	17
Cost (TAS)	4216	4216	4216	4216	4216	4216
Pole harvesting cost (TAS):	-	-	-	-	-	7140
Other inputs (TAS [2]:	36925	21850	24925	21850	24925	21850
Total cost (TAS):	43641	28566	31641	28566	31641	35703
Revenues:						
Maize-Yield (kg)	600	600	600	600	600	600
Price(TAS kg^{-1})	48	48	48	48	48	48
Returns (TAS)	28800	28800	28800	28800	28800	28800
Beans-Yield (kg)	550	550	550	550	550	550
Price(TAS kg^{-1})	40	40	40	40	40	40
Returns (TAS)	22000	22000	22000	22000	22000	22000
Grevillea-Poles(no.)	-	-	-	-	-	672
Price(TAS/pole)	-	-	-	-	-	15
Returns (TAS)	-	-	-	-	-	10080
Gross returns(TAS)[3]:	50800	50800	50800	50800	50800	60880
Gross margins(TAS)[4]:	7159	22234	19159	22234	19159	25177
Labour (mandays:	41	34	34	34	34	54
Returns to labour (TAS/mand.)	175	654	563	654	563	466

Note: [1] Agroforestry system 2: *Grevillea robusta* + maize + potatoes
[2] Other inputs: these are seeds/seedlings, chemicals and hand tools
[3] Gross returns = Maize returns + potato returns + tree returns
[4] Gross margins = Gross returns - total costs

4.5.3.2 Cost benefit evaluation

The results obtained using the NPV criterion for the agroforestry systems are presented on table 4.42. The results suggest that, at a discount rate of 10 and 28%, agroforestry system 1 consisting of *Grevillea robusta*, maize and beans, is more profitable than agroforestry system 2 which incorporates *Grevillea robusta*, maize and potatoes.

Table 4.42 Net present value for the agroforestry systems at Lukozi Village

Agroforestry system	Net present value at 10%	Net present value at 28%
System 1[(1)]	88653	53003
System 2[(2)]	80572	47883

Note: [(1)]Agroforestry system 1: *Grevillea robusta* + maize + beans
[(2)]Agroforestry system 2: *Grevillea robusta* + maize + potatoes

A numerical comparison shows that the net present value (NPV) of agroforestry system 1 are 88,653 and 53,003 TAS ha^{-1} at discount rates of 10 and 28% per annum respectively whereas the corresponding figures for the agroforestry system 2 are 80,572 and 47,883 TAS ha^{-1} (Table 4.42).

If land and family labour are limited resources, the farmer may choose agroforestry system 1 in favour of agroforestry system 2. This seems to be a reasonable option because maize is a staple cereal, beans are a source of protein and *Grevillea robusta* offers multiple products (main product in this case being poles) for the farmer.

Comparative results presented in Table 4.43 indicate that vegetable monocropping farming system, with a net present values of 1,334,540 and 841,990 TAS ha^{-1} at discount rates of 10 and 28%, is more profitable than the other farming systems. This is followed by the intercropping systems. The "maize/beans and beans" intercropping system has a net present values of 341,440 and 216,000 TAS ha^{-1} at discount rates of 10 and 28% as compared to 226,980 and 143,490 TAS ha^{-1} by the maize/beans farming system (Table 4.43). These results suggest that vegetable monocropping system is the most profitable followed by intercropping systems, which implies that the introduction of agroforestry is not profitable. On the other hand it may be argued that, private economic analysis underestimates the overall benefits of the agroforestry farming systems to the extent that only marketable products are considered. Trees have high ecological values such as maintenance of soils fertility which can hardly be measured at market prices. Furthermore the only product considered in this analysis is pole, a much cheaper product compared to sawntimber which *Grevillea robusta* is capable of producing once it is allowed to reach financial maturity. Therefore the economic profitability computed in this analysis may be lower than the combined social and ecological value of agroforestry systems especially in those areas with considerable problems related to fuelwood and land degradation.

Table 4.43 Net present value (NPV) for the farming systems at Lukozi Village (TASha^{-1})

Farming systems	Net present value at 10%	Net present value at 28%
Monocropping systems:		
Maize	153690	97050
Beans	126150	79600
Potatoes	111600	70380
Vegetables	1334540	841990
Intercropping systems:		
Maize/beans+beans	341440	216000
Maize+beans	226980	143490
Agroforestry systems:		
Grevillea+maize+beans	88650	53000
Grevillea+maize+potatoes	80570	47880

Note: (1)These values were truncated to the nearest tenth figure (digit)

The results of this analysis indicated some of the limitations of private economic analysis on subsistence farming systems where factors of production are fixed family resources. Thus it could be more realistic to include non market goods via shadow prices in analyzing farming systems when the available data permits (Hoekstra 1985(a)).

4.6 Assessment of soil productivity

4.6.1 General overview

The declining trend in agriculture production in Tanzania is threatening not only the welfare of the peasant farmers but also the economy of the entire country which is agro-based. This observation is based on doubts over the sustainability of the present farming practises in Tanzania. Sustainable agriculture depends on soils with sustainable productivity (Mnkeni 1987, 1992). On the other hand sustaining soil productivity relies upon proper soil management in particular those practises associated with replenishment of soil nutrients and maintenance of adequate organic matter content.

Several studies have shown that the supply (input) relative to removals (output) of soil nutrients is a key factor in judging the sustainability and potential for improvement of any farming system (Mnkeni 1987; Quresh 1987; Twyford 1988; Haule *et al.* 1989). Therefore it is most likely that the sustainability of a farming system is influenced by those factors which either directly or indirectly affect the input and output of soil nutrients necessary for supporting crop growth. It is an optimal balance between input and output that *actually* determines the sustainability of a farming system (Mnkeni 1992).

Therefore a prerequisite for assessing the viability of farming systems is to determine the extent of disparity between removals and replenishment of soil nutrients. Thus, the purpose of this chapter is to examine the sustainability and potential for improvement of farming systems, monocropping, maize/beans and agroforestry systems, practised by peasant farmers in Lukozi Village based on the assessment of soil productivity. This analysis will be based on both field and secondary data sources.

4.6.2 The concept of land productivity and soil fertility

Land productivity is defined as "the capacity of land to support the growth of useful plants, including crops, trees and pastures on a sustained basis" (Young 1989). Land productivity is not only a property of soil but of land in general embodying those features of the physical environment which have a bearing on the potential for the use and improvement of land (Young 1989; Stoorvogel and Smaling 1990; Mnkeni 1992). Examples of factors of the environment that influence land (soil) productivity are climate, hydrology, vegetation and fauna (*ibid*). In essence, therefore, soil productivity is determined by an integration of all pertinent factors.

Soil fertility is defined as "the capacity of soil to support the growth of plants, on a sustainable basis, under given conditions of climate and other properties of land" (Young 1989). The term "sustainable basis" implies the ability of the soil to support plants on a continuous basis. Decline in soil fertility *ceteris paribus* is observed through decrease in crop yields (Young 1989). The decline in soil fetility causes soil degradation which substantially reduces the response of crops to the application of mineral fertilizers and other inputs (*ibid*). Poor response lowers the economic margin of fertilizer application, tending to perpetuate the situation of low inputs with low outputs. In such a situation, the farming system becomes less profitable and jeopardises its sustainability. A conceptual framework linking soil fertility and other relevant parameters is shown in Figure 4.2.

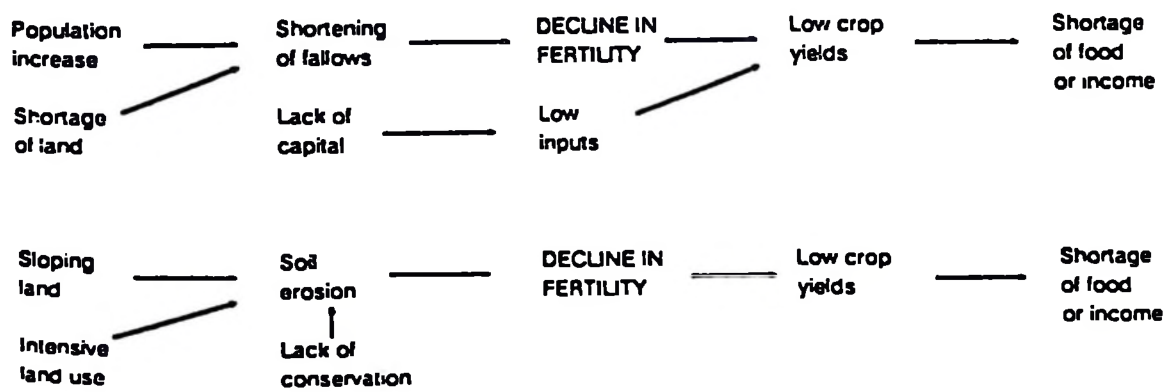


Figure 4.2. Chains of cause and effect linked to decline in soil fertility (adopted from Young 1989)

4.6.3 Soil parameters which influence productivity

Soil productivity is determined, *inter alia*, by physical properties, nutrient content, climate, hydrological situation, landforms, vegetation and fauna (Young 1989; Stoorvogel and Smaling 1990; Mnkeni 1992). The effect of these factors on crop yield is variable, but the discussion in this section will dwell only on physical properties and plant nutrient content of the soil, i.e., all other factors are assumed to be constant.

4.6.3.1 Soil physical properties

Soil physical properties form a single, interactive complex, which determines the degree of aggregation between particles and the volume and size distribution of pores (Young 1989). Aggregation and pore scale determine structure, consistence, bulk density and porosity. These attributes are linked to available water holding capacity, permeability, soil drainage and resitance to erosion (Young 1989). A well developed soil structure enhances tillage, provides favourable conditions for development of fine feeder roots and mycorrhizae thereby increasing the efficiency of nutrient uptake (*ibid*).

The factors which influences the physical properties of soil includes the type of clay minerals present and the amount of organic matter which supplies the natural gums that bind soil particles together. It is argued that the opportunity to influence physical properties through management, lies largely through maintenance of soil organic matter (Young 1989; Mnkeni 1992).

However, the effect of organic matter in maintaining soil fertility depends on the type of land use system (Young 1989). Under all land use systems organic matter maintains good physical conditions, including water holding capacity. Under low-input systems organic matter provides a balanced supply of nutrients, protected against leaching until released mineralization. Under medium- and high-input systems organic matter leads to more efficient use of fertilizers through improved cation exchange capacity (c.e.c), greater recycling and supply of micronutrients. The maintenance of adequate organic matter content produces favourable physical properties of the soil whereas its loss leads to their degradation and where serious can lead to consequences such as capping, compaction or pan formation (Young 1989). There is evidence that the degradation of physical properties of soil can reduce crop yields, and where severe it can lead to "formation of crusts, reducing infiltration, decreasing erosion resistance and hindering germination of seedling" (Lal 1989).

4.6.3.2 Plant nutrients

Plant nutrients are classified into macronutrients and micronutrients. The macronutrients are further divided into primary macronutrients and secondary macronutrients (Chapter 4). In this chapter the main concern is on primary macronutrients, nitrogen (N), phosphorous (P) and potassium (K). Nitrogen and phosphorous are most frequently the limiting nutrients in tropical soils (Stoorvogel and Smaling 1990).

In many situations there is initial tendency towards favourable response to the application of nitrogen fertilizer. Phosphorous deficiency commonly appears after a few years of cultivation when initial soil supplies become depleted. Potassium is less commonly limiting, except in situations where root crops are planted.

4.6.4 Pathways of soil nutrient losses

Low soil fertility is the consequence of nutrient loss through various pathways (or outputs). The common pathways of nutrient losses are harvested products, crop residues, leaching, gaseous and erosion losses (Stoorvogel and Smaling 1990). There are substantial amounts of nitrogen, phosporous nutrients which are held in the plant biomass (in both harvested product and residues) that are removed during harvesting (Table 4.46). It has been observed that the attitude of farmers towards utilizing crop residues differ greatly within and between locations (Stoorvogel and Smaling 1990). The nutrients removed with residues may be complete, if used for fuel, roofing or manufacturing, and incomplete if grazed or burned. In many villages of the West Usambaras, burning is a common practise, as a cheap method of clearing farmlands.

Leaching is a significant loss mechanism for some nutrients only. In tropical soils, phosphorous is often tightly bound by soil particles therefore relatively difficult to leach compared to nitrogen and potassium (Stoorvogel and Smaling 1990). Gaseous loss is especially important for nitrogen nutrient which is lost through essentially two processes, denitrification and volatilization (Stoorvogel and Smaling 1990). Denitrification is a process which takes place under anaerobic (limited O_2) conditions. Nitrogen loss through the denitrification process is especially great in wet climates, on highly fertilized and clayey soils and for crops with relatively small amounts of nitrogen (Stoorvogel and Smaling 1990). Ammonia volatilization is a gaseous loss mechanism and is very significant in alkaline environments. However such soils are not common in sub-Saharan Africa, therefore gaseous loss is not that important (*ibid*).

Nutrient loss through erosion is accounted for by the eroded top soil which is most often rich in nutrients and organic matter. To the extent that the finest soil particles are the first to be dislodged during erosion, eroded material tends to contain more nutrients than the original soil (Shenkalwa 1989; Stoorvogel and Smaling 1990). In this chapter nutrient loss pathways assessed were removal through harvested product, crop residues and though soil erosion. Earlier studies showed the three pathways to be the most important ones for the West Usambaras (Ngatunga 1981: Shenkalwa 1989).

4.6.5 Methods of replenishing soil nutrients

The methods which are used to replenish soil nutrients include the application of fertilizers, manuring, deposition, biological nitrogen fixation and sedimentation (Stoorvogel and Smaling 1990). The application of fertilizers is considered to be the most rational method of compensating the nutrient loss, at least in the short run (Mnkeni 1992). In the medium- and long-run, however, adequate manuring and improvement of the existing farming systems may be more desirable alternatives. Usually the nutrient content of commercial mineral fertilizers is specified. On the other hand the chemical composition of fresh manure is variable depending on its nature and moisture content (Stoorvogel and Smaling 1990).

Considerable amounts of nutrients are supplied to the soils by processes of wet and dry depositions (*ibid*). Atmospheric nitrogen (N_2) is an important source of nitrogen in several farming systems. Leguminous species and wetland rice draw considerably from this source (*ibid*). The exact nutrient content in sedimentation is yet to be established. In this report only three techniques, application of mineral fertilizers, manuring and biological nitrogen fixation will be considered when assessing soil productivity for farming systems practised at Lukozi Village.

4.6.6 Soil nutrient status in Lukozi Village

The status of essential soil nutrient elements in Lukozi Village is presented in Table 4.44.

Table 4.44 Soil nutrient situation at Lukozi Village

Soil characteristic	Actual value	Critical value
$pH_{(w)}$	7.10	-
Organic carbon (%)	6.28	-
Available P (ppm)	4.20	15.0
Available N (ppm)	0.27	-
Exchangeable K (m.e./100g soil)	0.50	0.20
Exchangeable Ca (m.e./100g soil)	15.60	4.50
Exchangeable Mg (m.e./100g soil)	2.70	2.00
Other soil properties:		
Cation exchange capacity (m.e.)	19.30	-
Particle sizes (%):		
sand	65.20	-
silt (loam)	13.20	-
clay	21.60	-
Textural class	SCL	-

Source: Own field data
Key; P = phosphorous, N = nitrogen, K = potassium, Ca = calcium,
Mg = magnesium, ppm = parts per million, m.e. = milligramme equivalent,
SCL = sand-clay-loam

It can be seen from the table that the soil situation is deficient in phosphorous (P). Also high content of sand, makes the soil moderately to well drained soil. The average slope on most farmlands is 10-15%, but due to rapid rolling terrain the soil is prone to serious erosion.

4.6.7 The potential and effect of soil erosion

Due to the presence of rolling steep terrain in the Lukozi area, the farmlands are prone to serious soil erosion. The potential hazard of soil erosion has been aggravated by the tendency of the farmers to clear trees on steep slopes. Clearing of trees exposes the soil to strong impact of rain drops, thereby increasing the risk of serious erosion (Shenkalwa 1989). Several factors, besides tree cover, such as rainfall intensity, soil type, slope characteristics, soil cover and management are known to influence soil erosion (Hudson 1977; Scheinmann 1986; Lal 1989).

The principle adverse effect of soil erosion is lowering of soil fertility through removal of organic matter and nutrients in the eroded material. The continuous removal of nutrients and organic matter causes low soil ferility which results into land degradation (Scheinmann 1986; Young 1989). The extent of land degradation is reflected by a decline in crop yields (Mnkeni 1992). In addition, low soil fertility cannot support plant growth on a sustainable basis (*ibid*).

4.6.8 Potential techniques for controlling soil erosion in West Usambaras

In controlling soil erosion, the slope characteristics, soil cover and management factors are the easiest to control (Shenkalwa 1989; Mnkeni 1992). The effect of soil cover and management factors on erosion of the soils in West Usambara mountain slopes were studied by Ngatunga (1981) and Shenkalwa (1989). The study by Ngatunga (1981) showed that bare fallow lost the highest amount of soluble nutrients ranging from 4.5 to 8.9, 4.0 to 7.0 and 3.0 to 4.2 kg $ha^{-1}yr^{-1}$ of calcium, magnesium and potassium respectively. Phosphorous losses were as low as 0.7 to 1.0 kg $ha^{-1}yr^{-1}$. In light of the inherently low fertility of soils in West Usambaras, these losses are considerable. This indicates the importance of proper soil cover.

The results, further, showed that sediments lost from the bare and ploughed treatments were of a coarser texture compared to those of the mulched and natural grass treatments (Ngatunga 1981). This observation is an additional evidence that adequate and proper soil cover is important in order to reduce the effect of soil erosion.

In an effort to combat soil erosion SECAP proposed two techniques, that were considered to have great potential for controlling soil erosion, construction of macro contour lines (mcls) which were planted with strips of a fodder bush, a creeper, grass and fruit trees; intercropping and the extensive use of farm yard manure (Scheinmann 1986; Woytek *et al.* 1987). The initial perception was that strips of shrubs of wooy perennials were likely to be more effective in soil and water conservation than single hedge rows (Shenkalwa 1989), but there is an optimum spacing for soil ersion control and yield of annual food crops which must be maintained (Lal 1989). Yield of annual crops are regularly assessed by SECAP personnel whereas the effect of macro contour lines was assessed by Shenkalwa (1989). The assessment covered three pilot villages, Ubiri, Nywelo and Silviculture Station plots. A summary of the effects of macro contour lines is presented in Table 4.45. These results are of considerable importance in controlling soil in the Lukozi area which fall in the same agroclimatic zone as the pilot villages.

The results in Table 4.45 show a substantial difference in soil properties between the plots with and without macrocontour lines at Silviculture Station. Less variation was shown for the soil at Ubiri village, which falls in the same agroclimatic zone. However, the macrocontour lines were observed to have the improvement effect on organic matter, exchangeable potassium (K^+) and magnesium (Mg^+) (Table 4.45). The accumulation of organic matter improves soil porosity hence water drainage and increased soil cation exchange capacity which leads to more efficient use of fertilizers (Mnkeni 1992, pers. comm.). These results signify the fact that macrocontour lines are not only important in controlling erosion, which was considerable, but also in influencing nutrient content and physical properties of the soil which are important for crop growth. However, macrocontour lines may cause a decrease in crop yields once planted close to them (Shenkalwa 1989) implying that proper spacing is important.

Table 4.45 Effects of macrocontour lines (mcls) on soil properties four years after establishment

Soil characteristics	Village					
	Silviculture Stat.		Ubiri		Nywelo	
	+mcl	-mcl	+mcl	-mcl	+mcl	-mcl
Soil composition(%):						
Clay	39	33	51	48	48	35
Sand	50	54	40	42	35	45
Silt	11	13	9	10	17	20
$pH_{(w)}$	5.7	4.9	6.4	6.3	6.5	6.8
Organic carbon (%)	4.5	4.6	2.8	2.4	3.9	5.7
Exchangeable base (m.e./100g soil):						
Potassium (K^+)	0.3	0.1	0.3	0.1	0.8	0.8
Calcium (Ca^+)	5.1	1.6	3.8	3.7	8.0	9.5
Magneasium (Mg^+)	1.3	0.7	2.8	2.0	4.8	6.0

Source: adapted with some modifications from Shenkalwa (1989)
+mcl = with macrocontour lines
-mcl = without macrocontour lines

A traditional technique practised by the Shambaa people to reduce erosion and general maintenance of soil was the establishment of guatemala grass (*Tripsacum laxum*) and *Canna edulis* along the contour (Woytek *et al.* 1987). The technique has dual advantage, the contour plants while reducing erosion and maintaining soil properties, also serve as feed for livestock (*ibid*). Furthermore the method is cheap, easy to apply and more socially acceptable to the local people (pers. observ.). The effectiveness of the traditional technique has not been evaluated in a scientific manner, but experience has shown that when properly spaced the contour plants have considerable positive effects in maintaining and improving soil properties.

Nutrient losses are not limited to erosion processes only but to other pathways as well. One such pathway is the loss of nutrients through crop harvesting. The feature that makes this pathway so important is the fact that it removes nutrient in larger quantities than the combined amount removed through the other pathways (Stoorvogel 1990; Mnkeni 1992). In the next section an assessment is made on the nutrient removals through crop harvesting from soils under three farming systems, monocropping, maize/beans intercropping and agroforestry systems. These farming systems are practised in the Lukozi area and other parts of the West Usambaras.

4.6.9 Assessment of nutrient removals through crop harvesting

The farming systems assessed in this report are monocropping, maize/beans intercropping and agroforestry systems. The major crops involved in the analysis were maize, beans, potatoes and vegetables. The only agroforestry tree included was *Grevillea robusta*. However, due to absense of data on *Grevillea robusta* under agroforestry, *Leucaena leucocephala* was used to derive proxy assessment.

4.6.9.1 Soil nutrient removal from land under monocropping system

In this analysis an assumption was made that peasants produce at low-input management system. The same observation was made by Mnkeni (1992) that "most farming systems in Tanzania operate at low management level". However for the purpose of comparison, both minimum and maximum values will be indicated whenever applicable. The baseline data used for computing removals through crop harvesting are summarized in Table 4.46. These are general data, therefore slight variation may be expexted due to differences in local soil and climatic conditions.

Table 4.46 Nitrogen, phosphorous and potassium content of harvested crops (kg t^{-1} of harvested crop)(1)

Crop	Harvested product			Crop residues(2)		
	N	P	K	N	P	K
Maize	16.8	9.4	5.7	7.6-11.8	3.0-5.8	23-28
Potatoes	4.4	3.0	8.3	2.3	1.6	5.4
Pulses(3)	20.0	7.8	13.3	10.4	2.3	15.7
Vegetables	9.0	2.1	3.1	3.2	3.2	9.4
Fodder	6.8	3.0	5.7	0.0	0.0	0.0

Notes: (1)Extracted from table 3.7 in Stoorvogel and Smaling (1990)
(2)Where a range is indicated minimum and maximum values apply to low and high management levels respectively.
(3)Beans are included in this group

Nutrient removals were computed using the following relationship:

Nutrient removal (kg ha^{-1}) = [actual harvest (kg ha^{-1})] x [Nutrient content (kg t^{-1})]

Based on these calculations the actual nutrient removals through harvested crops grown under monocropping system are presented in Table 4.47. It may be seen from the table that harvesting of maize removes 22.5, 12.6 and 7.6 kg ha^{-1} of nitrogen (N), phosphorous (P) and potassium (K) respectively (excluding residues). This rate of removal translates into a loss of 38.3, 21.4 and 12.9 kg of nitrogen, phosphorous and potassium nutrients respectively for an average household farm of 1.7 ha at Lukozi village (assuming the entire land area is planted with maize). The method currently used to compensate for nutrient removals (loss) is the application of fertilizers, triple super phosphate (TSP) and sulphate of ammonia (SA) meant to supply phosphorous and nitrogen nutrients respectively. In one regime the rates applied are 124 and 200 kgha^{-1} of TSP and SA fertilizers respectively. The nutrient content is 20 and 21% by weight for TSP and SA fertilizers respectively. Thus, in essence, the present regime supplies 24.8 and 42 kgha^{-1} of phosphorous and nitrogen nutrients respectively in a single application. The method of applying of SA is top dressing hence more prone to loss through leaching and gaseous pathways (Mnkeni 1992).

Table 4.47 Nutrient removals by crops planted in monocropping system (kg ha^{-1})

Crop	Yield	Harv. product			Crop residue			Total nutrient		
		N	P	K	N	P	K	N	P	K
Maize	1340	22.5	12.6	7.6	10.2	4.0	30.8	32.7	16.6	38.4
Beans	603	12.1	4.7	8.0	6.3	1.4	9.5	18.4	6.1	17.5
Potat.	1000	4.4	3.0	8.3	2.3	1.4	5.4	6.7	4.6	13.7
Veget.	10000	90.0	21.0	1.0	32.0	32.0	94.0	122.0	53.0	125

Harvesting of beans removes 12.1, 4.7 and 8.0 kg ha^{-1} of nitrogen, phosphorous and potassium respectively (excluding residues) (Table 4.47). Such a removal translates to a loss of 20.6, 8.0 and 13.6 kg of nitrogen, phosphorous and potassium nutrients respectively for an average household farm of 1.7 ha (assuming the entire land area is planted with beans). In bean growing only farm yard manure is applied to replenish soil fertility. The present application is 5 t ha^{-1} of farm yard manure. The nutrient content of farm yard manure is 0.48% N, 0.17% P and 0.54% K (Stoorvogel and Smaling 1990). Thus the application of 5 t ha^{-1} would contain 24.0, 8.5 and 27.0 kg of nitrogen, phosphorous and potassium nutrients respectively. This may seem to be a reasonable method of compensating nutrient losses. However, farm yard manure has one serious technical limitation. It takes fairly long time to release all the nutrients required for crop growth (Mnkeni 1992). The relatively short rotation of bean crop implies that nutrients are removed faster than they can be replenished. Furhtermore, beans are planted twice each year whereas farm yard manure is applied only once during the long rains season, hence more nutrients are removed.

Potato harvest removes 4.4, 3.0 and 8.3 kg ha^{-1} of nitrogen, phosphorous and potassium respectively (excluding residues) (Table 4.47). This amounts to a loss of 7.5, 5.1 and 14.1 kg of nitrogen, phosphorous and potassium nutrients respectively for an average farm size of 1.7 at Lukozi village (assuming the entire land is planted with potatoes). When potatoes are planted as monoculture stands, triple super phosphate and farm yard manure are applied. The rate of application is 124 kg ha^{-1} and 5 t ha^{-1} of TSP and farm yard manure respectively. In essence such a regime adds 24.0, 33.3 and 27.0 kg ha^{-1} of nitrogen, phosphorous and potassium nutrients respectively. If the regime is maintained it can sustain production for at least five years.

Vegetable harvesting removes 90.0, 21.0 and 31.0 kg ha^{-1} of nitrogen, phosphorous and potassium nutrients respectively (excluding residues) (Table 4.47). Such a removal translates into a loss of 72.0, 16.8 and 24.8 kg of nitrogen, phosphorous and potassium nutrients respectively for an average household farm of 0.8 ha in Lukozi village planted with vegetables (normally such plots are located in valley floors with a slope of < 10%). Vegetable growing entails the application of farm yard manure, TSP and SA fertilizers. In sum such a regime supplies 66.0, 33.3 and 27.0 kg ha^{-1} of N, P and K nutrients respectively. Considering the removals through crop harvesting such a regime cannot compensate fully for the lost nutrients. Therefore long term production on the area is likely to be affected by low soil fertility.

4.6.9.2 Nutrient removals under maize/beans intercropping system

Nutrient removals through crop harvesting when maize is intercropped with beans were computed on the basis of nutrient content in harvested product (Table 4.46). The results are shown that under intercropping maize and beans in combined effect removes a total of 31.2, 15.5 and 14.1 kg ha^{-1} of N, P and K nutrients respectively (Table 4.48). This translates to a total loss of 53.0, 26.4 and 24.0 kg ha^{-1} of N, P and K nutrients respectively from an average household farm of 1.7 ha in Lukozi Village.

The recommended fertilizer regime for maize/beans intercropping system is 50 kg N and 20 kg P per hectare for maize and 30 kg P per hectare for beans (Harrop and Samki 1984). However, at present the peasant farmers use farm yard manure only at an application rate of 5 t ha^{-1} which supplies an equivalent of 24.0, 8.5 and 27.0 kg ha^{-1} of N, P and K nutrients respectively. Compared to the nutrient uptake and subsequent removals in the maize/beans intercropping system, such a regime supplies not only below the recommended rates but also less than the plant nutrient requirements. The long term consequence in the long term is a decline in soil fertility which is most likely to affect crop production.

Table 4.48 Nutrients removed by harvesting crops planted under intercropping system in Lukozi Village (kg ha^{-1})

Crop	Yield	Harvested product			Crop residues			Total nutrient		
		N	P	K	N	P	K	N	P	K
Maize	1206	20.3	11.3	6.9	9.2	3.6	27.7	29.5	14.9	34.6
Beans	543	10.9	4.9	7.2	5.7	1.3	8.5	16.6	5.5	15.7
Total	-	31.2	15.5	14.1	14.9	4.9	36.2	46.1	20.4	50.3

It is often argued that the maize/beans system has the advantage of contributing to the nitrogen economy to the extent that beans are nitrogen fixing plants (Samki and Harrop 1984; Mnkeni 1987). However the contribution may not be realized because harvesting is often done by pulling the whole bean plant including roots (pers. obs.) thereby removing the root nodules responsible for nitrogen fixing. Removal of the entire plant increases the amount of nutrients lost to 46.1, 20.4 and 50.3 kg ha^{-1} of N, P and K nutrients respectively under the maize/beans intercropping system. Due to inherently low fertility and poor soil maintenance practises such nutrient losses are considerable.

4.6.9.3 Nutrient removals under agroforestry system

Agroforestry is a system which is gaining popularity because of its potential in not only supporting crop production but also in providing wood-based materials required by the rural people. In West Usambaras, the practise of agroforestry is not entirely new. The local people have been practicing agroforestry in a traditional way. Therefore, all that is needed is to study the practise and propose more meaningful improvement. One of the areas where local people seem to lack adequate skill is the choice of appropriate agroforestry trees. Appropriate in the sense that it must have socio-economic potential and be biologically compatible with farm crops.

The people of Lukozi village, based on their own past experience, have high preference for *Grevillea robusta* (locally known as *Mchongoma*). *Grevillea robusta* is widely grown as a shade tree and planted on soil-conservation structures. The tree has moderately slow litter decay although such feature has no adverse effect on soil fertility (Neumann 1983).

In traditional agroforestry practises trees were plated in hedgerows. In todays, mixed stands the tendency is to plant trees along with food crops especially maize, beans and potatoes. Thus in this analysis we examine nutrient output and input for "mixed stands" of *Grevillea robusta*/maize/beans and *Grevillea robusta*/maize/potatoes. There is no data available for this analysis regarding the nutrient content in the above-ground biomass of *Grevillea robusta*. However, in order to provide an insight into the tree/crop association in relation to nutrient balance, this analysis will make use of data on *Leucaena leucocephala* in Maghembe, Kaoneka and Lulandala (1986). It may as well be observed that *Leucaena leucocephala* is a potential agroforestry tree to the West Usambaras especially in the lower altitudes. The nutrient accumulation in the above-ground biomass of *Leucaena leucocephala* are 201.0, 25.1 and 267.0 kg ha^{-1} of N, P and K nutrients respectively for 4-year old trees (Maghembe, Kaoneka and Lulandala 1986).

Based on the forgoing information, the nutrient contents of maize, beans and potatoes were computed according to the technique described in section 4.6.6.1. The results are summarized in Table 4.49. Under the first agroforestry rotation trees are mixed with maize and beans. The nutrient uptake is 16.7, 8.2 and 7.8 kg ha^{-1} of N, P and K nutrients respectively on the harvested product. This removal translates to a loss of 28.4, 13.9 and 13.3 kg of N, P and K nutrients respectively in an average household farm of 1.7 ha in Lukozi Village.

In the second agroforestry system, trees are mixed with maize and potatoes. Under this system the nutrient uptake was 12.5, 7.3 and 8.0 kg ha^{-1} of nitrogen, phosphorous and potassium respectively (Table 4.49). Such removals amount to a total loss of 21.3, 12.4 and 13.6 kg of N, P and K nutrients respectively on an average household farm of 1.7 ha in Lukozi Village. Owing to the presence of trees, nutrient cycle under agroforestry is quite different from monocropping and maize/beans intercropping systems. For instance, litter fall from trees returns nutrients stored in above-ground biomass to the soil. Also nutrients accumulating on the tree biomass are held for a considerable period of time unlike in the monocropping and maize/beans intercropping systems where nutrients are removed annually by crops during harvesting. Furthermore trees minimize losses through soil erosion because the canopy breaks the strong impact of rain drops, litter fall increases organic matter content and roots improve soil porosity thereby reducing surface run-off. Therefore it requires a detailed study to establish the "net nutrient losses" under agroforestry systems as well realizing the fact that trees can have some negative effects on soil properties and crop growth (Young 1989).

Table 4.49 Nutrients removed by harvesting crops planted under agroforestry systems (kg ha^{-1})

Crop	Yield	Harvested product			Crop residues			Total nutrients		
		N	P	K	N	P	K	N	P	K
Maize	600	10.1	5.6	3.4	4.6	1.8	13.8	14.7	7.4	17.2
Beans	330	6.6	2.6	4.4	3.4	0.8	5.2	10.0	3.4	9.6
Potat.	550	2.4	1.7	4.6	1.3	0.9	3.0	3.7	2.6	7.6

The negative effects of trees include loss of organic matter and nutrients in tree harvest, competition for moisture and nutrients between trees and crops thereby reducing crop turnover, production of substances which inhibit germination or growth of crops (a condition known as allellopathy) and acidification by trees which produce mor-type humus (Maghembe, Kaoneka and Lulandala 1986; Young 1989). In fact trees of *Eucalyptus spp*. are widely known for their "drying effect" on moist soils. On the hand this property may be looked upon as an advantage as the drying effect of *Eucalypatus spp*. has been exploited to "reclaim" swampy areas for agriculture. Also nutrient removal through tree harvesting may be substantial. For instance harvesting the aerial biomass of *Leucaena leucocephala*, in essence, removes a total of 201.0, 25.1 and 267 kg ha^{-1} of nitrogen, phosphorous and potassium nutrients respectively (Maghembe, Kaoneka and Lulandala 1986). Furthermore the tree is fast growing and can be harvested for fodder and fuelwood in three years after establishment. Such frequent harvests removes some nutrients such that the contribution of trees to soil nutrient economy may be low. It is the complexity of an agroforestry system which poses challenge to its wide scale adoption as an alternative to traditional agriculture systems (O'kting'ati 1984; O'kting'ati and Kessy 1991). Finally, the effectiveness of trees in reducing soil erosion depends on climate, slope and soil cover and where these factors are adverse the effectiveness is minimal (Young 1989).

The maintenance of soil properties enhances, *inter alia*, the sustainability of agriculture systems which is influenced by the optimum balancing of input and output of soil nutrients that are limiting to crop growth. An assessment on the sustainability of monocropping, maize/beans intercropping and agroforestry farming systems is presented in section 4.6.10.

4.6.10 Assessment of the sustainability of the farming systems in the Lukozi area

The purpose of this section is to present an assessment (based on the analysis in section 4.6.9) regarding the sustainability and potential for improvement of the farming systems *viz* monocropping, intercropping and agroforestry systems as they are practised in the Lukozi area, and elsewhere in the West Usambaras. Trend and time series data were not available, therefore a *proxy* will be made on the basis of potential nutrient depletion through crop removals and soil maintenance practises.

4.6.10.1 Sustainability and potential for improvement of monocropping farming system

The monocropping farming system embody maize, beans, potatoes and vegetables. Nutrient removal data shown in Table 4.47 indicate that the four crops remove quite a substantial amount of nutrients during harvesting. For example a modest harvest of maize removes a total of 32.7, 16.6 and 38.4 kg ha^{-1} of N, P and K nutrients respectively, potatoes remove 6.7, 4.6 and 13.7 kg ha^{-1} of N, P and K nutrients respectively, beans remove 18.4, 6.1 and 17.5 kg ha^{-1} of N, P and K nutrients respectively and vegetables remove 122, 53.0 and 125.0 kg ha^{-1} of N, P and K nutrients respectively. Considering the inherently low fertility of the soil in the Lukozi area these removals were considerable.

Thus, there is a need for remedial measure to improve the current soil maintenance practises is necessary in order to make the monocropping farming system sustainable. At present scarcity of land at Lukozi village which means the opportunity for expanding the existing farm land is limited. Therefore, the remaining "viable" option is to apply fertilization regimes using the recommended rates. This, in essence implies the intensification of the present farming system. An added advantage is that the four crops maize, beans, potatoes and vegetables respond favourably to fertilizer application (Samki and Harrop 1984; Scheinmann 1986; Stoorvogel and Smaling 1990).

The application of optimum fertilization regimes to maize stands, *ceteri paribus*, increases crop production considerably, i.e., productivity index increases from 24 to 150 (Deckers *et al.* 1990). [Note: Productivity index is expressed in kg yield increase per kg of nutrient applied (Mnkeni 1992)]. This observation implies that there is considerable potential for increasing soil productivity in maize monocropping farming system by applying recommended fertilizer regimes.

Optimum application of nitrogen and phosphorous fertilizers to bean stands results in a substantial increase in bean yields (Swai *et al.* 1991). The effect of optimum fertilizer application results into productivity indices ranging from 8.3 to 12.1 (Deckers *et al.* 1990). Thus proper application of fertilizer and manure can sustain and improve the bean monocropping system.

Optimum fertilizer application for potatoes results into a substantial increase in yields with a productivity indices in the range of 80 to 153 (Deckers *et al.* 1990) thereby increasing the economic returns to the farmer. There is, of course, the issue of poverty. Mineral fertilizers are fairly expensive relative to the cash income generating ability of the peasant farmers. The situation is aggravated by removal of fertilizer subsidy by the government under structural adjustment programmes (see Kaoneka 1993(b)). The combined effect of high price, poverty and other social obligation limits the application of recommended level of mineral fertilizers.

4.6.10.2 Sustainability of the maize/beans intercropping system

The nutrient from maize/beans intercropping system is lost through essentially two pathways, soil erosion and through crop removals during harvesting. Soil erosion erodes top soil which is rich in nutrient minerals resulting into low soil fertility and degradation with the consequence of deline in crop yields. For instance, Lal (1979) observed that removal of 2.5 cm of top soil could result into a yield loss of 40-50%. In essence therefore, soil erosion processes may affect the sustainability of maize/beans intercropping system.

Nutrient removals through harvesting from the maize/beans intercropping system is substantial (Table 4.48). Every season a modest harvest of maize and beans removes 46.1, 20.4 and 50.3 kg ha^{-1} of nitrogen, phosphorous and potassium nutrients respectively. Presently the peasants at Lukozi Village apply only farm yard manure for the maize/beans intercropping system. An application of 5 t ha^{-1} supplies 24.0, 8.5 and 27.0 kg ha^{-1} of nitrogen, phosphorous and potassium nutrients respectively (Harrop and Samki 1984). This level of nutrient input is lower than the amount lost through crop harvesting. Therefore as it is practised, the system is not sustainable. However, if the system is to be sustained the peasant must apply at least 10 tha^{-1} of farm yard manure. Certainly the fact that livestock keeping at Lukozi Village is not widespread may pose a constraint. Also soil erosion must be kept to a minimum. According to a study by Shenkalwa (1989), soil erosion can be reduced considerably by manipulating slope characteristics for example through the construction of macrocontour lines and soil cover (see section 4.6.8).

The results in Table 4.48 show that nitrogen element, one of the most limiting nutrient element in the West Usambaras (Ngatunga 1981), is lost in large quantities through crop removals under maize/beans intercropping system and soil erosion as the organic matter is removed. The implication of this observation is that maintenance and sustainability strategy would involve the enrichment of the soil organic matter content.

One possible strategy of increasing soil organic matter content is by establishing legume cover crops such as *Crotalaria ochroleuca* (locally known as *marejea*) during the short rain season when the farmland are usually left fallow (Mnkeni 1992). In fact *Crotalaria ochroleuca*, a fast growing and nitrogen fixing crop, is already widely used in maize fields in Songea, one of the four regions (others are Mbeya, Rukwa and Iringa) relied upon for large scale production of maize which is a staple grain for many parts of Tanzania (Mnkeni 1987; 1992). The plant may release up to 50% of nitrogen content in a span of six weeks after being incorporated in a farming system (Msumali 1992). Thus, planting *marejea* has great potential for replenishing not only nitrogen content but also adding organic matter to the soil in the maize/beans intercropping farming system.

The application of farm yard manure and establishment of legume crops have been observed to be long-term soil maintenance measures because they release nutrient slowly. To this effect, Mnkeni (1992) proposes that the two techniques must be supplemented by the application of mineral fertilizers during immediate growing seasons. Thus when farm yard manure and *marejea* are releasing their nutrients slowly, crops can benefit from mineral fertilizers which release their nutrients relatively fast (*ibid*).

The sustainability of maize/beans farming system, demands the application of recommeded rates. The recommended application of nitrogen is 30 to 40 kg ha^{-1} and 70 to 120 kg ha^{-1} for lowlands and highlands respectively (Deckers *et al.* 1990, 1991). For instance, an application of optimum level of 80 kg ha^{-1} of nitrogen for intermediate and high altitude zones offsets nitrogen removed during crop harvesting and crop yield increases by up to 2 t ha^{-1} with a productivity index of 25 (*ibid*). Also this regime gives a value (benefit) cost ratio of 5.5 implying that a farmer, investing in the purchase of fertilizer is assured of economical returns (*ibid*; Mnkeni 1992).

4.6.10.3 Potential sustainability and improvement of agroforestry system

The agroforestry system is far more complex than both monocropping and intercropping farming systems. Therefore the potential for sustainability and improvement requires special treatment. The basic sustainability and improvement of an agroforestry system depends on proper selection of agroforestry tree species and maintenance of soil nutrients through the application of manure and mineral fertilizers. As stated above, some tree species, not only do they deplete soil nutrients but also produce chemicals which inhibit germination and growth of crops or *allelopathy*. Also certain tree species such as *Eucalyptus melliodora* is believed to absorb a lot of soil moisture. Such a feature is not especially beneficial to crops which need plenty of soil moisture in order to grow. These shortcomings point only to the need for proper selection of tree species intended for an agroforestry system. In the long run trees may be a key element to sustaining farming systems.

Grevillea robusta, a tree recommended/preferred for agroforestry at Lukozi village has a number of positive features which makes it particularly useful for farming systems. The tree has potential for sustaining crop production by improving soil productivity through increasing inputs (such as organic matter, nitrogen fixation and nutrient uptake), reducing losses (organic matter and nutrients) by promoting recycling and checking soil erosion, improving soil physical properties (including water holding capacity) and beneficial effects on soil biological processes (Young 1989).

In an agroforestry system the initial soil characteristics and nutrient balance are important aspects in enhancing the positive effects of subsequent fertilizer and farm yard manure applications. For example, Mnkeni (1992), observed that the mobilization and response of crops to the application of nitrogen and phosphorous fertilizers is dependent on the initial soil nutrients and organic matter content. To the extent that trees enhance proper maintenance of both soil fertility and organic matter content, there is reason to believe that the application of mineral fertilizers in an agroforestry system has the potential of increasing crop yields substantially.

Some studies have shown that nitrogen fixing trees, such as *Leucaena leucocephala*, growing within practical agroforestry systems (for example as hedgerow or intercropped) are capable of fixing about 50-100 kg $ha^{-1}yr^{-1}$ of nitrogen nutrient and nitrogen returned to the soil through litter fall and pruning may amount to as high as 100-300 kg $ha^{-1}yr^{-1}$ of nitrogen nutrient (Dommergues 1987). Furthermore a tree leaf biomass of 4000 kg $ha^{-1}yr^{-1}$ of dead-matter (DM) has the potential of returning via litter fall to the soil, 80-120, 8-12 and 40-120 kg $ha^{-1}yr^{-1}$ of nitrogen, phosphorous and potassium respectively (Young 1989). Considering the nutrient requirements of maize, beans and potatoes (Table 4.49), the crops intercropped with trees, such nutrient input is substantially high enough to offset nutrient loss through the crop removal pathway, if nutrient mobilization is complete.

4.6.11 Concluding remarks

In this chapter, an assessment of soil productivity for Lukozi Village has been presented. The assessment included nutrient loss, replenishment of soil nutrients, sustainability and potential for improvement of farming systems. The chapter included also a brief review of the measures taken to combat soil erosion in West Usambara mountains.

Soil nutrient loss pathways were identified as being, through crop harvests, removal of crop residues, leaching, gaseous and erosion losses. Based on earlier studies, the pathways considered more relevant for Lukozi Village were nutrient loss through crop harvesting, crop residues and soil erosion. The three pathways were discussed in detail to reflect the general trends with respect to soil productivity, sustainability and potential for improvement of the farming systems.

The methods with potential for replenishing soil nutrients were, application of mineral fertilizers, farm yard manure and biological nitrogen fixation, deposition and sedimentation. Based on earlier studies and actual field surveys the only input pathways of relevance to Lukozi Village and discussed in this chapter were, application of mineral fertilizers, farm yard manure and biological nitrogen fixation. The present application of mineral fertilizers is low compared to the recommended rates. Therefore the farming systems are not sustainable in the long run due to nutrient depletion.

The farming systems included in the assessment were monocropping, maize/beans intercropping and agroforestry farming systems. Monocropping and maize/beans farming systems are widely practised whereas agroforestry system is practised by a few peasant households of Lukozi Village. The assessment has shown that nutrient removals through harvested products and crop residues were considerably high. The available data did not permit the estimation of nutrient loss (in numerical terms) through soil erosion pathway. Based on the assessment, none of the two present farming systems, i.e. monocropping and intercropping systems, is sustainable.

The application of mineral fertilizer and farm yard manure were observed to be appropriate techniques to replenish soil nutrients. However, due to the fact that the present regimes were not enough to compensate for nutrient removals, the application of recommended rates was emphasized. Also in the long run establishment of nitrogen fixing legumes such as *marejea* was recommended to substitute for fertilizers which are fairly expensive to the ordinary farmer.

The assessment, further showed that, all three farming systems have potential for sustainability and improvement provided proper land management practises are applied. These include proper estimation of the balance between nutrient input and output and the use of recommended fertilization regimes. In the case of agroforestry system proper selection of tree species compatible with farm crops was emphasized. However, it was observed that a widespread adoption of agroforestry system must be based on site studies.

Regarding the techniques used to combat soil erosion in the West Usambaras, preliminary evaluative results showed that proper construction and management of macrocontour lines reduced soil erosion considerably and had favourable effect on soil nutrient content and physical properties. Therefore, based on further investigation, a wide scale application of the system may be desirable. On the other hand the traditional use of contour plants has great potential for minimizing soil erosion, although some improvements may be useful.

Agroforestry are complex ecosystems. The agroforestry systems analysed in this chapter could be of considerable potential for application in the Lukozi area, and other parts of West Usambaras. Therefore with increasing demand for wood material due to population growth and decline in the soil fertility it might be relevant to adopt agroforestry systems.

CHAPTER 5 GENERAL DISCUSSION AND CONCLUSIONS

5.1 Effect of population growth and income constraints

Fast population growth has been mentioned as one of the agents causing land use problems in Tanzania and in the West Usambaras (Kaoneka 1993a & b). Population growth creates considerable pressure on forest lands especially where arable land is limited. The pressure emanates from increased demand for food which necessitates the expansion of farmlands. In areas of limited arable land such expansion is achieved by way of clearing forest lands. Therefore population growth accelerates the rate of deforestation as long as it remains profitable to the farmer.

The increased demand for food compels the farmer to allocate more land and family labour to the production of subsistence crops in favour of cash crops. This behaviour seems logical because any rational farmer will secure that both food and cultural needs are satisfied before the cash income goal is pursued. It may be pointed out also that farmers rely largely on family labour for farm production. Due to limited cash incomes labour hiring is hardly possible. Therefore, the allocation of more labour to the production of subsistence crops reduces the available labour for cash crop production.

The diversion of large proportion of land and labour to the production of subsistence crops has the effect of reducing the amount of cash income earned by a household. Hence the per capita cash income declines to the extent that farmers rely on agricultural activities for generating cash income. The reduction in per capita cash income affects the welfare of the farmers because it implies that the ability to purchase market goods becomes limited.

The model used to simulate the effect of population growth put a restriction to the effect that the farming systems should be sustainable, i.e., non-declining per capita cash income and household food consumption from own farm. The purpose was that the present welfare of the farmer must be at least maintained over time. Therefore any simulation which produced cash income below the minimum acceptable (or desirable) level became infeasible meaning that the farming systems were no longer sustainable. Experience shows, however, that in the rural sector of Tanzania, and in particular in the West Usambaras, population growth is seldom matched with a corresponding socio-economic growth. Therefore a decline in per capita income is not surprising. In fact recent published reports indicate that the real income in the rural sector of Tanzania has declined by as high a margin as 70% in the last 25 years (EIU 1992).

5.2 Sustainability of the present farming systems

The analysis presented in this study has indicated that the present farming systems can sustain the present population growth rate (2.1% per annum for Lukozi Village) and per capita income for a maximum duration of 25 to 30 years. Life expectancy in Tanzania is over 45 years (based on 1988 population census, URT 1991). Thus the present farming systems cannot sustain even one human generation. Furthermore the assessment of soil productivity indicated that removals of soil nutrients through crop harvests alone are higher than the amount added to replenish soil fertility. The decline in soil nutrients causes a decrease in crop yields over time due to land degradation.

Therefore it can be concluded that the present farming systems are not sustainable in the long run i.e. > 30 years. These results suggest that, in order to enhance the sustainability of the existing farming systems, it is important to improve farming technology which could increase crop production through improvements in land productivity. Such a strategy will secure satisfaction of increased food demand as a result of population growth as well as limiting the expansion of farmlands through forest clearing. In addition the welfare of the farmers and general rural populace could be enhanced and improved. Also it might be relevant to expand small-scale industrial activities in order to increase income from off-farm activities.

5.3 Effect of risk aversion on per capita income and land use pattern

The analysis has indicated that risk aversion, especially the risk associated with over time variation in crop yields and product price, hence gross returns, has the effect of reducing income per capita and cultivated land area. The overall decision criteria applied was that, a farmer who is risk averse will accept an efficient farm plan with increase in risk level as long as the expected net cash income increases also. In the analysis *per se*, the compromise programming (CP) model did not produce a single optimum solution (i.e. farm plan) rather it produced a set of efficient farm plans or best-compromise solutions based on different subjective weights, δ_j, assigned to the objective functions. A set of efficient farm plans provides a range of choices for the farmer (decision maker) to choose. This is considered to be close to reality (and appealing) for two reasons, it gives the farmer a range of choices and in practise farmers are more apt to accept "good-enough" in favour of single optimum solution (based on the satisficing principle, Simon 1979). In an extreme case, if the farming situation is perceived to be very risky, a farmer may produce only enough to meet the subsistence needs and attempt to earn cash income from off-farm activities.

It is well to realize that there is no *a priori* preference for one efficient farm plan in favour of other in a compromise solution set. The choice is entirely left to the farmer whose choice depends on his utility function. The inherent human behaviour is variable as opposed to uniform pattern and farmers pursue multiple as opposed to a single goal. Thus a compromise programming model secures that at any one solution set multiple goals are compromised.

Finally, risk elements are important to a farmer due to the biological nature of crop production and market variability of agricultural crops. In essence, therefore, the inclusion of risk makes the modelling more realistic and increases the utility of a model.

5.4 General policy implications of the analysis

The analysis has indicated that the present farming systems are not sustainable in the long run given the present population growth. Thus, as a matter of policy issue, it could be important to develop a policy that will limit the population growth to levels that can be sustained by the present farming systems. This can be achieved, for instance, through family planning and birth control measures. In the long run it might be important to develop a comprehensive population policy which is, at present, non-existent in Tanzania (TFAP 1989; Kaoneka

1993a). Such a policy is likely to reduce the pressure on forest lands caused by population growth.

This strategy may, however, be contested by farmers on the premise that it will invariably reduce household labour available for farming activities. The farmers value children in terms of their contribution to future labour needs. Therefore, the opportunity cost of child rearing (mothers withdraw labour force from farming activities) is the benefit of future labour supply. Also children are looked upon as social security in kind for the old age to the extent that there is no welfare security for old people in Tanzania. Furthermore, in some tribes, including the Shambaa tribe, having many children is a symbol of status. Therefore, development of a national population policy must be accompanied by mass education. Otherwise, if adopted as a top-down directive, it is bound to be less acceptable to the rural populace.

Another option is to promote the adoption of improved (and efficient) farming technology, for example through the use of improved seeds and application of recommended fertilizers. Improved technology may seem to be fairly expensive to an ordinary farmer to the extent that it entails the use of market inputs the purchase of which demand cash income. Therefore, as a matter of policy, it could be important to extend an appropriate credit facility to enhance the purchasing power of the farmer to buy farm market inputs. However, to be meaningful, such a policy must not embody stringent conditions such as high interest rates. The analysis indicated that the availability of capital can stimulate the expansion of agricultural production.

The issues raised in this discussion could be an important step to improve the welfare of the farmers. Suffice to mention their importance to the national economy which depends largely on agricultural exports to earn foreign exchange. Also the improvement of the welfare of the rural populace is a national goal.

5.5 Limitations and possible future improvements of the model

The analysis presented in this report was based on mathematical modelling and economic theory of utility maximization. Mathematical modelling was used to abstract, in numerical terms, the otherwise complex socio-economic structure of the farming systems. The model was considered to be relevant for conducting and simulating "what if" analyses. In the course of applications, however, certain limitations were noted. Major proposals for future improvements are:

(a) The use of an average farmer may not be realistic. There could be important variations among the farmers which might influence the outcome of the model, depending on aspects such as farm size, income from off-farm sources and family size.

(b) The models applied uniform time allocation to various farm activities by the farmers. Between farmers variations are, however, not unusual.

(c) The compromise programming (CP) model used a period of five years to analyze the effect of risk associated with yields and product prices. In some cases a much longer period might be a realistic approach in order to elucidate long-term effects.

(d) Zoning land area by farming systems.

(e) Inclusion of land degradation elements in the model.

(f) Including labour hiring activities in the model as opposed to total reliance on family labour.

(g) Possibility of including agroforestry systems directly in the land use models.

(h) Comparative analysis of farming systems in which
   (i) application of fertilizers and manure (i.e. fertilization) regimes are practised;
   (ii) no fertilization regime is practised.

(i) Assumption of linearity, in particular the connection between increased fertilization and crop yield.

(j) Conducting detailed time studies on farming, social/cultural and off-farm economic activities.

(k) Incorporating all possible economic activities including those from other sectors such as, off-farm work opportunities.

All these factors will complicate the modelling if implemented. One should aim at a balance between the gain regarding decision quality compared to increased costs of developing a more complicated model.

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APPENDIX 1: FIELD SURVEYS IN LUKOZI VILLAGE, WEST USAMBARAS

A. Household data

Total number of household sampled	74
Average household size	7.5

(Population distribution in the sample area is presented in Tables A.1 & A.2 and Figure A.1)

B. Land acqusition and ownership

(a) Average land holding per household (ha) (for land distribution see Table A.3 and Figure A.2)	2.5

(b) Source of land (% of total respondents)

(i)	Inherited	78
(ii)	Bought	28
(iii)	Village land	7

(c) Land ownership (% of total respondents)

(i)	Own (private)	95
(ii)	Leasehold	1
(iii)	Village land	4

C. Farm crop production

(a) Average farm production (kg ha^{-1}):

(i)	Maize	1340
(ii)	Beans	603
(iii)	Potatoes	1000
(iv)	Vegetables	10000

(b) Proportion of households growing each type of crop (% of total respondents):

(i)	Maize	100
(ii)	Beans	99
(iii)	Potato	99
(iv)	Vegetable	91

(c) Average farm-gate prices for the farm crops (TAS kg^{-1}):

(i)	Maize	48
(ii)	Beans	68
(iii)	Potatoes	40
(iv)	Vegetables	22

Table A.1 Population distribution in sampled household

HH	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2	5	6.8	5	6.8
3	5	6.8	10	13.5
4	10	13.5	20	27.0
5	7	9.5	27	36.5
6	7	9.5	34	45.9
7	9	12.2	43	58.1
8	9	12.2	52	70.3
9	6	8.1	58	78.4
10	4	5.4	62	83.8
11	3	4.1	65	87.8
14	1	1.4	66	89.2
15	2	2.7	68	91.9
16	2	2.7	70	94.6
17	1	1.4	71	95.9
19	1	1.4	72	97.3
20	2	2.7	74	100.0

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Table A.2 Summary of population distribution in sampled household

NUMBER IN HOUSEHOLD						
MEAN	MAX	MIN	N	CV	STD	STDERR MEAN
7.5	20.0	2.0	74.0	57.2	4.3	0.5

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                              FREQUENCY OF HH

    HH                                                            CUM            CUM
MIDPOINT                                                   FREQ  FREQ  PERCENT  PERCENT
        |
   0    |                                                    0     0     0.00     0.00
   1    |                                                    0     0     0.00     0.00
   2    |********************                                5     5     6.76     6.76
   3    |********************                                5    10     6.76    13.51
   4    |****************************************           10    20    13.51    27.03
   5    |****************************                        7    27     9.46    36.49
   6    |****************************                        7    34     9.46    45.95
   7    |************************************                9    43    12.16    58.11
   8    |************************************                9    52    12.16    70.27
   9    |************************                            6    58     8.11    78.38
  10    |****************                                    4    62     5.41    83.78
  11    |************                                        3    65     4.05    87.84
  12    |                                                    0    65     0.00    87.84
  13    |                                                    0    65     0.00    87.84
  14    |****                                                1    66     1.35    89.19
  15    |********                                            2    68     2.70    91.89
  16    |********                                            2    70     2.70    94.59
  17    |****                                                1    71     1.35    95.95
  18    |                                                    0    71     0.00    95.95
  19    |****                                                1    72     1.35    97.30
  20    |********                                            2    74     2.70   100.00
        ----+---+---+---+---+---+---+---+---+---+
            1   2   3   4   5   6   7   8   9   10

                        FREQUENCY
```

Figure A.1 Population distribution in sampled households

Table A.3 Land distribution in sampled households

AREA	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0.5	1	1.4	1	1.4
0.8	2	2.7	3	4.1
1	8	11.0	11	15.1
1.2	8	11.0	19	26.0
1.5	1	1.4	20	27.4
1.6	4	5.5	24	32.9
2	12	16.4	36	49.3
2.5	3	4.1	39	53.4
2.8	1	1.4	40	54.8
3	11	15.1	51	69.9
3.5	2	2.7	53	72.6
4	9	12.3	62	84.9
5	3	4.1	65	89.0
6	2	2.7	67	91.8
7	1	1.4	68	93.2
8	2	2.7	70	95.9
10	3	4.1	73	100.0

Frequency Missing = 1

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FREQUENCY OF AREA

```
   AREA                                                                        CUM              CUM
MIDPOINT                                                          FREQ  FREQ  PERCENT  PERCENT
          |
    0     |**                                                        1     1     1.37     1.37
    1     |**************************************                   19    20    26.03    27.40
    2     |**************************************                   19    39    26.03    53.42
    3     |****************************                             14    53    19.18    72.60
    4     |******************                                        9    62    12.33    84.93
    5     |******                                                    3    65     4.11    89.04
    6     |****                                                      2    67     2.74    91.78
    7     |**                                                        1    68     1.37    93.15
    8     |****                                                      2    70     2.74    95.89
    9     |                                                          0    70     0.00    95.89
   10     |******                                                    3    73     4.11   100.00
          ----+---+---+---+---+---+---+---+---+--
              2   4   6   8  10  12  14  16  18
```

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Figure A.2 Land distribution in sampled households

(d) Land management practices (% of total respondents):

(i)	Terracing	15
(ii)	Manuring	91
(iii)	Application of mineral fertilizers	61
(iv)	Decline in crop yields	81

D. <u>Off-farm activities</u>

(a) Proportion (%) undertaking the following activities:

(i)	Pitsawing	0
(ii)	Petty trading/business	73
(iii)	Livestock keeping	72

(b) Average household earnings from the off-farm activities (TAS/month):

(i)	Pitsawing	0
(ii)	Petty trading/business	6400
(iii)	Livestock keeping	3400

E. <u>Assessment of income and expenditure (TAS/household):</u>

(a)	Average annual income	98000
(b)	Average annual expenditure	62000

F. <u>Fuelwood assessment</u>

(a) Source (% of total respondents):

(i)	Natural forest reserves	58
(ii)	Plantations	74
(iii)	Own farm plantations	68

(b) Loads

(i)	Average loads per week	5
(ii)	Average size of loads (pieces)	10
(iii)	Estimated volume (m^3/week)	0.015

(c) Distance travelled in search for fuelwood (% of total respondents):

(i)	Less than 2 km	43
(ii)	Between 2-5 km	38
(iii)	More than 5 km	15

G. <u>Tree planting activities</u>

(a) Proportion (%) of households planting the following tree spp.:

(i)	*Albizzia spp.*	8
(ii)	*Grevillea robusta*	86
(iii)	*Eucalypt spp.*	11
(iv)	*Acacia mearnsii*	20
(v)	Fruit trees	5

(b) Average annual number of tree spp planted (trees/household):

(i)	*Albizzia spp.*	18
(ii)	*Grevillea robusta*	174
(iii)	*Eucalypt spp.*	5
(iv)	*Acacia mearnsii*	136
(v)	Fruit trees	48

H. Qualitative exploration of risk elements

(a) Risk factors:

(i) Rainfall-amount, duration and distribution
(ii) Market fluctuations-fall in price, absence of buyers and credit purchase by Cooperative Unions.

(b) Risk aversion:

(i) Early planting
(ii) Planting at different times
(iii) Diversification and interplanting crops
(iv) Planting both drought and disease/pest resistant crops

I. Summary of welfare and infrastructure facilities

(a) Lukozi village is accessible from Lushoto town by an all-weather earth/murram road.

(b) The village has the following welfare services/facilities:

(i) Two primary schools
(ii) Five various merchandise shops
(iii) Two grain milling machines
(iv) Piped water in addition to direct streams flowing from the natural forest reserve
(v) Mobile bank (branch of the National Bank of Commerce).

J. Factors causing environmental pollution

(a) Haphazard clearing/cutting of trees
(b) Free-range grazing
(c) Indiscriminate burning of crop residues

K. Estimates of livestock in Lukozi Village (herds/flock)

(a) Sheep	250
(b) Goats	234
(c) Cattle	840

APPENDIX 2. CALCULATION OF GROSS REVENUE DEVIATIONS

Notes: (a) The procedure used to compute the absolute deviations was based on Hazell (1971) and Boisvert and McCarl (1990).
(b) Yield data were obtained from DADO and SECAP, Lushoto.
(c) Crop prices, at 1990/91 prices, were adjusted using consumer price indices as published in EIU (1992). [Base year 1977 = 100]

Monocropping farming system

Table A.4 Calculation of deviations for maize crop

Year	Yield ($kgha^{-1}$)	Price ($TASkg^{-1}$)	Gross returns (TAS)	Deviations (TAS)
1992	1340	48	64320	+12338
1991	1470	37	54390	+2408
1990	1620	30	48600	-3382
1989	1780	25	53400	+1418
1988	1960	20	39200	-12782
Average			51982	

Table A.5 Absolute deviations for bean crop

Year	Yield ($kgha^{-1}$)	Price ($TASkg^{-1}$)	Gross returns (TAS)	Deviations (TAS)
1992	603	68	41004	+9411
1991	660	51	33660	+2067
1990	730	42	30660	-933
1989	800	35	28000	-3593
1988	880	28	24640	-6953
Average			31593	

Table A.6 Calculation of deviations for potato crop

Year	Yield ($kgha^{-1}$)	Price ($TASkg^{-1}$)	Gross returns (TAS)	Deviations (TAS)
1992	1000	40	40000	+8960
1991	1100	31	34100	+3060
1990	1200	25	30000	-1040
1989	1300	21	27300	-3740
1988	1400	17	23800	-7240
Average			31040	

Table A.7 Calculation of deviations for vegetable crop

Year	Yield ($kgha^{-1}$)	Price ($TASkg^{-1}$)	Gross returns (TAS)	Deviations (TAS)
1992	10000	22	220000	+53800
1991	11000	16	176000	+9800
1990	12100	13	157300	-8900
1989	13300	11	146300	-19900
1988	14600	9	131400	-34800
Average			166200	

APPENDIX 2..continues

Intercropping farming system

Table A.8 Calculation of deviations for maize crop

Year	Yield (kgha^{-1})	Price (TASkg^{-1})	Gross returns (TAS)	Deviations (TAS)
1992	1206	48	57888	+12802
1991	1320	37	48840	+3754
1990	1450	30	43500	-1586
1989	1600	25	40000	-5086
1988	1760	20	35200	-9884
Average			45086	

Table A.9 Calculation of deviations for bean crop

Year	Yield (kgha^{-1})	Price (TASkg^{-1})	Gross returns (TAS)	Deviations (TAS)
1992	543	68	36924	+8597
1991	590	51	30090	+1763
1990	650	42	27300	-1027
1989	720	35	25200	-3126
1988	790	28	22120	-6207
Average			28327	

APPENDIX 3. QUEISTIONNARES USED DURING THE FIELD SURVEYS

1. Household data

(To be completed by the Head of the Family/Household)

A. Structured Questionnaire

(a) Family size

i) Male..........Ages.......years/month

ii) Female........Ages.......years/month

(b) Farm size...........acres or hectares

(c) Land ownership

i) Own................. Area.................ha

ii) Lease.............. ....ha

iii) Village land...... ....ha

(d) How was the land acquired

i) Inheritance.........................

ii) Bought...........................

iii) Village offer...........................

iv) Other.........................

(e) Crops grown

i) Maize...........................

ii) Beans...........................

iii) Potato.........................

iv) Vegetables......................

v) Other..........................

(f) Soil (land) management

i) Fallow...........area..............ha

ii) Manure........... ....ha

iii) Chemical fertilizer.... ....ha

(g) Harvest per season

i) Maize..................kg, bags/acre, ha

ii) Beans..................kg, bags/acre, ha

iii) Potato.................kg, bags/acre, ha

iv) Vegetables............kg, bags/acre, ha

v) Other..................kg, bags/acre, ha

(h) Crop sale prices

i) Maize.............shs/bag or kg

ii) Beans...........shs/bag or kg

iii) Potato...........shs/bag or kg

iv) Vegetable.......shs/bag or kg

(i) Does the harvest per season decline over time

Yes.................No...........

If yes indicate the proportion...............
....

(j) Do you grow border/line trees in your farm

Yes......No......

(k) Source of fuel-wood

i) Natural forest......................

ii) Forest plantation...................

iii) Border/line trees ....

iv) Others specify......................

(l) Fuel-wood loads

i) Size............pieces/load or kg/load

ii) Number of loads.............per day/week

(m) Travel distance

i) Less than 2 km.........................

ii) Between 2 - 5 km...............................

iii) More than 5 km..........................

n) Other sources of income for the family

i) Pitsawing.................................

ii) Petty/commercial business..................

iii) Livestock...................................

iv) Other, specify................................

(o) Receipts/revenues from the income services

i) Pitsawing ....shs/month

ii) Petty /commercial business....................shs/month

iii) Livestock..............kgs/month

iv) Other..................shs./month

(p) How many family children attend

i) Primary school.......................

ii) Secondary school....................

iii) Training institute.................

(q) How much do you pay for

(i) Tax.....................shs./year

(ii) Development levy................shs./year

(r) What are the savings per year....................shs./year

B. <u>Semistructured Questionnaires</u>

(a) What are the main activities of the family?

....

(b) What type of crops are grown by the family?

....

(c) Does the family have enough farm land?

....

(d) What are the sources of income for the family?

....

(e) What is the annual income and savings for the family?

....

(f) What are the sources of fuel-wood for the family?

....

(g) Do you receive the services of Bwana shamba (i.e. extension service)?

....

(h) Explain the labour allocation during

i) Rainy season...

ii) Other seasons ....

(i) What is the main food stuffs consumed by the family

....

(j) How are the food staffs obtained

i) Own produced...

ii) Bought...

(k) How many trees does the family grow on the farms ?
....

(l) What types of trees are grown on the farms?
....

(m) Steepness of the farm according to agroforestry/farming systems e.g terracing, contouring etc.

a) 0 - 10%

b) 10 - 15%

c) 10 - 30%

d) > 30%

(n) Soil types and distribution.......................

2. Village/Ward level data

(To be completed by the Ten-cell Leaders/Ward Secretary)

A. Structured Questionnaire

(a) Name of village...............................

(b) Number of house hold/families.................

(c) Average size of household/family.............

(d) Social and welfare services

i) Dispensary................................

ii) School(s)................................

iii) Shops....................................

iv) Other, specify............................

(e) Condition of road network

i) All weather/season........................

ii) Seasonal..................................

iii) Tracts ....

(f) Source of water

i) Piped.....................................

ii) Wells.....................................

iii) River/streams.............................

(g) Village main activities

i) Farming...................................

ii) Livestock husbandry.......................

iii) Pitsawing.................................

iv) Petty/commercial business.................

v) Other, specify............................

(h) Revenue/income, generated from the following activities for household/village

i) Farming..........Shs/year/household/village

ii) Livestock husbandry.........shs/year

iii) Pitsawing...................shs/year

iv) Petty/commercial business.....shs/year

v) Others...................... shs/year

(i) Main crops grown by the villages

i) Maize.................

ii) Beans.................

iii) Vegetables............

iv) Potatoes........

(j) Average production levels

i) Maize..............kg,bags/acre,ha

ii) Beans ....kg,bags/acre, ha

iii) Vegetables .... kg/acre, ha

iv) Potatoes............kg/acre, ha

(k) Land management

i) Fallow..........................

ii) Manure..........................

iii) Chemical fertilizer..............

(l) Source of fuel-wood for the villagers

i) Natural forest ....

ii) Forest plantation................

iii) Border/line plantation............

(m) Fuel-wood consumption

i) Number of loads.............per week/household

ii) Bags of charcoal............ per month/household

iii) Others specify..............

(n) Type and preparations of fuel used in the village

i) Fuel-wood.............# households

ii) Kerosine ....# households

iii) Electricity..........# households

iv) Others, specify ......# households

(o) How important is the problem of environmental pollution

i) Less important...................

ii) Moderately important.............

iii) Somewhat important...............

iv) Very important....................

(p) What in your opinion is the most important environmental pollutant?

(q) What type and numbers of livestock is kept in the village?

i) Sheep...................flocks

ii) Goats.................. herds

iii) Cattle................. herds

iv) Other........mention.

B. <u>Semi Structured Questionnaire</u>

(a) What are the main economic activities of the village?

....

(b) What is the average earning from each of these activities?..................................

(c) What are the main sources of energy for the village?

....

(d) Where do the villagers obtain fuel-wood?

....

(e) What type of environmental pollution problems are caused by the present village activities?..................
....

(f) What are the main sources of energy for the village?
....

(g) What type of legal fees are villages obliged to pay?.......................................

(h) Do villagers receive any subsidy from the government?
....

(i) How is the economic development plan drawn in the village?.......................................

(j) What political issues do affect the village activities
....

3. Risk assessment

(To be completed by head of household/family)

(a) Age.......................................(years).

(b) Education level.....................(highest class reached).

(c) Income per year................................(shs.).

(d) Wealth owned (can estimate in shs.)....................

(e) What risks do you face in the following economic activities?

(i) Farming...

(ii) Marketing of your produce..........................

(iii) Any other activity...............................

(f) What are the most important environmental related risks in your village?..

(g) Classify risks you have stated in order of importance.......

(h) How do you avoid or avert such risks?...................