LAND SUITABILITY ASSESSMENT OF THE WAMI PLAINS IN MOROGORO, TANZANIA WITH RESPECT TO THE PRODUCTION OF THE MAIN FOOD CROPS AND EXTENSIVE GRAZING

BY

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ABSTRACT

A study was conducted at Wami Plains in Morogoro to assess the suitability of land for the production of the main food crops and for extensive grazing. Field land resources survey was conducted covering an area of 35,810 hectares. Soil profiles were excavated, studied and sampled for laboratory analysis. Soils of Wami Plains are mostly well drained, sandy clay loams, except on the valley bottoms, floodplains and mbuga where they are poorly drained. They have low to medium available water capacity (83 - 135 mm/m) except profile NYN-P7 which has high available water capacity (164 mm/m). The soils are generally poor in chemical fertility. The levels of nitrogen range from very low (0.04%) to low (0.17%) while those of organic carbon are between low (0.66%) to medium (1.46%). Available phosphorus contents range between low to medium (0.96-16.0 mg/kg) The level of micronutrients in these soils is adequate except for Zn which is rated as inadequate for most crops. The soils were classified according to both FAO-World Reference Base and USDA Soil Taxonomy systems. The FAO-WRB soil names with their mapping units in brackets are as follows: Chromi-Rhodic Cambisols and Hapli-Hypocalcic Calcisols (Alluvial fan); Rhodi-Profondic Lixisols (Ridge summits); Rhodi-Profondic Lixisols (Ridge slopes with red soils); Hypereutri-Ferralic Cambisols (Ridge slopes with sandy soils); Hypereutri-Mollic Fluvisols and Calcari-Mollic Cambisols (Valley bottoms); Chromi-Profondic Lixisols and Hapli-Hypocalcic Calcisols (Flats with red soils); Calcari-Mollic Fluvisols (Flats with sandy soils); Hypocalci-Endosodic Calcisols (Floodplains) and Endosodi-Pellic Vertisols (Mbuga).

Three land utilisation types (LUTs) (maize, rice and extensive grazing) were selected for land suitability evaluation and the results of physical suitability evaluation are as follows: About 38% of the area was classified as moderately suitable, 44% marginally suitable and 18% physically not suitable for maize production. As for rice production, about 55% of the area was classified as marginally suitable and 45% is physically not suitable for the LUT. About 84% of the area was classified as moderately suitable for extensive grazing while only 16% is marginally suitable for the LUT. Major limitations in these soils are: nutrient availability and retention, moisture availability, flooding hazards, oxygen availability to roots and biological hazards.

DECLARATION

I, EMMANUEL PETER KILEO, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has never been submitted for a degree award in any other University.

Signature..

Date....02/11/2006..........

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DEDICATION

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ABBREVIATIONS

ALES	= Automated Land Evaluation System
AP	= Aerial photographs
API	= Aerial photo interpretation
AWC	= Available water capacity
BD	= Bulk density
BS	= Base saturation
C:N	= Carbon to nitrogen ratio
CEC	= Cation exchange capacity
ECe	= Electrical conductivity
ESP	= Exchangeable sodium percentage
ET_o	= Evapotranspiration
EV	= Estate value
FAO	= Food and Agricultural Organisation
FV	= Future value
GIS	= Geographical Information System
GM	= Gross margin
IR	= Interest rate
km^2	= Square kilometres
LC	= Land characteristic
LECS	= Land Evaluation Computer System

LIRMP = Low input rainfed maize production

LIRRP = Low input rainfed rice production

LMU = Land mapping unit

LQ = Land quality

LUR = Land use requirements

LUT = Land utilisation type

NORAD = Norwegian Agency for Development Co-operation

NSS = National soil service

^oC = Degree centigrade

OC = Organic carbon

OM = Organic matter

PV = Present value

QUEFTS = quantitative evaluation of the fertility of tropical soils

SISTAN = Soil information system for Tanzania

SUA = Sokoine University of Agriculture

URT = United Republic of Tanzania

USDA = United States Department of Agriculture

WRB = World Reference Base

CHAPTER ONE

INTRODUCTION

Tanzania is predominantly an agricultural country with a total area of about 945,090 km^2 (826,973 km^2 excluding the water bodies). The country has about 26 million people with an average population density of about 27 persons per km^2 increasing at a rate of 2.8% per annum (Bureau of Statistics, 1992). More than 80% of the population is living in villages in the rural areas (Kajumulo, 1992). The gross area planted annually is in the order of 5.1 million ha, of which about 85% is under food crop production (United Republic of Tanzania (URT), 1995b). The agricultural sector in Tanzania contributes about 58% of Gross Domestic Product (Kajumulo, 1992) and more than 80% of export earnings (Kauzeni, 1989). In addition, it provides employment for the major part of the population (Ministry of Agriculture, 1983).

Despite the agricultural potential in many parts of the country, Tanzania continues to face frequent and intermittent food shortages (URT, 1988). According to URT (1995a) production levels for maize and rice which are the major food crops in the country are very low. Current average yield levels for maize are between 0.6 and 1.5 tonnes per ha while the potential yields are between 4.0 and 8.0 tonnes per ha. With respect to rice, the current levels are between 1.5 and 2.0 tonnes per ha while the potential yield is 8.0 tonnes per ha. It is further reported that food demand in Tanzania is likely to increase due to rapid population growth and expanding urbanisation (World Food Summit, 1996).

According to URT (1995b) the domestic food production in Tanzania for 1993/94 season was 3.1 million tonnes which was lower by 7% when compared to the 1992/93 season. In the 1995/96 season the country had a cereal deficit of 444,000 tonnes. The low food production has forced the Tanzania Government to spend the merger available foreign exchange to import food so as to curb the frequent food deficit. For example, in 1993/94 a total of 135,000 tonnes of cereals were imported in the country (URT, 1995b).

The low food production in Tanzania is contributed to a large extent by poor agricultural technical packages including inadequate research and lack of information on different agro-ecological zones (Kimaro, 1989), poor land use planning (Msanya *et al.*, 1999), poor crop husbandry and management and growing of crops in marginal areas. Low food production is also caused by unreliable rainfall (Kaboni, 1996), poor soil fertility (Eele *et al.*, 1992), land degradation and soil erosion (Mawenya, 1994).

Deliberate measures identified by the government towards increasing food production in the country include: (i) identifying and increasing access to new farm land by farmers and improving means of communication, (ii) intensifying production on already cultivated land through improved technologies and inputs, (iii) encouraging increased investment in small holder irrigation systems, (iv) increasing the availability of credit and other forms of financial support to the agricultural sector, (v) improving and speeding up the process of land surveying (Araki *et al.*, 1998) and issuing title deeds to individuals and communities, (vi) developing and setting aside grazing land (URT, 1998), (vii) encouraging agricultural production in areas with higher potential to maximise yields, (viii) encouraging large scale private farming to supplement small holder production to obtain surplus for export and (ix) emphasis on maize research and other crops using sound technical packages (Kimaro, 1989). In order to enhance the implementation of the above strategies, it is deemed necessary to carry out land evaluation studies to explore high potential agricultural areas of the country.

Morogoro region covers an area of about 73,000 km^2 which is about 8% of the total land of Tanzania (Ngasongwa, 1980). It has a high potential for agricultural production especially in valleys and plains such as Wami. Various food crops are grown in Wami area including bananas, sorghum, maize, rice, cassava, field beans and peas (Conyers, 1971; Cook, 1976). However, information on the potentials and constraints of land for production of food crops like maize and rice, and extensive grazing is lacking. This situation has lead to inappropriate land use and resulted to inefficient exploitation of natural resources, destruction of the land resource, poverty and other social problems. Since land is the ultimate source of wealth and the foundation on which many civilisations are constructed, the society must ensure that land is not degraded and that it is used according to its capacity to satisfy human needs for the present and future generations while also maintaining the earth's ecosystems. Part of the solution to the land use problem is land evaluation to support rational land use planning and appropriate and sustainable use of land and human resources. Therefore, there is a need to assess the land suitability of the Wami Plains for the production of food crops such as maize and rice, and for extensive grazing.

The information gathered from this study will enable the land users and developers of the Wami area to make proper decisions as to what crops and management level to be applied so as to meet the increasing food demand by the rapidly growing population. The results of this study will also provide recommendations on potentials and constraints of the land in the study area for strategic land use planning. The information generated can be transferred to other areas with similar conditions to provide a firm base for future research and assessment of land potential in Tanzania.

Assessment of potentials and constraints of land in Tanzania and Morogoro in particular have in most cases been carried out using conventional land evaluation systems. Such systems are quite tedious and time consuming as they are basically manual land evaluations involving large amounts of natural resource data. Introduction of computerised systems for land evaluation such as Automated Land Evaluation System (ALES) will be of tremendous benefit as they will assist to quickly process the large natural resource data base for decision making on land use and management and for timely generation of information required by investors.

This study therefore, intends to conduct land suitability assessment of a part of the Wami Plains with respect to maize, rice and extensive grazing. Specifically, the study has the following objectives:

1. to identify soils and terrain characteristics of the area.
2. to characterise soils of Wami area including their morphological and physico-chemical properties
3. to classify the soils of the area using internationally recognised systems of soil classification commonly used in Tanzania (i.e. FAO World Resource Base (WRB) (FAO, 1998) classification and USDA Taxonomy (Soil Survey Staff, 1998).
4. to assess the suitability of the area for maize, rice and extensive grazing using Automated Land Evaluation System (ALES).

CHAPTER TWO

LITERATURE REVIEW

2.1 Definitions and basic concepts on land evaluation

Some important definitions from FAO-style land evaluation have been given by various authors. These are synthesised and updated from those in (FAO, 1976, 1983, 1984, 1985).

"Land evaluation" is a process of assessment of land performance when the land is used for specified purposes (FAO, 1985), or all methods to explain or predict the use potential of land (Van Diepen *et al.*, 1991). Once this potential is determined, land use planning can proceed on a rational basis, at least with respect to what the land resource can offer (FAO, 1993). Thus, land evaluation is a tool for strategic land use planning as it predicts land performance, both in terms of the expected benefits from and constraints to productive land use, as well as the expected environmental degradation due to these uses. A comparison of requirements of different land uses is done against what the land can offer and the best land use alternative is selected on the basis of social, physical, political, economic and/or even ecological conditions (Young, 1973; FAO, 1976).

"Land" is an area of the earth's surface, the characteristics of which embrace all reasonably stable, or predictably cyclic attributes of the biosphere vertically above and below this area, including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity (e.g. reclamation from the sea, vegetation clearance, and also adverse results, e.g.

soil salinization) to the extent that these attributes exert a significant influence on present and future uses of the land by humans. However, the concept of land excludes purely economic and social characteristics. Land is therefore a wider concept than soil or terrain. Variation in soils, or soils and landform, is often the main cause of differences between land mapping units within local area and thus soil surveys are sometimes the main basis for definition of land mapping units. But since the fitness of soils for land use cannot be assessed in isolation from other aspects of the environment, land is often employed as the basis for suitability evaluation.

"Land mapping unit" (LMU) is a specific area of land that can be delineated on a map and whose land characteristics can be determined. It is the evaluation unit about which statements will be made regarding its land suitability. Land mapping units are defined and mapped by natural resource surveys, such as soil survey and forest inventory. Their degree of homogeneity or of internal variation depends on scale and intensity of the study. In some cases a single land mapping unit may include two or more different types of land, with different suitabilities, e.g. a river flood plain, mapped as a single unit but known to contain both well drained alluvial areas and swampy depressions.

"Land use" is any kind of permanent or cyclic human intervention to satisfy human needs from a complex of resources which are together called land (Vink, 1975). Thus, land use is the application of human control on natural ecosystems in a relatively systematic manner in order to derive benefits from it. Land use always involves specific surface areas and can be considered as a geographic concept which is a result of a continuous field of tension created between available resources and human needs. The activities in land evaluation which are specifically concerned with land use include two parts, namely, description of the kinds of land use and the assessment of the land use requirements.

Land use can be very different, ranging from areas of urban expansion, permanently cultivated cropland or extensive grazing land to biosphere reserves. It is obvious that each kind of land use, the criteria to be taken into account for evaluating the suitability of the land will differ considerably. Identifying and defining the relevant land use alternatives is important before carrying out a land suitability classification and this should be done even before the soil survey is carried out.

"Land utilisation type" (LUT) is a specific land use system with specified management methods in a defined technical and socio-economic setting, and with a specific duration or *planning horizon* (Rossiter, 1996). Constraints on production factors such as labour and capital affect the feasibility of the LUT while income expectations of the social groups engaging in a LUT are used to define overall suitability (Rossiter, 1995). The description of a LUT may include a time-series of activities and outputs. The definition of a LUT is not a complete description of the farming or other land use system but rather includes only those attributes that serve to differentiate the suitability of land areas, for example, those that can be expressed as "land use requirements" (LURs) with critical values in the study area. The definition of a LUT also includes attributes that limit the land use options by discarding those that are *a priori* unfeasible over the entire evaluation area. The degree of detail required varies with the scale and intensity of the study in question. Thus a rainfed arable farming enterprise based on maize and tobacco constitute a land utilisation type, as does any individual crop, tree species, or a particular kind of recreational park and tourism.

"Land characteristic" (LC) is an attribute of land that can be directly measured or estimated in routine survey, including remote sensing and census as well as natural resource inventory (FAO, 1976; Dent and Young, 1981) and that can be used for distinguishing between land units and used as means to describe land qualities. Examples include rainfall, slope angle, soil drainage class, effective soil depth, topsoil texture, available water capacity, biomass of vegetation, pH and soil nitrogen content.

"Land quality" (LQ) is a complex attribute of land that acts in a distinct manner in its influence on the suitability of land for a specific kind of use; the ability of the land to fulfil specific requirements for a LUT (FAO, 1976). It can not usually be measured or estimated in routine survey, and so must be inferred from a set of "diagnostic" LCs. The LQ expresses the "supply" side of the land use versus land area matching procedure. If the LUT is defined as a set of LURs, land suitability is based on the set of severity levels of the LQs corresponding to LURs. The value of a LQ may vary over time, resulting in a time-series of severity levels LQ*(t)*. Examples are moisture availability, erosion resistance, flooding hazard, nutritive value of pastures and accessibility. Moisture availability can be determined by a combination of characteristics such as the amount of rainfall, its distribution over the year, the available water capacity of the soil, and in some cases, the presence of groundwater table close to the surface or seepage moisture. FAO (1983) has identified 25 important land qualities to be used in land evaluation; some of these are very relevant in Tanzania (Samki, 1989).

"Land suitability" is the fitness of a given LMU for a LUT, or the degree to which it satisfies the user. Suitability expresses how well the LMU matches the requirements of the LUT. It may be expressed on a continuous scale of "goodness" (e.g. 0 to 100) or, more commonly, as a set of discrete classes, which are conventionally numbered from class 1 meaning "completely suited" upwards to some maximum meaning " completely unsuited". The land may be considered in its present condition or after improvements. The process of land suitability classification in accordance with FAO (1976) involves the following: (a) the description of a set of land use alternatives deemed important and relevant for the study area, (b) the description of a choice of land qualities (and land characteristics) which ecologically have the most direct influence on the performance of the selected land use alternatives, (c) quantification of the ecological requirements of the land use alternatives in terms of the chosen land qualities, i.e. soil fertility, soil moisture, erosion hazards, drainage conditions etc., (d) comparison of the requirements of the land use alternatives and land qualities.

Some LUTs require a combination of activities, each of which with different LURs. For example, a LUT of extensive grazing in a tropical area with a single rainy season may require some land that is dry all year and which will produce during the rainy season, and some that is seasonally flooded, that will produce pasture during the dry season, after flood waters have receded. Both types of land are necessary for the success of the LUT, which is defined to include the movement of animals between the two areas according to the season. To analyse this case, the LUT must be defined as a compound LUT, with several homogeneous (or, simple) constituent LUTs. Furthermore, the evaluation unit (the potentially-suitable land area) must be defined as compound LMU, with several constituent LMUs. According to Rossiter (1996), the general formulation is:

$S_{cLUT,cLMU} = f_{cLUT}(\{S_{hLUTi,hLMUj}\})$

where cLMU is the compound LMU made up of set of homogeneous constituents {hLMUj}, j =1...*n*, and cLUT is the compound LUT made up of a set of constituents {hLUTi}, i = 1...*m*.

To evaluate suitability in this situation, each homogeneous LMU is evaluated separately for each homogeneous component of the compound LUT, resulting in one thematic map of suitability of the *m* homogeneous LUTs. Then, spatial analysis is used on the set of thematic maps to see if location and size requirements are met for any of the compound LMUs. In the example, each homogeneous LMU is evaluated for its suitability for both dry and wet season grazing (i.e. the two homogeneous LUTs), and then the two maps are combined to find a compound LMU made up of homogeneous LMUs with right proportion, area, proximity, and adjacency requirements for the compound LUT "extensive grazing with migration".

"Severity level" (factor level or degree of expression of a LQ) is ranking or classification of the LQ, according to the degree of limitation or hazard associated with the LQ of a particular land area. Severity levels are conventionally numbered from level 1 indicating "no limitation" upwards to some maximum meaning "completely limiting" in the context of a specified LUT.

"Land use requirements" (LUR) is a condition of the land necessary for successful and sustained implementation of a specific LUT. A LUT may be defined by a set of LURs. A LUR expresses the "demand" side of the land use-land area matching procedure.

2.2 Land evaluation systems

2.2.1 Conventional systems

To date, land evaluation has been "pedocentric" (Rossiter, 1996), i.e. emphasising the soil resource and being carried out by soil scientists, mainly because the FAO land evaluation methodology was developed by soil scientists whose experience had been in agricultural land suitability classification. As such many countries have adopted the FAO framework for land evaluation (Samki, 1980).

In Tanzania the FAO methodology has been adopted as a conventional or local standard land evaluation method for evaluating land for various land uses (FAO, 1976). According to FAO (1976), this methodology comprises four categories in a decreasing generalisation namely; land suitability order, land suitability classes, land suitability subclasses and land suitability units. However, in Tanzania only the first three categories are used. Following the FAO (1976) principles for land evaluation land suitability assessment is normally carried out for several LMUs and a number of land use types. In most cases soil maps are the basis for the delineation of the LMUs. Other data on climate and vegetation are eventually superimposed on the soil map to produce land suitability for various uses (Van Diepen *et al.*, 1991).

2.2.2 Computerised land evaluation systems

Computers have been applied to land evaluation at different levels of detail. According to Elbersen (1989) there are many computerised land evaluation systems that have been developed to facilitate the interpretation of land and soil resource information for quick land suitability evaluation. Most of them are purely physical in nature and they assess suitability for various uses and often predict yields of specific crops under defined conditions of land, soil and climatic data.

The first implementation of the FAO Framework was the Land Evaluation Computer System (LECS) in Indonesia (Wood and Dent, 1983); which has recently been incorporated into the FAO's Agricultural Planning Toolkit (APT) to execute land evaluation at the regional level based on small scale soil surveys (Elbersen *et al.*, 1988). It assesses the suitability of land for specific kinds of use by comparing land qualities with the requirements of the particular type of use. The system is capable of handling a wide range of crops (Wood and Dent, 1983) both annual and perennial.

LECS consists of three modules; (i) a module for entry and validation of the agro-ecological data, and subsequent updating and maintenance for agro-ecological inventories. (ii) the LECS stage-1, Agro-ecological crop suitability module, covering analysis of the agro-ecological potential in terms of crop suitability and soil degradation hazard; the crop suitability being expressed without levels of input or management consideration. (iii) the LECS stage-2, which assesses agro-economic crop suitability and feasible soil conservation management options for different management levels (management and economic analysis module).

Automated Land Evaluation System (ALES) (Rossiter, 1990; Rossiter and Van Wambeke, 1994) is the second micro computer system. ALES has been used to implement several provincial, country and regional land evaluations (Johnson and Cramb, 1991; Mantel, 1994; Van Lanen *et al.*, 1992; Van Lanen and Wopereis, 1992; Venema and Daink, 1992). It is a specialised program for physical and economic land evaluation based on *in situ* land characteristics, using Land Qualities (Rossiter, 1995). Land evaluators use the program as a framework within which they build their own expert systems for physical land evaluation and simple micro-economic models of land suitability. It is usually applied to map units of natural resource inventories or to management units and can create thematic maps of all results in the IDRISI-GIS. It can also write the results to interchange files that can be read by spreadsheets, databases and other GISs.

ALES has the following components: (i) a framework for a knowledge base describing proposed land uses, in both physical and economic terms; (ii) a framework for a data base describing the land areas being evaluated (Rossiter and Van Wambeke, 1989); (iii) an influence mechanism to relate (i) and (ii) thereby computing the physical and economic suitability of a set of map units for a set of proposed land uses; (iv) an explanation facility that enables model builders to understand and fine-tune their models; (v) a consultation model; (vi) a report generator.

ALES evaluation follows that of the FAO methodology. The evaluation consists of a set of land utilisation types and a set of map units. Each map unit is evaluated for its suitability for each LUT. While computing a physical evaluation, ALES shows the degree of suitability of a land disregarding economic conditions and emphasises on the relatively permanent aspects of suitability rather than the fluctuating ones like prices.

The economic evaluation of ALES is intended to provide the land use planners with a realistic estimate of economic suitability of each map unit for each proposed land use. Economic suitability tells the evaluator the degree to which a given land satisfies the land user which in turn depends entirely on the financial feasibility of the land user. In any case for land to be classified as suitable, it must result in a positive gross margin, but beyond this minimum standard, the concept of 'economic suitability' depends on the financial expectations of the land user who will implement the LUT (Rossiter, 1995). This suitability can be based on a predicted gross margin. The link between gross margin and the land use requirements is as follows: If there are limitations, the result is that there will be an increase in the cost of production and hence, lower gross margins. The results are given in the form of a matrix which answers questions like: where is the best land for each land use?.

Another computer program is a microcomputer-based Mediterranean land evaluation information system (MicroLEIS) (De la Rosa *et al.*, 1992) for land evaluations in Mediterranean climates. Land evaluation by map analysis techniques may be accomplished with any geographical information system (GIS) (Burrough, 1986; 1987). Among these systems LECS and ALES are capable of incorporating the results of farming systems analysis (Elbersen, 1989) to arrive at a complete agro-economic suitability assessment and are both developed within the FAO framework for land evaluation.

2.3 Computerised land evaluation systems used in Tanzania

Kimaro (1989) carried out a study to assess the suitability of Kilosa soils for the production of rainfed maize using both LECS and ALES. He concluded that LECS is capable of producing realistic predictions of yield values provided that the available phosphorus is corrected according to a formula derived from the QUEFTS. In this study ALES was found to be compatible due to its flexibility. Kimaro and Kips (1991) carried out physical and economic land suitability assessment for smallholder low-input maize in Kilosa District using ALES and concluded that ALES could fairly well be adapted to the physical and agro-economic evaluation conditions in the test area especially when a multi-disciplinary approach is employed.

Magoggo and Meliyo (1994) carried out land suitability of Mbulu District using ALES. Kimaro and Msanya (1999) have done a study to assess the applicability of ALES and LECS to Tanzanian conditions: a case study of Kilosa District. The conclusions reached were similar to those obtained by Kimaro (1989).

2.4 Land evaluation for extensive grazing

Extensive grazing is the predominant form of land use on at least a quarter of the world's land surface, in which livestock are raised on food that comes mainly from rangelands (FAO, 1991). The term livestock includes both domesticated animals such as cattle, sheep, goats, camels, horses etc. and a broad range of wild animals kept for meat or game viewing. It is estimated that tropical grasslands alone cover 18 million square kilometres, where the natural vegetation is used by mobile animals requiring forage and water throughout the year. It is the animal production system that rely mainly on a food resource base of natural and naturalised vegetation that is not subjected to major improvements via management. Inputs for improvements to the primary production are minor; inputs to meet the requirements of animals or management may be included. A special characteristic of extensive grazing is the multi-stage production character of the land (ground cover, shrub layer, trees). Another characteristic of extensive grazing is the ability of animals to move from one land unit to another. Adjoining contrasting land units that are unsuitable on their own, can be suitable if both can be used alternatively (e.g. land unit A does not have drinking water available, but all other requirements are met; land unit B does not have enough forage, but can provide shade. The distance between "shade" and "water" is acceptable for the animals). Other important aspect in extensive grazing is connected with the mobility of the herds, i.e. the seasonality of the utilisation of the land. Therefore seasonal LUTs need to be defined (e.g. areas for winter and summer grazing; dry and wet season grazing, etc.). Extensive grazing, as a land utilisation type, can be subdivided into nomadic pastoralism, transhumance and sedentary pastoralism.

Rangeland can be defined as a tract of land currently used for grazing by domestic livestock and/ or wildlife, where natural vegetation is the main forage resource (Gils, 1984). They may be used for ranching, where animals graze on private and usually fenced land, or for three other systems of extensive grazing: nomadic pastoralism, transhumance, or sedentary pastoralism.

2.5 State of land evaluation in Tanzania

Land evaluation in Tanzania dates back to the colonial days when attempts were made by farm planning staff to use the land according to its capability to produce crops (Mpepo, 1986). The capability classification was on the basis of slopes in relation to erosion. Since 1967 the Bureau of Resources Assessment and Land Use Planning (BRALUP) has carried out broad land evaluations for social and economic planning. The bulk of these evaluations are on demography, rainfall and communication (Mpepo, 1986).

Samki (1989) carried out a land suitability classification of an extensive agricultural area in Tanga region (Tanga Livestock Research Centre, Kange Dairy Farm, Pongwe Sisal Estate, and Azimio Ranch) for sisal, citrus, maize and groundnuts using local land evaluation system. Six land units were identified in this study area. He concluded that maize and groundnuts were marginally suitable in all the land units and sisal in three land units. Sisal was marginally unsuitable in three land units and citrus in three land units; citrus was highly unsuitable in two land units and marginally suitable in only one land unit.

Other studies on land evaluation include those of Kaaya *et al.* (1994) who carried out land suitability classification of a part of the Sokoine University of Agriculture (SUA) farm based on slope, soil drainage, topsoil texture and effective soil depth; land suitability assessment of Mtibwa Sugar Estate for optimum sugarcane production (Mushi, 1983); suitability assessment of soils of SUA farm for production of various crops (Mpepo, 1986); suitability assessment of Mkindo irrigation scheme (Morogoro) for rice production (Semoka *et al.*, 1985) and suitability assessment of soils of the SUA farm for maize cultivation under different levels of management (Sharma, 1986).

In recent years computerised land evaluations have been applied in Tanzania including those of Kimaro (1989), Kimaro and Kips (1991), Magoggo and Meliyo (1994) and those by Kimaro and Msanya (1999).

2.6 Measures of economic suitability

There are various 'yardsticks' which may be used for economic land suitability evaluation. The choice of a measure for use depends much on the economic reality faced by decision makers, as well as their values and attitudes towards money and risk.

2.6.1 Gross margin

This is the cash flow into the LUT, less the cash flow out of the LUT, on a per unit area (normalised) or aggregate (per-field or per-farm) basis, in one accounting period (usually a year) (Rossiter, 1995). If the gross margin calculated includes the fixed cost of production, it is called 'net return'; otherwise the 'gross return'. This measure does not take into account the time value of money. Thus, the gross margin is not sensitive to interest rates, and as such is a good first approximation of financial feasibility. It is an appropriate measure of economic suitability for annual or short-term rotational LUTs with few or no capital costs.

2.6.2 Capitalised value

This variant of the gross margin accounts for the time value of money. The annual return from a steady-state investment is a percentage of the total value of the investment determined by the interest rate. So, the total value can be calculated as EV = GM/IR, where EV is the estate value, GM is the annual gross margin, and IR the interest rate in percent. It is an appropriate measure of economic suitability in the same situations as the gross margin. The capitalised value is an approximation to the portion of the land's value that can be attributed to its productive capacity.

2.6.3 Discounted cash flow analysis

Money received in the future is less valuable than money in hand. To take into account this 'time value of money', amounts received or spent in the future are discounted to their present value according to the formula:

$PV = FV \times [100/100+IR]^{Y}$ where PV is the present value, FV the future value, IR the interest rate in present, and Y is the number of years from present, counting from zero. A typical use of discounted cash flow analysis is to evaluate the economic feasibility of agricultural project such as land reclamation, where an initial investment is expected to yield benefits in the future.

There are three measures derived from the discounted cash flow and which can be used in land suitability evaluation. These include:

i) Net present value (NPV)

This is defined as the total value of the cash flows to be generated by the LUT, summed over its planning horizon, discounted to the present. It can be annualised, since each year is discounted differently.

ii) Internal rate of return (IRR)

This is the interest rate below which land use option (project) becomes financially attractive. At higher prevailing interest rates than the IRR, an investor would be better off investing the required capital at the offered rate rather than investing in the project. Mathematically, it is the discount rate below which the NPV becomes positive. The IRR is dimensionless, with no spatial or temporal component, and so can be used to compare land uses with different planning horizons. It is a rough measure of the financial risk of a project that is due to rising interest rates, and is often used to compare investment options.

iii) Benefit-to-cost ratio (BCR)

This is the present value of the cash-in divided by the present value of the cash-out. The project is said to be feasible if and only if the BCR >1. The BCR is a measure of the return to investment; thus the BCR is an appropriate measure for the land user who wants to maximise the leverage of a limited investment.

Other measures of economic suitability include utility, non-cash measures and economic suitability classes.

2.7 Factors to include in the calculation of economic suitability

Since land is the entity being compared in land evaluation, no costs associated with acquisition or rental of the land should be included in any of the economic measures. Economic suitability may be expressed in terms of return to labour or the return to land. In the first case, the farmer's family labour is not included as an expense, and the gross margin must be sufficient to allow the farm family an adequate income. In the second case, some of the family's income has been accounted for, since their labour is included in the expenses as if labour had been hired.

If the land areas to analyse are map units or delineations of natural resource inventories or management units, labour is usually included as an expense (Rossiter, 1995); if the units of analysis are production units (e.g. farms), family labour is usually omitted, because the return to labour is not on the basis of one land area but on the basis of the whole farm.

2.8 Crop requirements

2.8.1 Crop requirements for maize (*Zea mays*)

Maize has a wide range of tolerance to environmental conditions, short-season varieties being able to develop with as little as 300 mm of rainfall in the growing season, and 750 mm or more for longer-season varieties. The growing period ranges between 90 to 150 days depending on maize variety. Young maize plants (3 to 5 weeks) can tolerate low moisture supply than older ones. Maize crop is most sensitive to moisture stress from the beginning of tussling until the end of grain formation (i.e. 50 to 100 days from planting).

The growth of the crop is optimal at temperatures between 18°C and 32°C. The minimum temperature should be in the range of 12 °C to 24 °C; with the mean maximum temperature range of 26 °C to 29 °C.

Maize can be grown on a wide variety of soils. The best are well drained, well-aerated, deep, loams, silt loams and clay loams with adequate organic matter. For soils with a low moisture potential, or in areas of low rainfall, a low plant density should be used to avoid competition for water and nutrients. The pH range from 5.0 to 8.0, but 6.0 to 7.0 is optimal.

Nitrogen is the most important nutrient. Young maize has difficulty in taking up phosphorus from the less available phosphate forms in the soil. The maximum rooting depth is 2.0 m but the most active roots ranges between 80 to 100 cm deep.

Maize crop has low tolerance to salinity and sodicity, and a moderate tolerance to aluminium toxicity. ECe values at initial yield decline thresholds are 1.8 mS/cm for forage corn, 1.7 mS/cm for sweet and grain corn (Landon, 1996). Landon (1996) reported yield decrease per unit increase in salinity beyond the threshold of 7.4% for forage corn, 12% for sweet and grain corn and 50% yield reduction when ECe = 10 mS/cm. Maize shows a medium tolerance to boron.

2.8.2 Crop requirements for rice (*Oryza sativa*)

Wetland rice

Rice tolerates a very wide range of climatic conditions and can be grown in temperate or hot tropical climates from sea level to high altitude. The average temperature should lie between 20°C and 38°C during the growing period. Long periods of sunshine are essential for high yields. Availability of irrigation water is probably more important than rainfall though ideally both should be in good supply. Good management is more important than an ideal soil or climate.

Rice crop grows on a wide range of soils, there being no optimum soil. Heavy alluvial soils of river valleys and deltas are usually better suited to rice than lighter soils, though rice can be grown on many soils from sandy loams and shallow lateritic soils to heavy clays. It should be possible to puddle the soil to maintain a high water-table during growth, and to drain the soil for ripening and harvesting.

The optimum pH is 5.5 to 6.5 when dry, though this may rise to 7.0 to7.2 when flooded.

Sys and Riquier (1979), suggests an optimal pH-range from 5.5 to 7.5 for rice; as marginal values they accept a lower range down to 5.2 and an upper limit of 8.2. Cultivation is possible on alkaline soils, e.g. black soils in India have a pH of 8.0 to 9.0.

Rice crop shows a medium tolerance of soluble salts (50% yield reduction with ECe = 10 mS/cm). ECe at initial yield decline threshold is 3.0 mS/cm. At the other hand the rice crop supports a high alkalinity status. Up to 10 to 20 % sodium saturation no yield reductions have been observed. Sodium saturation levels from 30 to 40 percent are marginal (Sys and Riquier, 1979).

Upland rice

During its shorter growing season upland rice responds to the same soil conditions as irrigated or 'swamp' rice. In Asia this is generally appreciated but in Africa much upland rice is grown on soils that are too sandy, shallow or pervious, hence the very poor yields are commonly obtained.

2.8.3 Requirements for extensive grazing

The primary consideration for extensive grazing is its tendency to cause erosion. Thus prime grazing lands are those that are unlikely to be eroded (e.g. Mbuga and other bottomlands). Ideally, grazing lands should be within reach of water points away from cultivation fields. Trampling of animals (especially cattle) in the crop fields is undesirable. Therefore, good grazing lands are those that, have good biomass productivity and availability of water points and do not require animals to traverse through arable lands while to and from the homesteads. Factors of terrain (e.g. very steep slopes or very rocky lands), tsetse infestation etc. reduce the suitability of lands for extensive grazing (Appendix 8).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Geographical location

The study area extends from the footslopes of Nguru ya Ndege mountains to the south and extends to as far as "Mbuga ya Rumanda" to the north-west. The area is within Morogoro Rural District. Approximate geographical co-ordinates are 37°30′00″ to 37°38′6.7″E and 6°30′ to 6°41′3.3″S. Average elevation of the study area ranges from 380 m.a.s.l. in the north-west to about 600 m.a.s.l. in the south-west. The areal extent of the study area is about 35,810 ha (358.10 km^2) and is covered by the topographic map sheet 183/1 (Nguru ya Ndege).

3.1.2 Climate

Generally speaking Morogoro experiences a sub-humid and semi-arid type of climate. The climatic conditions are very variable due to the marked variation in relief. The constant easterly direction of the rain-carrying winds combined with the NE orientation of the Uluguru mountain ranges has led to the uneven distribution of rainfall in Morogoro. Although the rainfall amounts tend to vary locally and generally decrease gradually with increasing distance from the Uluguru mountains, the pattern of variation of climatic conditions in the plains is generally similar. The area receives a mean annual rainfall of about 600 mm. Since the study area has at least one rainy season of at least three months, it follows therefore that the area has ustic soil moisture regime (Soil Survey Staff, 1996).

The mean monthly air temperature range from 21.1°C in July to 26.5°C in December with mean annual air temperature of 24.3°C. The mean annual soil temperature has been estimated to be 25.3°C after adding 1°C to the mean annual air temperature (Soil Survey Staff, 1975). Moberg *et al.* (1982) reported a soil temperature amplitude of 2-4°C higher than the average air temperature above the soil because soil absorbs the sun's heat much more readily than air does and thus the soil temperature regime for the surveyed area is classified as iso-hyperthermic.

3.1.3 Geology, physiography, landforms and soils

Geology

Geology of the area is described as "Mbuga", "Alluvium" and "Red and reddish-brown soils" of Neogene age (Sampson and Wright, 1961). The underlying geology in the area is comprised of old precambrian rocks of the Usagaran system which have suffered a different plutonic history and thus different sedimentary facies. The metasediments formation comprises of both migmatite and acid gneiss.

The migmatitic formation consists of microcline-quartz rocks with abundant muscovite and biotite. Bands rich in biotite alternate with others lacking mica and give the formation a strongly banded appearance. The acid gneiss formation is composed of strongly foliated, micaceous gneisses, with predominant biotite. Some bands are rich in hornblende. With increase in the hornblende-rich bands, the rocks grade into hornblende gneisses and granulites. The presence of hornblende granulites suggests that the whole formation had previously attained the granulite facies of metamorphism but has subsequently been modified in places by migmatization.

Physiography and landforms

The topography of the area is a mixture of flat or almost flat to undulating slopes (0.5-6%). Local depressions are observed from place to place. Undulating areas of peneplanes including footslopes have moderately deep, deep or very deep soils. Almost flat areas (river plains and bottomlands) have in general deep to very deep soils. Soils in depositional landforms such as river plains and mbuga are generally somewhat more fertile than those in erosional landforms (e.g. peneplane-summits and on middle slopes) due to accumulation of nutrients.

On the upper and lower slopes of the peneplane soils are dominantly well drained. In valley bottoms, floodplains and mbuga moderately well drained to very poorly drained soils are common. Here hydromorphic processes dominate the soil development. Accumulation of secondary lime in the subsoils is common in these soils. Dark cracking clays are characteristic in mbuga.

The three major landforms are described in the study area. These include piedmont (Pi), peneplane (Pe) and plain (PL). Piedmont is situated at an altitude range of 520 -600 m.a.s.l. Most of them have almost flat to undulating topography. The second major landform, the peneplane (Pe) is situated at an altitude range of 480 to 520 m.a.s.l. The peneplane consists of ridge summits (Pe1), ridge slopes with red soils (Pe2) and ridge slopes with sandy soils (Pe3) and valley bottoms (Pe4). The third major type of landform is the plain (PL) which consists of flats with red soils (PL1), flats with sandy soils (PL2), floodplain (PL3) and Mbuga (PL4) with almost flat to flat topography and are situated at altitudes between 380 to 480 m.a.s.l.

Soils

Neogene rocks are to be found on the peneplanes to the north, stretching on to the floodplain of the Wami River. Superficial deposits occur mainly on the plains including deep red soils, clays, sands, limestones, "mbuga" deposits and alluvium. Soil of the area are complex of: Deep, well drained, dark greyish brown clays, and moderately well to imperfectly drained, dark greyish brown, sandy clay and very shallow, well drained, dark reddish brown, sandy clay to clays.

The piedmont slopes and peneplanes have moderate to very deep, well drained dark reddish brown sandy clays to sandy loam soils. On the valley bottoms soils developed from fluvial deposits are to be found. These soils are complex of: shallow to deep, moderately well drained black to dark brown sandy clay loams. The soils are stratified as a result of cyclic deposition of materials of diverse origin (Msanya *et al.*, 2000).

3.1.4 Vegetation and land use

Natural vegetation

Under natural conditions almost the whole of the Wami plains would be lightly or thickly wooded with very little open grassland. However, native cultivation, charcoal burning and cutting trees for timber have replaced the natural vegetation to a very large extent. This together with uncontrolled grazing has led to soil erosion leaving bare land in some places. There are remnants of *miombo woodland* in which the typical species are *Brachystegia boehmii*, *B. bussei*, *Isoberlina* spp. and *Acacia nigrescens* as characteristic tree species.

There are two types of timber of economic importance which are *Pterocarpus angolensis* (mninga) and *Afzelia quanzensis* (mkongo) which are very valuable and are among the few timbers that are resistant to termite/ant damage. Thickets, bushes, scrub and tussock grasses dominated by *Panicum maximum*, *Cynodon* spp. and *Hyparrhenia rufa* are to be found in most places of the surveyed area.

Land use

Most of the study area is utilised for subsistence cultivation of various food crops including maize, cow peas, cassava, beans and bananas under rainfed conditions. Few fruit trees such as mango, oranges and some cashew and coconuts are observed in some places. Large area east of the Morogoro- Dodoma road is used as fuel reserve while rests of the study area is used for extensive grazing. Extensive grazing, clearing of woody vegetation for fire wood, timber and charcoal burning are the most of important human activities in the study area.

3.2 Pre-field work activities

3.2.1 Collection of materials and relevant data

Prior to field work, collection of materials such as geological and topographic maps, aerial photographs (AP), climatological data and vegetation data was done. Review of existing literature was also done to identify areas underlain by different parent materials/rocks on the basis of age/stratigraphy of rocks, lithology and geomorphological parameters.

3.2.2 Aerial photo interpretation.

Aerial photo interpretation (API) was done stereoscopically using a Leica APT2 stereoscope. This exercise was done in order to get a general impression of features which are commonly related to kinds of soils. Land units were identified based on relief features and then delineated on the aerial photos. Aerial photos used in this study were taken in 1964 and 1966 at an approximate scale of 1:40,000.

The geomorphic units established during API were then used to predict broad soil patterns and the associated range of soil properties since the processes responsible for landform features are known to have strong influence on parent materials and soils.

The resulting soil landscape mapping units represent associations and/or complexes of soils described and delineated by means of geomorphic units. These were then scaled down and transferred to a base map obtained from the available topographical maps at a scale of 1:50,000 on which field survey and soil investigations were to be based.

3.2.3 Socio-economic data collection

Semi-structured questionnaires were used for socio-economic data collection using key attributes like production packages, farming systems, capital and labor intensity, level of technical know-how, observed yields and prices, land tenure and farm size, information related to population and extension services. Informal meetings with farmers provided additional information which was used in the definition of LUTs. These data were used in ALES model for economic suitability evaluation.

3.3 Field survey and revision of mapping units

3.3.1 Land resources survey

Free survey procedure was adopted (Dent and Young, 1981). Soil survey and mapping was done at a semi-detailed scale of 1:50,000 (observation intensity of 1 observation per 12.5 ha). Reconnaissance visits of the study area for a general appreciation of landforms and confirmation of boundaries made on the physiographic maps were done. Selection of representative transects in sample area was done and soils were described along the selected transects by hand augering to a depth of 100 cm except where there was a limitation by bedrock or other limiting layers.

The information recorded at each auger hole include vegetation type, slope (%), soil drainage, soil colour, soil texture, soil structure (topsoil), soil consistence, surface cracks and surface stoniness (if present). This information was then used to make the general description of soils of each mapping unit.

Basing on information from auger hole observations in different delineated land units, representative soil profile pits for all major soil types were excavated to a depth of 2 m or to lithic or paralithic contact and described according to FAO (1990) and WRB (FAO, 1998) Guidelines for Soil Profile description, and the data were recorded on profile description forms. Moist and dry soil colours were described using Munsell Soil Colour Charts (Munsell Colour Company, 1992).

Both undisturbed and disturbed soil samples were collected following the generally practised soil survey procedures (FAO, 1967, 1976, 1977; Young, 1976; Dent and Young, 1981; ILACO, 1981). The disturbed soil samples were used for physical and chemical analysis. Undisturbed core samples were taken and used for the determination of the soil moisture characteristics and bulk density. Composite soil samples (0-20) and (25-50) cm depths were collected for general soil fertility evaluation.

Global Positioning System (model GARMIN 12XL) was used to determine the geographical locations of the sites.

3.3.2 Climatic data collection

Climatic data on rainfall, temperature, and evapotranspiration were collected from Kihonda and Wami Prison meteorological stations which were found to be representative of the study area both in proximity and altitude. These data were compiled and analysed to produce physical land suitability appraisal for agricultural land use planning.

Mean annual temperature collected from Morogoro meteorological station was used to calculate the evapotranspiration using Blaney-Criddle methodology (FAO, 1991) for Kihonda and Wami Prison meteorological stations.

The length of the rainy and growing seasons are calculated according to FAO (1984) methodology based on mean monthly rainfall and potential evapotranspiration (ET_o) which assumes 100 mm soil moisture storage. The rainy season here is defined as the period between the time when rainfall first exceeds half the potential evapotranspiration to the time when rainfall again falls below half the potential evapotranspiration. This period normally includes a humid period, i.e. a period when rainfall exceeds the potential evapotranspiration.

Woodhead's equation was used to calculate the average annual evaporation (E_o) (Woodhead, 1968). This equation relates E_o to the altitude as follows; $E_o = 2422 - 0.358$ h (E_o in mm; h in m). The values of E_o were then related to rainfall to obtain the 'moisture availability index' (r/E_o), which is defined as the ratio of the measured mean annual rainfall (r) and the average annual potential evaporation (E_o).

3.4 Post-field work activities

3.4.1 Laboratory methods

Soil samples were air dried, ground and sieved through a 2 mm sieve to obtain the fine earth fractions. Particle size distribution was carried out by Hydrometer method as elaborated by Gee and Bauder (1986). There was no need of pre-treatment to remove organic matter because its content is too low. Bulk density for non-stony soils was determined by core method (Black and Hartge, 1986) while bulk density for shrink-swell soils was calculated as follows; Bulk density $_{(max.)}$ = $1/(W_{max.} + 0.4046)$ (Shaw and Yule, 1978) where $W_{max.}$ is the maximum gravimetric water content of the horizon in question (the field saturated water content). Soil moisture characteristics was determined by sand/kaolin box and pressure membrane apparatus (NSS, 1990).

The pH of the soil and water samples, and that of saturated soil paste extract was determined potentiometrically in water and 1MKCl at the ratio of 1:2.5 soil-water and soil-KCl respectively (McLean, 1986). The electrical conductivity of the saturated soil paste extract (ECe) for soil samples was determined by an EC meter at a standard temperature of 25°C at the ratio of 1:2.5 soil-water (Rhodes, 1982). The exchangeable bases were determined by atomic adsorption spectrophotometer (Thomas, 1982). The CEC of soils with pH < 7.5 was determined by NH_4OAc method, at pH 7.0, and soils with pH > 7.5 was determined by sodium saturation method with sodium acetate, at pH 8.2 (Hesse, 1971).

Total exchangeable bases, base saturation and ESP were determined by calculations. CEC of clay was calculated using the following formula (Baize, 1993) which corrects for the CEC contributed by organic matter; $CEC_{clay} = [CEC_{soil} - (\% OM \times 2) \times 100]/\% clay$. Organic carbon was determined by Walkley and Black wet-acid dichromate digestion method (Nelson and Sommers, 1982). Organic matter percentage was estimated by multiplying the percentage organic carbon by 1.724.

Total nitrogen was determined by Semimicro Kjeldahl digestion followed by ammonium distillation titrimetric determination (Bremner and Mulvancy, 1982). Available phosphorus was determined by Kurtz-Bray-1 and Olsen method (Olsen and Sommers, 1982). Available Zn, Cu, Fe and Mn were extracted with DTPA solution (pH 7.3) and analysed on atomic absorption spectrophotometer. Available B was extracted in hot water and analysed on UV/VIS spectrophotometer. Calcium carbonate content was determined titrimetrically following methods outlined by National Soil Service (NSS, 1990).

3.4.2 Soil classification

Soil properties identified in the field and those determined from laboratory analysis were used to classify the soils based on FAO classification system (WRB) (FAO, 1998) up to third level soil unit names and USDA Soil Taxonomy (Soil Survey Staff, 1998) to the subgroup level names.

3.5 Land evaluation

3.5.1 Rating of land utilisation types (LUTs)

Land evaluation for agricultural suitability of the soils was done by matching LQs and LURs in ALES program. Class limits for the LUTs were set on the basis of farmers experience and literature sources. The LURs were rated as (1) no limitation, (2) moderate limitation, (3) severe limitation and (4) very severe limitation. The final physical suitability of the soil units was decided using the decision tree severity levels provided in ALES computer program and following Liebig's law of minimum (Rossiter and Van Wambeke, 1989) by which the most limiting LUR determines the suitability class. Four physical suitability classes were defined as (1) good potential, (2) moderately potential, (3) poorly potential and (4) very poorly potential.

3.5.2 ALES model building

ALES model was established using ALES software and different statistical techniques for use by farmers in the Wami and other areas with similar agro-ecological conditions. The following components were used for entry in the economic model; commodity price, maximum attainable yield and kind and cost of material and labor inputs.

LURs that are useful in the land suitability evaluation for rainfed maize, rice and extensive grazing were rated (Appendices 6, 7 and 8) respectively. The ratings of LURs were used in model building (severity level decision trees) for physical suitability classification. The decision trees for maize, rice and extensive grazing are presented in

Appendices 9, 10 and 11 respectively. The decision tree depends much on the expert knowledge of the model builder on soil and agronomic aspects of each LUT. The optimum yield for the LUT in consideration were specified, and the limiting yield factors for each severity level were established. The law of minimum was applied in which the most limiting factor determines the yield.

Data from soil survey, laboratory soil physical and chemical data, socio-economic and climatic data were coded to produce digital database file (Appendix 4) which was then entered from the keyboard into the ALES programe.

3.5.3 Data handling and preparation of soil map

Input of the field and laboratory analytical data recorded on the analogue forms into the digital soil data base management system (SISTAN) (Magoggo, 1991) was done (Appendix 1). Base map derived from aerial photo interpretation was digitised using ARC/INFO Geographical Information System (GIS) software to produce the final soil map of the study area (Appendix 13).

3.5.4 ALES analysis

ALES was used in land evaluation of the study area (Rossiter and Van Wambeke, 1989; 1994) and also to predict yields on the basis of limiting yield factors. Predictions were made by multiplying the chosen yield factors with maximum attainable yield. The yield factors were derived from the proposed FAO suitability classes (FAO, 1984).

These are 80-100% (S1), 40-80% (S2), 20-40% (S3) and 0-20% (N1) of the maximum attainable yield. FAO suitability classes were used as follows: S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), N2 (not suitable for physical reasons) and N1 (economically not suitable). Except for S1, all other classes have subclass indicated by small letters meaning the most limiting land quality. The ALES yield factors were: class 1=1, class 2=0.8, class 3=0.4 and class 4=0.2. Predicted yields derived from the physical evaluation were used to carry out the economic suitability classification. Gross margin was used as a measure of economic suitability in which economic suitability class limits were set using the gross margins based on the maximum attainable yields.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soils and terrain characteristics of the area

4.1.1 Climatic data base

Climatic data particularly moisture availability are important in order to assess the potential of the land for crops and livestock. The most important climatic factors affecting plant growth are rainfall, temperature and evapotranspiration.

Rainfall

The average rainfall in Wami Plains ranges from 768 mm in the southern part to about 1036 mm in the northern part. The rainfall pattern is largely monomodal i.e. with a single rainy season and dry conditions during the rest of the year. Rains start in December through May with a slight decrease in February (Table 1). April is the wettest month in the study area with a mean rainfall varying between 139 and 204 mm. In May the rainfall decreases to between 59 and 94 mm.

Temperature

The seasonal distribution of temperature is almost the same throughout the surveyed area with the coldest month in July (21.2-21.9°C) and the hottest month in December (26.0°C) (Table 1).

Evapotranspiration (ET_0)

Generally evapotranspiration increases during the dry season, reaching a maximum in November- December (162-165 mm), just in the onset of rainy season and reaches its minimum in July (142-145 mm) (Table 1). As observed from the Table 1, the seasonal variation of potential evapotranspiration is rather small compared to the seasonal variation in rainfall (Figure 1).

Growing season

The relationship between rainfall and evapotranspiration gives an indication of the onset date, duration and quality of the growing season. According to the results in Table 1, the length of growing season varies from about 5 months, from December through April in southern part (Makunganya) to 6 months, from December through May in the northern part (Rumanda, Sokoine and Dakawa).

Table 1. Rain season, humid months and growing season, calculated according to FAO (1984) at selected rainfall stations in Wami Plains

Met. Station	Climatic parameter	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Year
Wami	Temperature (°C)	22.9	24.3	25.4	26.2	26.0	26.0	25.8	24.7	23.2	21.3	20.8	21.8	24.0
Prison	ET_o	150.1	155.3	159.4	162.4	161.7	161.7	160.9	156.8	151.2	144.2	142.3	146.0	1429
(579 m)	$05ET_o$	75.1	77.7	79.7	81.2	80.9	80.9	80.5	78.4	75.6	72.1	71.2	73.0	1852
	Rainfall (mm)	17	43	68	139	138	110	161	204	94	19	11	7.5	1036
	Rain season				+	+	+	+	+	+				
	Humid months								+					
	Growing season				+	+	+	+	+	+				
Kihonda	Temperature (°C)	23.5	24.9	26.0	26.8	26.6	26.6	26.4	25.3	23.8	21.9	21.4	22.4	24.6
(480 m)	ET_o	152.4	157.6	161.7	164.7	163.9	163.9	163.2	159.1	153.5	146.4	144.5	148.3	1879
	$05ET_o$	76.2	78.8	80.8	82.4	82.0	82.0	81.6	79.5	76.7	73.2	72.3	74.1	
	Rainfall (mm)	13	26	70	117	129	90	121	139	59	9.2	9.5	5.1	768
	Rain season				+	+	+	+	+					
	Humid months													
	Growing season				+	+	+	+	+					

ET_o = Potential evapotranspiration (Penman); 0.5 ET_o = half of the potential evapotranspiration; + = this month is part of the rainy season (if rainfall > 0.5 ET_o); a humid month (rainfall > ET_o) or part of the growing season.

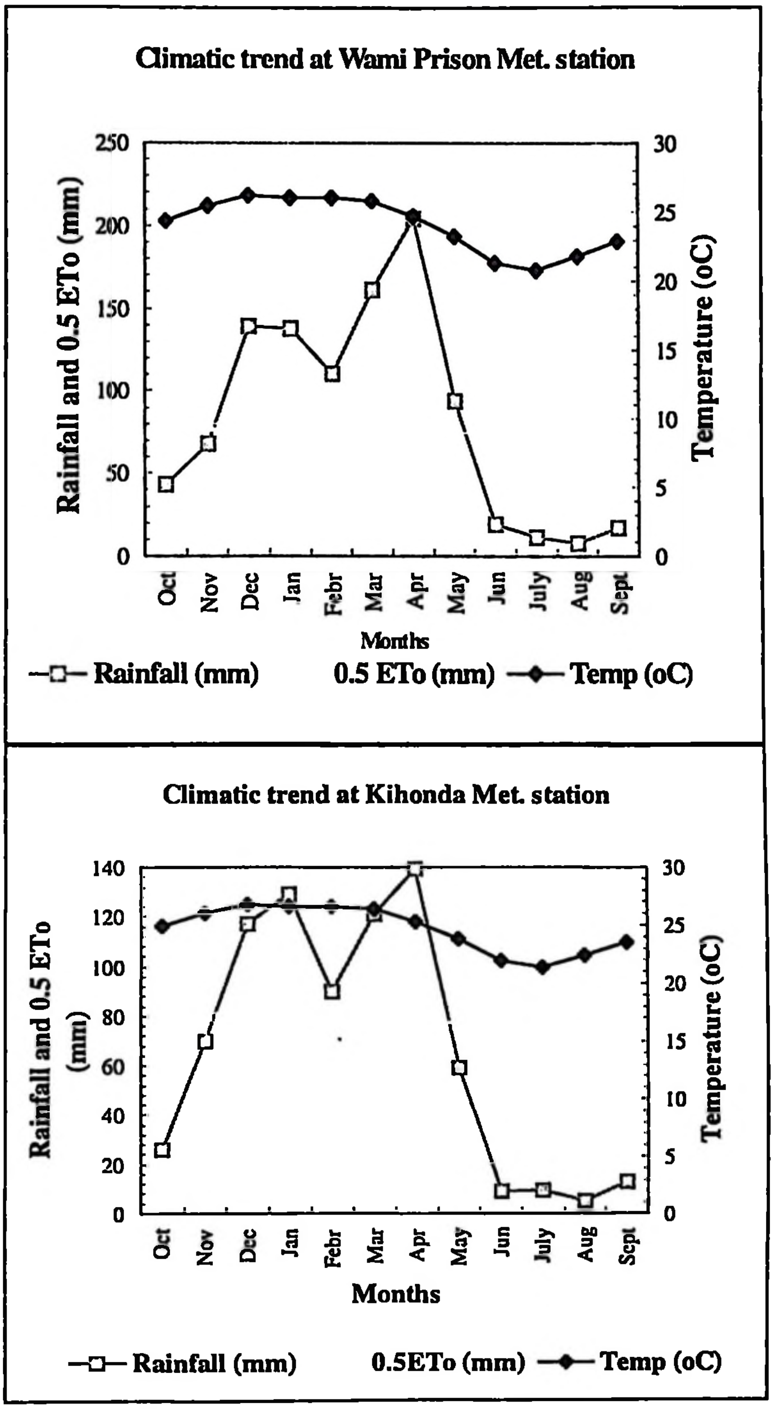

Figure 1. Climatic regime at two meteorological stations in the study area

The southern part (Makunganya) has no humid months whereas the northern part (Dakawa, Sokoine and Rumanda) has only one humid month (April). It must be noted that the length of growing season calculated here gives only rough indications of the length of the growing season, based on several assumptions. The modifications of the growing season due to soil-specific moisture storage capacity and crop-specific evapotranspiration have not been taken into account. Furthermore, it has been assumed that all rainfall is effective i.e. no rainfall is lost by runoff or deep percolation beyond the reach of the plant roots.

Table 2. Average annual potential evaporation (E_o) and moisture availability index (r/E_o) in Wami Plains

Mapping unit	Soil unit	Altitude (m)	E_o (mm)	Mean annual rainfall (mm)	r/E_o
Pi1	NYN-P8	465	2255.5	768	0.340
	NYN-P11	580	2214.4	768	0.347
Pe1	NYN-P12	460	2255.3	768	0.340
Pe2	NYN-P1	480	2250.2	768	0.341
Pe3	NYN-P3	530	2232.3	768	0.344
Pe4	NYN-P2	420	2271.6	768	0.338
	NYN-P4	440	2264.5	768	0.339
PL1	NYN-P7	420	2271.6	1036	0.456
	NYN-P10	440	2264.5	1036	0.457
PL2	NYN-P6	420	2271.6	1036	0.456
PL3	NYN-P9	450	2260.9	1036	0.458
PL4	NYN-P5	420	2271.6	1036	0.456

Average annual evaporation (E_o)

The calculated average annual evaporation varies between approximately 2214 mm in the southern part and 2272 mm in the northern part (Table 2).

4.1.2 Moisture availability zones

The boundary criteria for the moisture availability zones and their climatic designation is given in the Table 3. From zone I with a moisture availability ratio (r/E_o) of more than 80% to zone VII with a ratio of less than 15% the average annual amount of available moisture decreases from over 80% to less than 15% of the annual potential evaporation. Assuming that the potential evapo-transpiration is 0.8 of the potential evaporation, then the values of 80% and 15% can be expressed as an average of 80/0.8 = 100% and 15/0.8 = 20% of full moisture days during the year, i.e. an average of 365 days and 70 days respectively.

In the study area moisture availability is highest in the northern part near (Dakawa, Sokoine and Rumanda) and lowest in the southern part (near Makunganya). The moisture availability zones falls under zones IV ($r/ E_o = 33.8\%$) and V ($r/ E_o = 45.6\%$) which are classified as 'semi-humid to semi-arid' and 'semi-arid' with an average of 153 and 208 full moisture days during the year respectively.

Table 3. Moisture availability zones and climatic designation according to Sombroek *et al.* (1982)

Zone	r/ E_o ratio	r/ E_o (%)	Climatic designation
I	>0.8	80	Humid
II	0.65-0.80	65-80	Sub-humid
III	0.50-0.65	50-65	Semi-humid
IV	0.40-0.50	40-50	Semi-humid to Semi-arid
V	0.25-0.40	25-40	Semi-arid
VI	0.15-0.25	15-25	Arid
VII	<0.15	<15	Very arid

4.2 Some morphological and physico-chemical properties of the soils

Tables 4 and 5 summarise some site features, landform, vegetation/land use and physical properties of the study area. A guide used in rating of some physical and chemical properties of the soils is presented in Appendix 12. Figure 2 gives percentage particle size distribution of some selected soils in the study area.

4.2.1 Some morphological and physical properties of the soils

Mapping unit Pi1

This mapping unit is represented by profiles NYN-P8 and NYN-P11. It has gently undulating to undulating topography with slopes ranging from 1.5 - 6 % at an altitude of 520-600 m.a.s.l. The soils are an association of: very deep, well drained, reddish brown to dark reddish brown loamy sand to sandy clay loams, with thick reddish brown loamy sand topsoils and deep, well drained very dark grey to dark brown sandy clay loams, with thick very dark grey sandy clay topsoils developed on banded muscovite-biotite sediments and superficial sands of Nguru ya Ndege mountains. The topsoils have bulk densities ranging from 1.4 to 1.5 g/cc. This mapping unit has available water capacity ranging from low (96 mm/m) to medium (130 mm/m). The structure of the topsoil is weak medium to moderate, fine and medium sub-angular blocky while that of subsoil is moderate, fine and medium sub-angular blocky. Patchy, thin clay cutans are found in subsoil in some places which is an indication of clay illuviation from the upper horizons. The topsoils have soft to slightly hard consistence when dry, friable when moist and sticky and plastic to non-sticky and non-plastic when wet.

Table 4. Salient site features, landform, vegetation/land use and soils of the study area

Mapping unit symbol	Landform	Dominant slopes (%)	Vegetation/ Land use	Soil description	Area	
					ha	%
PIEDMONT (Pi)						
(Pi1)	Alluvial fan	1.5-6	Secondary miombo woodland, thickets, bushes and grass used for grazing, cultivation of maize sunflower, sweet potatoes and sorghum.	Association of: Very deep, well drained, reddish brown to dark reddish brown loamy sand to sandy clay loams, with thick reddish brown loamy sand topsoils (representative profile NYN-P8) **and** deep, well drained, very dark grey to dark brown sandy clay loams, with thick very dark grey sandy clay topsoils, (representative profile NYN-P11).	1524.8	4.3
PENEPLANE (Pe)						
(Pe1)	Ridge summit	2-4	Secondary miombo woodland, thickets, bushes and grass used for grazing, forest reserve and cultivation of maize, cassava and sweet potatoes in some places.	Shallow to moderately deep, well drained, dark reddish brown to dark red sandy clay to clays, with thin dark reddish brown sandy clay topsoils. In some places stones and gravels mainly quartz occur, (representative profile NYN-P12).	3025.9	8.5
(Pe2)	Ridge slopes with red soils.	2-3	Secondary miombo woodland, thickets, bushes and grass used for grazing and forest reserve.	Very deep, well drained, dark reddish brown sandy clays, with thick very dark reddish brown sandy clay loam topsoils (representative profile NYN-P1).	2506.7	7.0
(Pe3)	Ridge slopes with sandy soils.	2-3	Secondary miombo woodland, thickets, bushes and grass used for grazing, cultivation of maize coconut and cashew nut	Moderately deep, well drained, dark brown sandy loams, with very thick very dark grey sandy loam topsoils, (representative profile NYN-P3).	4327.5	12
(Pe4)	Valley bottom	0.5-2	Acacia woodland and few scattered miombo trees, bushes, thickets and grasses. This area is used for low extensive grazing and forest reserve.	Complex of: shallow, moderately well drained, black sandy clay loams, over very dark grey to dark yellowish brown saprolite (representative profile NYN-P2) **and** deep, moderately well drained, dark brown to brown sandy clay loams, with thick black sandy clay loam topsoils, (representative profile NYN-P4).	3452.7	9.6

Table 4. Continued.

Mapping unit symbol	Landform	Dominant slopes (%)	Vegetation/ Land use	Soil description	Area	
					ha	%
PLAIN (PL)						
(PL1)	Flats with red soils.	0.5-1	Acacia woodland and few scattered miombo trees, bushes, thickets and grasses. This area is used for extensive grazing	Association of: Very deep, well drained, reddish brown to yellowish red sandy clay to clays, with thick dark brown sandy clay loam topsoils (representative profile NYN-P7) and very deep, well drained, dark reddish brown sandy clay to clays, with thin dark reddish brown sandy clay loam topsoils, (representative profile NYN-P10).	5510.4	15.4
(PL2)	Flats with sand soils.	0-0.5	Remnants of miombo woodland, thickets, bushes and grasses mainly used for extensive grazing.	Shallow, well drained, very dark greyish brown sandy clay loams, over dark greyish brown to dark yellowish brown saprolite, (representative profile NYN-P6).	8252.2	23.0
(PL3)	Floodplain.	0-1	Acacia woodland and few scattered miombo trees, bushes, thickets and grasses. This area is used for extensive grazing, cultivation of maize, rice, sweet potatoes and cassava.	Very deep, poorly drained, dark brown to very dark greyish brown loamy sand to sandy loams, with thin very dark grey sandy clay loam topsoils, (representative profile NYN-P9).	4097.9	11.4
(PL4)	Mbuga	0.5-1	Acacia woodland, scrubs and grasses used for extensive grazing and rice cultivation.	Deep, poorly to very poorly drained, very dark grey sandy clays, with very thick black sandy clay topsoils, (representative profile NYN-P5).	3111.7	8.7
				Total	35,810	100

Table 5. Physical characteristics of the studied soils

Profile/ Horizon	Depth (cm)	Moist munsell soil colour	% Particle size distribution			Textural class	Silt/Clay ratio	BD g/cc	AWC mm/m
			Sand	Silt	Clay				
NYN-P1									
Ah	0-17/20	5YR3/2 (drb)	57	13	30	SCL	0.5	1.6	nd
Bt	17/20-114	2.5YR3/3 (drb)	53	5	42	SC	0.1	1.4	84
C	114-170	2.5YR3/3 (drb)	51	5	44	SC	0.1	nd	nd
NYN-P2									
Ah	0-25	10YR2/1 (bl)	73	6	21	SCL	0.3	1.5	nd
C1	25-80	10YR3/1 (vdg)	68	5	27	SCL	0.2	1.7	nd
C2	80-100	10YR4/3 (b)	63	5	32	SCL	0.2	1.7	89
C3	100-140	10YR4/6 (dyb)	75	5	20	SCL	0.2	nd	nd
NYN-P3									
Ap	0-32/40	7.5YR 3/1 (vdg)	79	7	14	SL	0.5	1.5	nd
Bw	32/40-64/72	7.5YR3/2 (db)	71	11	18	SL	0.6	1.6	nd
Cm	64/72-120	7.5YR4/4 (b)	75	5	20	SCL	0.2	1.5	135
NYN-P4									
Ah	0-12/24	7.5YR2.5/1 (bl)	70	6	24	SCL	0.2	1.6	nd
AB	12/24-40/50	7.5YR3/2 (db)	67	5	28	SCL	0.2	nd	nd
Bw(m)	40/50-95	7.5YR 4/3 (b)	69	5	26	SCL	0.2	1.8	98*
Cmk	95-145	7.5YR8/1 (w)	59	11	30	SCL	0.4	nd	nd
NYN-P5									
Ah	0-25/45	N2.5/0 (bl)	50	10	40	SC	0.2	1.6	nd
ACk	25/45-100	N3/0 (vdg)	49	10	41	SC	0.2	1.7	nd
Ck	100-160	2.5Y5/2 (gb)	27	10	63	C	0.2	1.8	113
NYN-P6									
Ah	0-26	10YR 3/2 (vdgb)	64	16	20	SCL	0.76	1.7	nd
2C	26-46	10YR 3/4 (dyb)	54	13	33	SCL	0.38	nd	nd
3Ck	46-110	10YR 4/3 (b)	48	14	38	SC	0.35	1.6	111
4Ck	110-150+	10YR 3/4 (dyb)'	29	19	52	C	0.35	nd	nd
NYN-P7									
Ah	0-20	7.5YR 3/1(rdg)	62	10	28	SCL	0.34	1.7	nd
Bts1	20-40	5YR 4/3 (rb)	46	6	48	SC	0.11	nd	nd
Bts2	40-125	5YR 4/6 (yr)	28	6	66	C	0.08	1.3	164
BCk	125+	5YR 4/6 (yr)	36	8	56	C	0.13	nd	nd
NYN-P8									
Ah	0-15	5YR4/4 (rb)	80	8	12	LS	0.66	1.4	nd
BA	15-35	5YR4/4 (rb)	74	8	18	LS	0.44	nd	nd
Bw1	35-75	2.5YR3/4 (drb)	68	6	26	SCL	0.23	1.4	nd
Bw2	75-160+	2.5YR3/4 (drb)	62	4	28	SC	0.14	1.5	130
NYN-P9									
Ah	0-6	10YR3/1 (vdg)	65	6	29	SCL	0.21	1.5	nd
BA	6-23	10YR3/4 (db)	87	4	9	LS	0.44	nd	nd
Bg1	23-40	10YR3/4 (dyb)	83	8	9	LS	0.88	nd	nd
Bg2	40-64	2.5Y3/2 (vdgb)	85	6	9	LS	0.66	1.6	nd
BC	64-90	2.5Y4/4 (ob)	78	3	19	SL	0.12	nd	nd
C1	90-126	2.5Y5/4 (ob)	85	2	13	LS	0.15	1.6	132
C2	126-165	2.5Y6/4 (lyb)	76	7	17	SL	0.41	nd	nd
NYN-P10									
Ah	0-6	5YR3/2 (drb)	65	7	28	SCL	0.25	1.5	nd
BA	6-13	5YR3/4 (drb)	55	9	36	SC	0.25	nd	nd
Bt1	13-26	2.5YR2.5/4 ((drb)	49	6	45	SC	0.13	nd	nd
Bt2	26-58	2.5YR3/4 (drb)	42	9	49	C	0.18	1.6	nd
Bts1	58-104	2.5YR3/6 (dr)	42	6	52	C	0.12	1.6	112
Bts2	104-150+	2.5YR4/6 (r)	39	24	37	CL	0.65	nd	nd
NYN-P11									
Ap	0-13	7.5YR3/0 (vdg)	52	10	38	SC	0.26	1.5	nd
ABm	13-40	10YR3/1 (vdg)	64	6	30	SCL	0.20	nd	nd
Bwm	40-100+	7.5YR3/2 (db)	69	5	26	SCL	0.19	1.6	96
NYN-P12									
Ah	0-10	5YR3/3 (drb)	56	14	30	SCL	0.46	1.5	nd
BA	10-26	2.5YR3/4 ((drb)	61	5	34	SC	0.15	nd	nd
Bts1	26-53	2.5YR3/6 (dr)	53	5	42	SC	0.12	1.4	nd
Bts2	53-80	2.5YR3/6 (d/r)	48	6	46	SC	0.13	nd	83**

nd = not determined   * AWC was determined at 95 cm   ** AWC was determined at 80 cm

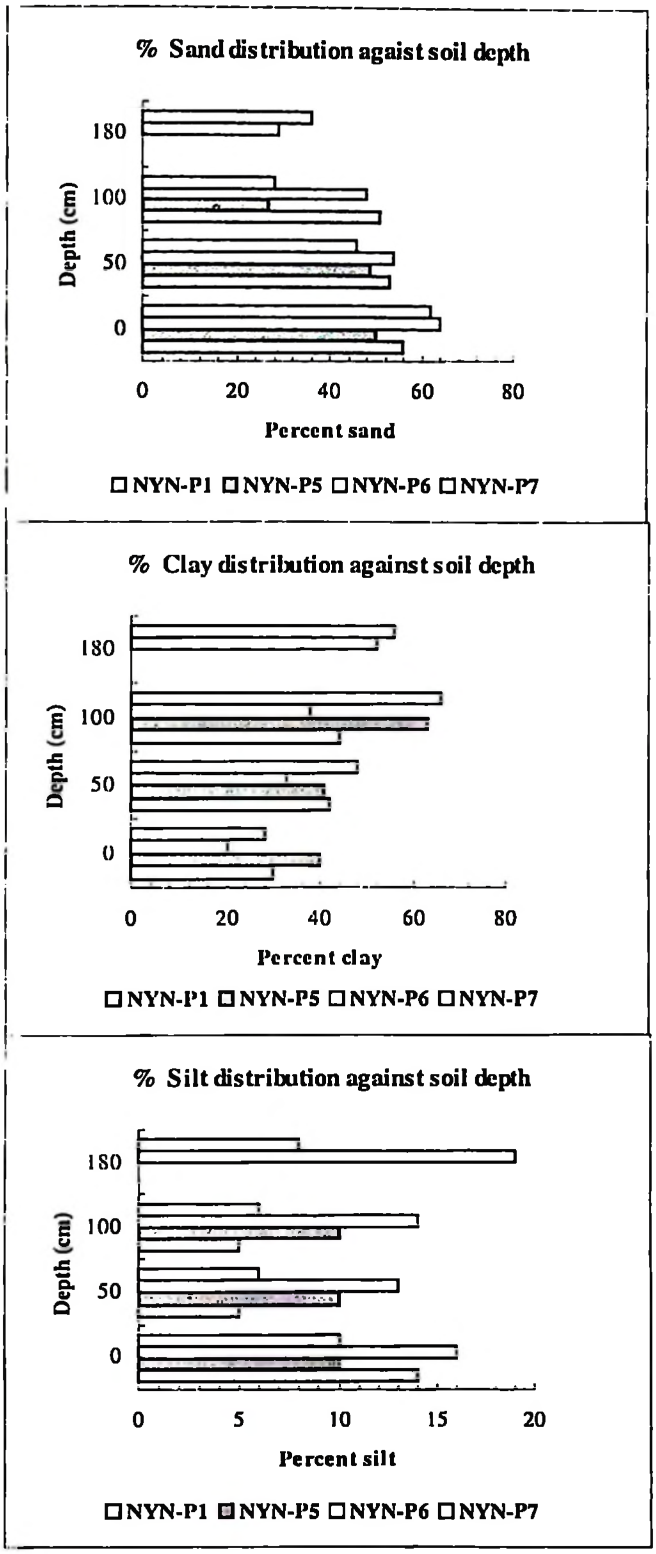

Figure 2. Percent particle size distribution of some selected soils in Wami Plains

The consistence of subsoils is slightly hard to very hard dry, friable to very firm when moist, slightly sticky and slightly plastic to sticky and plastic when wet. $CaCO_3$ concretions are found in places in the subsoils of this mapping unit.

Mapping unit Pe1

This mapping unit has nearly flat to undulating topography with slopes ranging from 2-3 % and an altitude of 480-520 m.a.s.l. The soils are shallow to moderately deep, well drained, dark reddish brown to dark red sandy clay to clays, with thin dark reddish brown sandy clay topsoils developed from colluvial materials overlying banded muscovite-biotite migmatites. The soils of this mapping unit are represented by the soil profile NYN-P12. This unit has bulk density of 1.5 g/cc in topsoils. These soils have low (83 mm/m) available water capacity. The structure of the topsoil is moderate, fine and medium sub-angular blocky while that of subsoil is weak, fine and medium sub-angular blocky. The topsoil consistence is slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet while the subsoils are soft when dry, friable when moist, sticky and plastic when wet. The subsoils have patchy thin clay cutans.

Mapping unit Pe2

Profile NYN-P1 represents the soils of this mapping unit. It comprises gently undulating dissected peneplane with slopes ranging from 2-3% at an altitude of 450-480 m.a.s.l. The soils are very deep, well drained dark reddish brown sandy clays, with thick very dark reddish brown sandy clay loam topsoils overlying banded muscovite biotite migmatites. The surface of these soils is characterised by ant and termite mounds a microrelief which occurs almost everywhere in the mapping unit.

The bulk densities of these soils range from 1.4 g/cc in the subsoils to 1.5 g/cc in the topsoils. The available water capacity of the soils in this mapping unit is ranked as low 84.8 mm/m depth indicating that these soils do not store enough water readily available for uptake by plant roots.

The structure of the topsoils is weak to moderate fine and medium sub-angular blocky, while most of subsoil horizons have moderate coarse and medium sub-angular blocky and the deeper horizons are structureless massive. The topsoils have very friable to friable consistence when moist and slightly sticky and slightly plastic when wet. The consistence of subsoil is hard to slightly hard when dry, friable when moist, slightly sticky to sticky and plastic to non-plastic when wet. In the deeper horizons there are many medium and coarse fresh angular and spherical rock fragments of quartzitic and banded muscovite-biotite migmatitic nature.

Mapping unit Pe3

This mapping unit has gently undulating topography with slopes ranging from 2-3 % situated at an altitude of 460-480 m.a.s.l. The soils are moderately deep, well drained, dark brown sandy loams, with very thick, very dark grey sandy loam topsoils developed from colluvial-alluvial deposits overlying banded muscovite-biotite migmatites. The soils of this mapping unit are represented by soil profile NYN-P3. The bulk densities of this unit range between 1.5 g/cc in topsoils and 1.6 g/cc for subsoil. These soils have medium available water capacity (135 mm/m). The structure of the topsoils is weak fine sub-angular blocky while that of subsoils is weak medium sub-angular blocky and the deeper horizon is structureless massive. Consistence is very friable to friable when moist, non-sticky and non-plastic to slightly sticky and slightly plastic when wet.

Mapping unit Pe4

This mapping unit has a topography ranging from almost flat to flat to gently undulating with slopes ranging from 0.5 -2 % at an altitude of 440 - 480 m.a.s.l. The soils are complex of: shallow moderately well drained, black sandy clay loams, over very dark grey to dark yellowish brown saprolite and deep, moderately well drained, dark brown to brown sandy clay loams, with thick black sandy clay loam topsoils developed from fluvial deposits derived from banded muscovite-biotite migmatites. The soils of this mapping unit are represented by profiles NYN-P2 and NYN-P4. The soils have bulk densities ranging from 1.4 to 1.7 g/cc. In some places the topsoils have bulk density of 1.4 g/cc while other places have 1.6 g/cc. The bulk densities of subsoil range from 1.6 - 1.7 g/cc. The available water content of these soils is ranked as low (89.4 - 97.6 mm/m). These low values of AWC suggest that these soils do not store enough water which could be readily available for plant roots.

The structure of the topsoil is mainly weak medium and coarse sub-angular blocky, while the subsoil is commonly structureless massive.

Throughout the profiles the consistence is friable when moist except in NYN-P4 third horizon which has firm consistency when moist. These soils are sticky and plastic when wet except topsoils of NYN-P2 which are non-sticky and non-plastic. The accumulation of secondary $CaCO_3$ in the subsoils is common in this unit.

Mapping unit PL1

Profiles NYN-P7 and NYN-P10 represent the soils of this mapping unit. The unit is an almost flat to gently undulating plain with slopes ranging from 0.5 - 1 % at an altitude of 400 - 450 m.a.s.l. The soils are association of: very deep, well drained, reddish brown to yellowish red sandy clay to clays, with thick dark brown sandy clay loam topsoils and very deep, well drained dark reddish brown sandy clay to clays, with thin dark reddish brown sandy clay loam topsoils developed on orange-red colluvium overlying banded muscovite-biotite migmatites. The topsoils have higher bulk density (1.7 g/cc) than subsoils (1.3 g/cc). The soils of this unit have high available water capacity (164.4 mm/m) indicating that they can store enough water readily available for uptake by plant roots. The structure of the topsoil is moderate, fine and medium sub-angular blocky, while most of subsoil horizons have moderately strong, medium and fine sub-angular blocky structure.

Few, fine clay cutans are found in the third horizon which is an indication of clay illuviation from the overlying horizons. The topsoils have soft to slightly hard consistence when dry, friable when moist and slightly sticky and slightly plastic to sticky and plastic when wet. The consistence of the subsoils is slightly hard to hard when dry, friable when moist, sticky and plastic to very sticky and very plastic when wet. $CaCO_3$ concretions are common in the subsoils of this mapping unit.

Mapping unit PL2

Profile NYN-P6 represents soils of this mapping unit. The unit is an almost flat to flat plain with 0.5 % slopes at an altitude of 360 - 440 m.a.s.l. The soils are shallow, well drained, very dark greyish brown, sandy clay loams, over dark greyish brown to dark yellowish brown saprolite developed on recent alluvial deposits derived from banded muscovite-biotite migmatites. The soils of this mapping unit are represented by profile NYN-P6. The bulk densities range from 1.6 to 1.7 g/cc with high values in the topsoils. These soil have medium available water content (111.5 mm/m). The structure of the topsoils is mainly weak medium and fine sub-angular blocky. The subsoil horizons are dominated by structureless massive structures.

The topsoils consistence is soft when dry, friable when moist and non-sticky and non-plastic when wet. The subsoil horizons have very hard consistence when dry, friable to very firm when moist and sticky and plastic when wet. $CaCO_3$ concretions are common in the subsoils of this mapping unit.

Mapping unit PL3

This mapping unit has almost flat to flat topography with slopes ranging from 0.5-1 % situated at an altitude of 450 - 470 m.a.s.l. The soils of this mapping unit are very deep, poorly drained dark brown to very dark greyish brown loamy sand to sandy loams, with thin very dark grey sandy clay loam topsoils developed on post-miocene orange-red colluvium. The soils are represented by soil profile NYN-P9. The bulk densities of this unit range between 1.5 g/cc in topsoils and 1.6 g/cc for subsoils.

These soils have medium available water capacity (132 mm/m). The structure of the topsoil is weak, fine sub-angular blocky while that of subsoil is moderate, medium and coarse prisms. Fine distinct mottles are common in the subsoils of this unit. The topsoils consistence is soft when dry, friable when moist, non-sticky and non-plastic when wet while subsoils have extremely hard when dry, friable when moist, sticky and plastic when wet.

Mapping unit PL4

This land unit comprises flat to almost flat alluvial plains with slopes ranging from 0-1% at an altitude of 380 to 420 m.a.s.l. It is mainly a depositional area of materials deposited from higher geomorphic units. Soils are deep, poorly to very poorly drained very dark grey sandy clays, with very thick black sandy clay topsoils developed from recent alluvial deposits overlying banded muscovite-biotite migmatites.

The soils of this mapping unit are represented by soil profile NYN-P5. This mapping unit has a low gilgai microrelief which occur nearly everywhere. Deep, moderately to widely spaced hexagonal cracks are common during dry season due to alternate swelling and shrinking of the expanding clays. The bulk densities of these soils range from 1.7 g/cc in the subsoils to 1.6 g/cc in the topsoils. The available water capacity of the soils in this mapping unit is ranked as medium 113.4 mm/m soil depth.

The structure of the topsoil is mainly weak to moderate coarse and medium subangular blocky. Subsoil horizons have moderate coarse angular blocky and wedge-shaped structures and a few of them are angular blocky parallelepiped. The deeper horizons have very weak, very coarse subangular blocky. The consistence of these soils is very hard when dry, firm to very firm when moist and sticky and plastic to very sticky and very plastic when wet. The soils of this mapping unit are known to have very deep effective soil depth with moderately to strongly calcareous subsoils.

4.2.2 Soil chemical properties

Chemical properties of the studied soils are summarised in Table 6. Figure 3 represents relatioship between some soil chemical properties of some selected soils in Wami Plains with soil depth.

Mapping unit Pi1

Soil reaction of the soils of this mapping unit ranges from slightly acid to neutral (6.5- 6.9). Most plants thrive well in neutral soils since most of the nutrients are made available to plants at this pH values. The soils are non-sodic since they have very low ESP (<6%). The soils have low to medium levels (0.66-1.46%) of organic carbon in the topsoils which decreases with depth. Total nitrogen levels are very low to low (0.07-0.17%) with good quality organic matter. The available phosphorus in topsoils varies from low to medium (3.7-16.0 mg/kg).

The soils have CEC values ranging from very low to medium (5.32-25 cmol(+)/kg). Base saturation is more than 50% throughout the profiles. The exchangeable calcium in this mapping unit is high to very high (3.3- 14.46 cmol(+)/kg) while the exchangeable magnesium levels range from high to very high

Table 6. Selected chemical properties of the study area

Profile/ Horizon	Depth (cm)	pH		ECe mS/cm	% OC	%N	C:N ratio	P (mg/kg)		CEC Soil	Ca	Mg	K	Na	% BS	% ESP	% $CaCO_3$
		H_2O	KCl					Bray	Olsen	(cmol(+)/kg							
NYN-P1																	
Ah	0-17/20	6.8	5.2	0.08	1.39	0.11	12.6	1.53	nd	11.9	5.0	3.3	1.70	0.21	86.0	1.76	6.41
Bt	17/20-114	7.0	5.4	0.04	0.44	0.06	7.3	0.26	nd	7.92	4.3	3.0	0.29	0.06	97	0.76	7.46
C	114-170	8.0	7.4	0.17	0.32	0.05	6.4	nd	0.45	4.73	3.0	1.6	0.40	0.20	110	4.20	7.61
NYN-P2																	
Ah	0-25	6.7	5.2	0.03	0.79	0.07	11.3	1.27	nd	6.72	4.6	1.6	0.38	0.05	98	0.74	2.15
C1	25-80	6.8	5.1	0.03	0.12	0.06	2.0	0.99	nd	7.20	4.7	1.8	0.43	0.17	99	2.40	6.66
C2	80-100	6.9	5.2	0.04	0.48	0.08	6.0	0.57	nd	10.6	7.6	2.2	0.48	0.24	99	2.30	3.20
C3	100-140	6.8	5.0	0.02	0.24	0.03	8.0	0.36	nd	5.40	3.5	1.3	0.33	0.05	97	0.93	2.80
NYN-P3																	
Ap	0-32/40	6.8	5.7	0.03	0.59	0.06	9.8	6.82	nd	3.80	2.0	0.84	0.73	0.10	97	2.63	2.75
Bw	32/40-64/72	6.4	4.7	0.04	0.40	0.06	6.7	3.67	nd	3.64	1.3	1.5	0.33	0.05	88	1.40	4.35
Cm	64/72-120	6.8	4.5	0.04	0.28	0.04	7.0	1.28	nd	3.52	1.6	10.6	0.52	0.22	97	6.30	2.30
NYN-P4																	
Ah	0-12/24	7.9	7.1	0.14	1.70	0.17	10.0	nd	7.42	18.2	13	3.2	1.98	0.15	101	0.82	2.25
AB	12/24-40/50	7.6	6.2	0.06	1.03	0.11	9.40	nd	1.11	13.9	8.7	4.1	1.61	0.13	105	0.94	3.30
Bw(m)	40/50-95	7.8	6.4	0.06	0.52	0.05	10.4	nd	1.76	12.3	8.3	5.0	0.71	0.10	114	0.89	2.65
Cmk	95-145	8.4	7.4	0.17	0.44	0.06	7.30	nd	1.48	13.6	11	2.6	1.40	0.40	109	2.94	11.8
NYN-P5																	
Ah	0-25/45	7.7	6.1	0.09	0.79	0.08	9.9	nd	0.96	21.2	14	5.0	0.71	0.90	97	4.25	3.95
ACk	25/45-100	8.4	7.0	0.38	0.52	0.04	13	nd	0.68	25.3	10	11	0.76	4.82	103	19.1	3.90
Ck	100-160	8.6	7.2	0.94	0.08	0.03	2.7	nd	0.31	35.9	13	11	1.37	13.8	109	38.4	4.90
NYN-P6																	
Ah	0-26	6.2	4.6	0.03	0.71	0.04	17.8	2.29	nd	4.84	1.9	1.5	0.39	0.13	81	2.70	3.15
2C	26-46	8.9	6.9	0.76	0.60	0.04	15.0	nd	0.16	10.8	5.4	1.4	0.54	4.70	111	43.5	3.70
3Ck	46-110	7.5	5.2	0.18	0.16	0.03	5.3	nd	0.6	13.0	4.6	3.9	0.33	5.02	106	38.6	4.65
4Ck	110-150+	8.7	6.7	1.09	0.51	0.01	51	nd	1.11	21.8	8.2	4.7	0.54	9.50	105	43.6	4.85
NYN-P7																	
Ah	0-20	6.5	4.8	0.03	0.91	0.06	15.2	2.23	nd	8.3	3.4	2.3	0.99	0.12	82	1.44	2.65
Bts1	20-40	5.7	4.0	0.03	1.03	0.05	20.6	2.52	nd	8.0	2.0	2.4	0.66	0.21	67	2.60	3.55
Bts2	40-125	5.9	3.7	0.02	0.79	0.04	19.8	1.04	nd	8.4	2.7	1.8	0.44	0.44	64	5.20	3.40
BCk	125+	6.2	3.7	0.03	0.51	0.04	12.8	0.52	nd	7.9	2.8	2.2	0.80	1.15	87	14.6	2.30

Table 6. Continued.

Profile/ Horizon	Depth (cm)	pH		ECe mS/cm	% OC	%N	C:N ratio	P (mg/kg)		CEC Soil	Ca	Mg	K	Na	% BS	% ESP	% $CaCO_3$
		H_2O	KCl					Bray	Olsen	(cmol(+)/kg							
NYN-P8																	
Ah	0-15	6.9	5.4	0.02	0.66	0.07	9	3.7	nd	5.9	3.0	1.8	0.05	0.03	84	0.51	0.14
BA	15-35	7.1	4.7	0.02	0.38	0.04	10	nd	14.7	7.2	3.9	2.4	0.05	0.05	89	0.69	1.40
Bw1	35-75	7.2	4.4	0.02	0.26	0.03	9	nd	8.08	8.0	4.6	2.7	0.04	0.06	93	0.75	4.60
Bw2	75-160+	7.7	4.5	0.03	0.19	0.02	10	nd	2.58	9.0	5.4	3.1	0.01	0.09	95	0.01	3.80
NYN-P9																	
Ah	0-6	6.1	5.5	0.02	0.69	0.07	9.9	3.2	nd	3.0	0.72	0.68	0.17	0.02	86	1.9	44.0
BA	6-23	6.1	5.6	0.03	0.42	0.04	10.5	4.1	nd	2.1	1.08	0.24	0.14	0.03	71	1.5	31.0
Bg1	23-40	6.1	5.5	0.02	0.24	0.02	12	5.2	nd	2.8	1.01	0.48	0.08	0.15	61	5.6	21.0
Bg2	40-64	5.6	4.9	0.04	0.11	0.01	11	5.6	nd	2.9	1.03	0.88	0.04	0.08	70	2.7	34.0
BC	64-90	6.2	5.8	0.03	0.12	0.01	12	7.2	nd	3.39	1.10	0.40	0.04	1.06	77	31.0	60.0
C1	90-126	7.3	6.9	0.04	0.09	0.01	9.0	nd	2.0	5.2	1.81	1.53	0.02	1.13	86	21.6	99.0
C2	126-165	8.0	7.5	0.03	0.06	0.01	6.0	nd	2.0	5.4	1.92	1.39	0.05	0.70	76	13.1	75.0
NYN-P10																	
Ah	0-6	6.7	5.8	0.03	1.35	0.14	10	8.5	nd	9.10	4.53	2.85	0.77	0.13	91.5	1.44	54.0
BA	6-13	6.7	5.9	0.04	1.32	0.13	10	7.6	nd	11.4	4.35	2.45	0.91	0.10	68.3	0.88	41.0
Bt1	13-26	6.5	5.8	0.03	0.98	0.10	9.8	8.7	nd	11.2	3.76	2.71	1.05	0.08	67.8	0.71	34.0
Bt2	26-58	6.3	5.9	0.05	0.43	0.04	11	9.1	nd	10.4	2.52	2.44	0.83	0.11	57.0	1.06	27.0
Bts1	58-104	5.9	5.1	0.04	0.40	0.04	10	10	nd	9.20	2.07	2.07	0.39	0.15	50.6	1.62	26.0
Bts2	104-150+	5.9	5.2	0.05	0.29	0.03	9.7	11	nd	14.9	2.61	2.07	0.24	0.34	35.2	2.27	21.0
NYN-P11																	
Ap	0-13	6.5	5.9	0.03	1.46	0.15	9	16.0	nd	25.0	14.5	9.92	0.04	0.21	98.5	0.84	64.0
ABm	13-40	6.6	6.0	0.04	0.94	0.10	10	9.60	nd	13.2	5.75	3.52	0.42	0.03	73.4	0.23	35.0
Bwm	40-100+	6.6	5.9	0.02	0.66	0.07	9	6.12	nd	8.08	4.20	2.50	0.33	0.12	88.5	1.49	35.0
NYN-12																	
Ah	0-10	6.2	5.1	0.06	1.29	0.13	9.9	1.46	nd	17.4	4.2	3.3	1.60	0.21	53	1.21	3.6
BA	10-26	6.5	5.3	0.03	0.54	0.05	11	0.26	nd	9.9	3.3	3.4	0.28	0.06	71	0.61	3.3
Bts1	26-53	6.7	5.6	0.15	0.30	0.03	10	0.46	nd	13.2	7.0	3.7	2.40	0.26	101	1.97	2.2
Bts2	53-80	6.6	5.5	0.12	0.23	0.02	12	0.39	nd	15.7	9.0	3.1	0.98	0.19	85	1.21	2.0

nd = not determined.

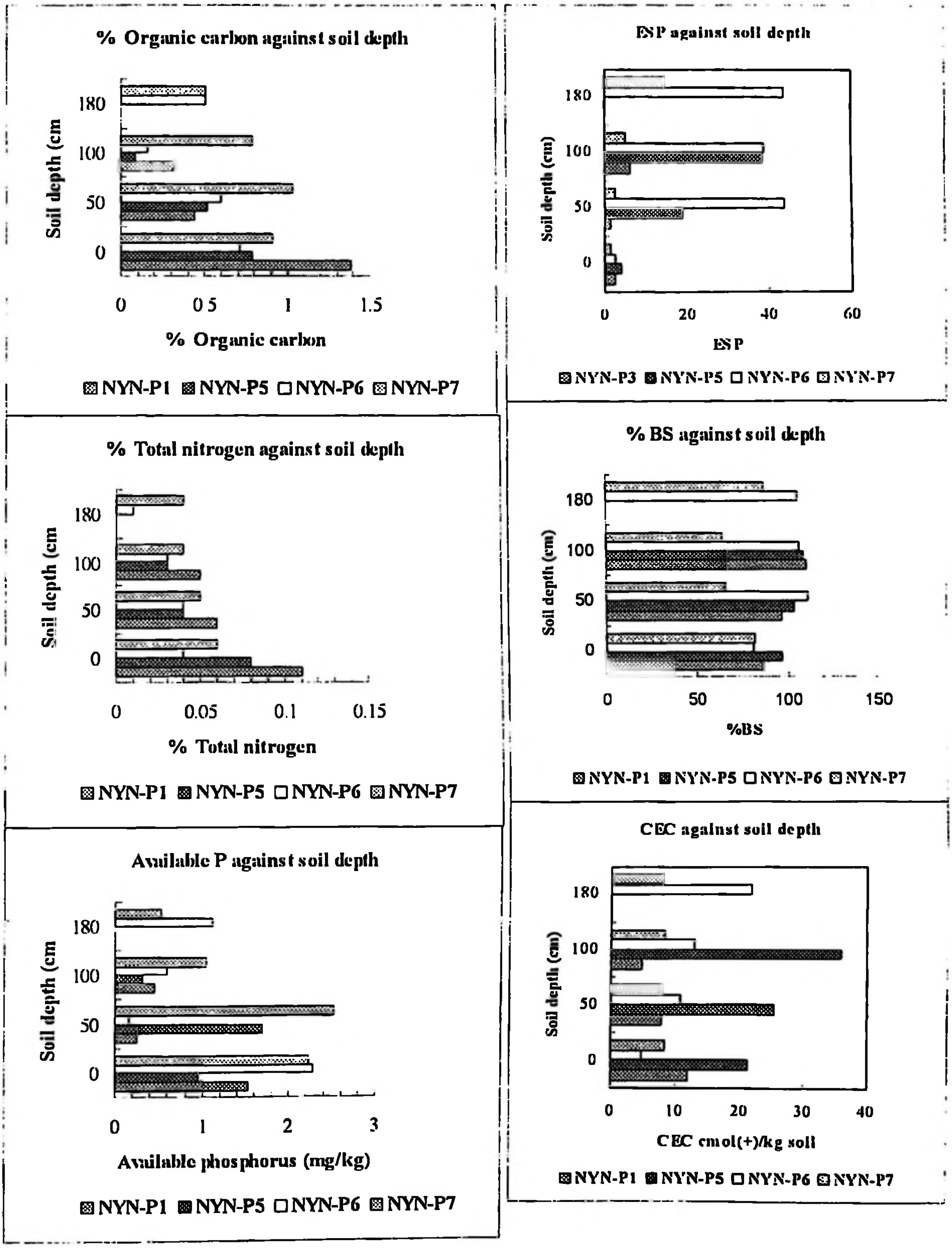

Figure 3. Relationship between some soil chemical properties with soil depth

(1.8-9.92 cmol(+)/kg). The levels of exchangeable potassium in this unit are generally very low (0.05 cmol(+)/kg) in topsoils and medium in subsoils (0.42 cmol(+)/kg). The levels of exchangeable sodium are very low to low (0.03-0.21 cmol(+)/kg) in topsoils.

Mapping unit Pe1

The topsoils of this unit show a slightly acid soil reaction while subsoils are neutral. The electrical conductivity of these soils is very low indicating that no yield reduction will be caused by soluble salts in this mapping unit.

The soils are found to be non-sodic as indicated by their very low values of exchangeable sodium percentage (ESP < 6.0).

The soils have in general medium CEC (17.4 cmol(+)/kg). Base saturation values are high (>50%) throughout. The exchangeable calcium levels are high in the topsoils (4.2 cmol(+)/kg) and have a tendency to increase with depth. The exchangeable magnesium levels are high throughout the profile and increase with depth. The exchangeable potassium levels are very high in topsoils while those of exchangeable sodium are low throughout.

The levels of total nitrogen ranges from low in the topsoils to very low in subsoils while those of organic carbon are medium in the topsoil and very low in the subsoil with good quality organic matter. The available phosphorus levels are low throughout the profile thus phosphorus fertiliser recommendations in this area is important.

Mapping unit Pe2

The soils have a net negative charge as indicated by their pH (KCl) being lower than pH (H_2O). The topsoils and subsoils show neutral soil reaction while the deeper horizons are moderately alkaline. The electrical conductivity of these soils is very low thus no yield reduction which may be caused by soluble salts in this mapping unit. The soils are found to be non-sodic as indicated by their very low values of exchangeable sodium percentage.

The soils of this unit have low CEC values throughout. Percentage base saturation is high (>50%) throughout. The exchangeable calcium and magnesium levels are high throughout the profile while those of exchangeable potassium range from very high in the topsoils to low in the subsoils. The available phosphorus levels are low throughout the profile thus phosphorus fertilisation is highly recommended in these soil. The levels of total nitrogen range from low in the topsoils to very low in subsoils while organic carbon levels are medium in the topsoil and very low in the subsoils with good quality organic matter.

Mapping unit Pe3

Soil reaction of the soils of this mapping unit ranges from to neutral in the topsoils to slightly acid in the subsoils as indicated by their pH values (6.8 to 6.4) respectively. Most plants thrive well in neutral soils since most of the nutrients are made available to plants at this pH values. The exchangeable sodium percentage of this unit varies from 2.63 to 6.3 % which indicates that these soils are slightly sodic in the deeper horizons. The available phosphorus in the topsoils is low (6.8 mg/kg) and decreases with depth. The levels of organic carbon and total nitrogen are very low throughout the profile.

The soils have very low CEC ranging from 3.5 to 3.8 cmol(+)/kg indicating that the unit is dominated by low activity clay (kaolinitic). Base saturation is more than 50% throughout the profile. The exchangeable calcium in this mapping unit is low throughout the profile with higher values in topsoils. The levels of exchangeable magnesium and potassium are medium throughout the profile while those of exchangeable sodium are low throughout the profile.

Mapping unit Pe4

Soil reaction of the soils of this mapping unit ranges from neutral to mildly alkaline (6.7 to 7.8) indicating that most nutrients are made available to plants at this pH values. The exchangeable sodium percentage of this unit is very low (<6%) which indicates that these soils are non-sodic. The soils have low to medium levels (0.79 to 1.7%) of organic carbon in the topsoils with good quality organic matter. Total nitrogen levels are very low to low (0.07 to 0.17%). The available phosphorus in the topsoils varies from low (1.95 mg/kg) to medium (7.42 mg/kg) and there is a tendency to decrease with soil depth.

The soils have CEC values ranging from low to medium (6.72 to 18.2 cmol(+)/kg). Base saturation is more than 50% throughout the profile. The levels of exchangeable calcium in this mapping unit range from high to very high (4.6 to 13.1 cmol(+)/kg). The exchangeable magnesium levels range from medium to very high (1.57 to 4.95 cmol(+)/kg). The levels of exchangeable potassium in this unit ranges from medium to very high (0.38 to 1.98 cmol(+)/kg). The levels of exchangeable sodium are very low to low (0.05 - 0.15 cmol(+)/kg) throughout the profiles.

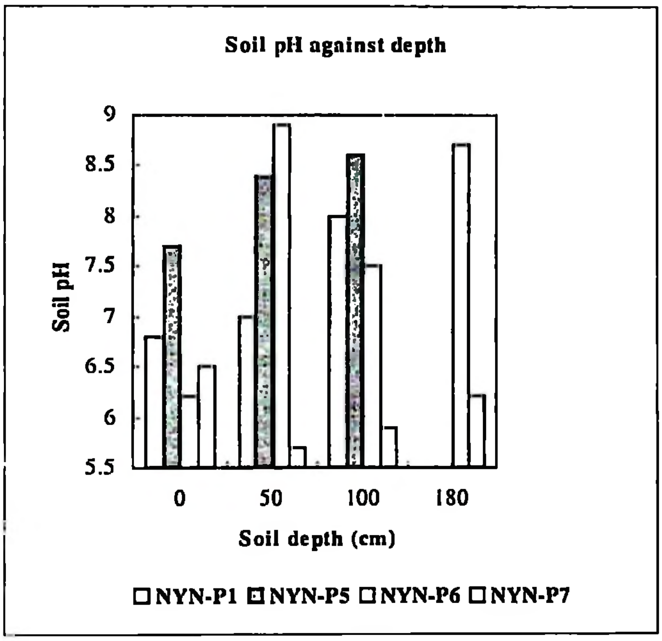

Figure 4. Relationship between soil pH of some soils in Wami Plains with soil depth

Mapping unit PL1

The soils of this unit have a net negative charge as indicated by their pH (KCl) being lower than pH (H_2O). The topsoils show slightly acid to neutral soil reaction which decreases with depth (Figure 4). The electrical conductivity of these soils is very low thus no any yield reduction due to soluble salts in this mapping unit. The topsoils and subsoils are found to be non-sodic as indicated by their very low values of exchangeable sodium percentage while deeper horizons are moderately sodic (14.6%).

The soils of this unit have low levels of CEC throughout the profiles. Percentage base saturation are high (>50%) throughout. The exchangeable calcium levels range from medium to high (3.4 to 4.53 cmol(+)/kg) in the topsoils and decreases with soil depth. The levels of exchangeable magnesium are high throughout the profiles. Exchangeable potassium levels are found to range from medium to high throughout while those of exchangeable sodium are low in topsoils and in some places the levels increase to high in subsoils.

The available phosphorus levels range from very low to medium throughout thus phosphorus fertilisation is highly recommended in these soils. The levels of total nitrogen range from very low to low (0.06-0.14%) in the topsoils while organic carbon of these soils are low to medium (0.91-1.35%) in the topsoils with moderate to good quality organic matter.

Mapping unit PL2

Soil reaction of the soils of this mapping unit ranges from slightly acid in the topsoils (6.2) to strongly alkaline in the subsoils (8.9) (Figure 4). The available phosphorus in the topsoils is 2.29 mg/kg which is low while that of the subsoils is very low suggesting the need for phosphorus fertilisation in this mapping unit. The levels of total nitrogen are very low throughout the profile while those of organic carbon range from low (0.71 to 0.6 %) in the topsoils to very low (0.16 to 0.51 %) in the subsoils. The levels of exchangeable sodium percentage in this mapping unit varies from non-sodic (2.7%) in the topsoils to extremely sodic (43.5%) in the subsoils.

The CEC values of these soils range from very low (4.84 cmol(+)/kg) in the topsoils to medium (13 cmol(+)/kg) in the subsoils. The CEC increases with soil depth following the trend of clay content increase. The exchangeable calcium levels are low (1.9 cmol(+)/kg) for topsoils and medium (5.4 to 8.2 cmol(+)/kg) in the subsoils. The exchangeable magnesium levels range from medium in topsoils to high in the subsoils (3.9 cmol(+)/kg). The levels of exchangeable potassium in the topsoils are medium (0.39 cmol(+)/kg) and high in the subsoils (0.54 cmol(+)/kg). The levels of exchangeable sodium are low (0.13 cmol(+)/kg) in the topsoils and very high (5.02 cmol(+)/kg) in the subsoils. Base saturation is more than 50 % throughout the profile.

Mapping unit PL3

Soil reaction of the soils of this mapping unit is generally slightly acid throughout with pH values of 6.1. The soils are non-sodic (ESP < 6) in topsoils to a depth of 64 cm and very strongly sodic in the deeper horizons (ESP > 31). The available phosphorus levels are very low (< 6.0 mg/kg). The levels of organic carbon and total nitrogen are low and very low respectively in the topsoils and decreases with depth.

The soils have very low levels of CEC (< 6.0 cmol(+)/kg) and >50% base saturation throughout the profile. The exchangeable calcium levels are low to medium with lower values in the topsoils. The exchangeable magnesium levels range from low in the topsoils to medium in the subsoils (0.68 to 0.88 cmol(+)/kg). The levels of exchangeable potassium in the topsoils are generally very low (0.17

cmol(+)/kg) and decreases with soil depth. The levels of exchangeable sodium are very low (0.02 cmol(+)/kg) in the topsoils and low in the subsoils (0.15 cmol(+)/kg).

Mapping unit PL4

The soils of this unit have pH (KCl) which is lower than pH (H_2O) throughout which is an indication that the soils have a net negative charge. The topsoils are mildly alkaline (pH 7.7) and pH increases gradually with soil depth to moderately and strongly alkaline (pH 8.4 to 8.6) in the subsoils. It has been observed that in the dry subtropics, soil reaction may be higher than 7.0, i.e. alkaline due to the accumulation of alkaline elements such as calcium and sodium (FAO, 2000). The fertility problems associated with soils having such high pH values include not only decreased availability of phosphorus but also that of most of the micronutrients such as B, Cu, Fe, Mn and Zn. Borkert and Sfredo (1994) observed that the solubility and consequently the availability of all micronutrients except Mo is low when soil pH is near neutrality. The available phosphorus in the topsoil is 0.96 mg/kg which is very low suggesting the need for phosphorus fertilisation in this mapping unit.

CEC can be used as a measure of potential productivity in terms of the capacity of the soil to retain and supply plant nutrients and can give a clue about the nature of the clay minerals present. The soils of this mapping unit have high CEC and high percent base saturation indicating that the soils are generally fertile in terms of macronutrients which is a general characteristic of many Vertisols. The topsoils CEC value is 21.2 cmol(+)/kg and increases with soil depth to 35.9 cmol(+)/kg soil. Base saturation is >50% throughout the profile with high calcium and high to very high magnesium contents. The Ca:Mg ratio is 3.02 in the topsoils which is favourable for most crops. The CEC of clay is fairly high in these soils suggesting high contents of smectite in the clay fraction. The levels of exchangeable potassium are medium throughout while those of exchangeable sodium in the topsoils are high (0.90 cmol(+)/kg) and increases with soil depth.

The levels of total nitrogen and organic carbon are generally very low and low respectively in the topsoils and are both very low in the subsoils. These soils have good quality organic matter throughout the profile since the C:N ratio ranges from 8-13.

Vertisols are known to have high agricultural potential, but require special management practices for optimal rainfed or irrigated agriculture. They are characterised by relatively high chemical fertility with poor workability due to their poor physical properties. Poor infiltration of water and high vulnerability to erosion are the major problems associated with poor physical properties of these soils. Management practices should therefore aim at increasing infiltration rates of water as well as reducing erosion hazard in these soils. Mulching with crop residues, contour cultivation and contour banding are some of the recommended management practices for successful crop (rice and maize) production in these soils.

4.2.3 DTPA-extractable micronutrient content of the soils of Wami Plains

The depth-wise distribution of copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) in the soils of Wami Plains is summarized in Table 7. Landsay and Novell (1978) suggested the critical levels for Zn by DTPA method to range between 0.5-1.0 mg Zn/kg soil.

Table 7. Micronutrients levels of the studied soils

Profile/ Horizon	Depth (cm)	DTPA-extractable				Hot-water extractable
		Cu	Fe	Mn	Zn	B
		(mg/kg)				(mg/kg)
NYN-P1						
Ah	0-17/20	1.79	8.22	35.0	0.046	0.14
Bt	17/20-114	1.02	3.34	12.8	0.002	0.15
C	114-170	1.28	2.26	7.32	0.002	0.22
NYN-P2						
Ah	0-25	0.36	14.9	24.1	0.020	0.12
C1	25-80	0.65	17.1	28.3	0.030	0.02
C2	80-100	0.82	9.35	24.4	0.050	0.15
C3	100-140	0.30	6.29	13.9	0.062	0.08
NYN-P3						
Ap	0-32/40	0.27	8.33	20.5	0.066	0.22
Bw	32/40-64/72	0.22	8.70	12.4	0.014	0.09
Cm	64/72-120	0.29	7.49	12.2	0.002	0.19
NYN-P4						
Ah	0-12/24	0.21	2.74	5.34	0.082	0.28
AB	12/24-40/50	0.24	3.79	10.4	0.052	0.17
Bw(m)	40/50-95	0.29	3.06	9.90	0.022	0.11
Cmk	95-145	0.76	2.03	11.4	0.040	0.01
NYN-P5						
Ah	0-25/45	1.29	10.3	15.8	0.010	0.15
ACk	25/45-100	1.13	4.86	5.15	0.018	0.22
Ck	100-160	1.06	2.93	6.58	0.060	0.32
NYN-P6						
Ah	0-26	0.25	20.9	12.1	0.080	0.13
1C	26-46	0.41	1.75	5.02	0.022	0.28
2Ck	46-110	0.67	8.94	11.2	0.082	0.31
3Ck	110-150+	0.88	1.52	3.46	0.040	0.25
NYN-P7						
Ah	0-20	0.38	9.34	17.1	0.082	0.17
Bts1	20-40	0.52	7.13	3.66	0.036	0.27
Bts2	40-125	0.80	3.17	1.17	0.090	0.09
BCk	125+	0.85	28.4	3.25	0.034	0.09
NYN-P8						
Ah	0-15	0.35	9.33	17.2	0.08	0.15
BA	15-35	0.47	7.16	3.56	0.04	0.25
Bw1	35-75	0.78	3.18	1.27	0.09	0.06
Bw2	75-160+	0.79	2.70	3.35	0.03	0.13
NYN-P9						
Ah	0-6	0.21	2.74	5.32	0.08	0.27
BA	6-23	0.24	3.79	10.3	0.05	0.17
Bg1	23-40	0.29	3.06	9.90	0.02	0.11
Bg2	40-64	0.76	2.03	11.3	0.04	0.12
BC	64-90	0.35	2.01	11.9	0.03	0.15
C1	90-126	0.79	2.50	6.85	0.05	0.13
C2	126-165	0.81	1.98	7.80	0.02	0.14
NYN-P10						
Ah	0-6	0.23	6.54	5.12	0.06	0.25
BA	6-13	0.20	3.59	9.30	0.04	0.15
Bt1	13-26	0.28	3.16	8.90	0.02	0.12
Bt2	26-58	0.66	2.23	12.3	0.02	0.13
Bts1	58-104	0.33	1.90	10.9	0.03	0.14
Bts2	104-150+	0.59	2.30	6.55	0.03	0.12
NYN-P11						
Ap	0-13	0.23	4.14	4.32	0.06	0.23
ABm	13-40	0.14	3.19	7.30	0.04	0.15
Bwm	40-100+	0.22	3.00	6.90	0.03	0.14
NYN-12						
Ah	0-10	1.86	8.27	35.0	0.05	0.14
BA	10-26	1.06	3.84	12.8	0.02	0.15
Bts1	26-53	1.16	2.19	7.30	0.02	0.22
Bts2	53-80	1.42	1.21	5.40	0.03	0.27

Sims and Johnson (1991) proposed the critical level for Zn ranging from 0.2-2.0 mg Zn/kg soil. From the results obtained it follows that the soils of all mapping units are low in available Zn and thus, frequent application of Zn containing fertilizer is required. This low values of available Zn may be attributed by low organic matter of these soils.

The content of DTPA extractable Fe ranged between 20.9 mg Fe/kg soil to 2.74 mg Fe/kg soil in the surface soils. Most of the soils in the study area have Fe content between 8-14 mg Fe/kg soil in the surface soils. In almost all mapping units the content of Fe show a general decrease with soil depth. Fe levels in soils of all mapping units are higher than the critical levels of 2.5-5.0 mg Fe/kg soil (Sims and Johnson, 1991). In all profiles except NYN-P4 and NYN-P9 there is a regular decrease in Fe content with soil depth. The highest levels of Fe in the surface soils are observed in mapping unit PL2 (20.9 mg Fe/kg soil) while the lowest values are observed in mapping unit PL3 and in some soils of the mapping unit Pe4 (2.74 mg Fe/kg soil).

According to Sims and Jonhson (1991), the critical levels of DTPA-extractable Cu ranges from 0.12-0.25 mg Cu/kg soil. Generally soils of all mapping units in the study area have adequate levels of Cu since none of the profiles has Cu content less than 0.12 mg Cu/kg soil.

Levels of Mn in the soils of Wami Plains are generally above the critical levels of 1.0-5.0 mg Mn/kg soil (Sims and Johnson, 1991). The highest level in topsoils are observed in profiles NYN-P12 (35.0 mg Mn/kg soil) and the lowest levels are found in profile NYN-P11 (4.32 mg Mn/kg soil). There is a general decrease of DTPA extractable Mn with soil depth although in some profiles (e.g. NYN-P4, NYN-P9 and NYN-P10) showed an irregular decrease in Mn levels with soil depth.

The availability of micronutrients in the soils is influenced by, among other factors, level of organic matter, soil pH, calcium carbonates and phosphorus levels (sims and Johnson, 1991). Vadivelu and Bandypadhyay (1995) observed that most DTPA micronutrients are positively correlated with organic carbon and negatively correlated with $CaCO_3$ and soil pH. FAO (2000) reported that micronutrient deficiencies are caused through a soil pH which is too low (acid), or more often, through a soil pH which is too high (neutral to alkaline), and thus, a change in soil pH of the studied soils may increase Zn availability to plants.

Organic carbon of the topsoils in the study area are relatively higher than those of the subsoils. This may have provided favourable environment for the availability of the micronutrients in the surface soils. Moreover, the sharp decline in the available micronutrient content in the subsurface horizons may be due to the fact that these elements were being mined by vegetation and redeposited in the surface layer having higher contents of complexing organic materials (Follet and Lindsay, 1970).

The levels of hot-water extractable Boron (B) in all mapping units are very low when compared with the critical levels of 0.3 and 0.5 mg/kg soil for coarser-textured and finer-textured soils respectively (Landon, 1991).

4.3 Soil classification

Tables 8 and 9 give a summary of morphological and diagnostic features while Table 10 presents the classification of the studied soils according to both WRB and USDA Taxonomy systems respectively. Using FAO system of classification, five soil levels were identified namely; Lixisols, Fluvisols, Vertisols, Cambisols and Calcisols. The Cambisols are found on the peneplane (ridge slopes with sandy soils, valley bottoms) and on the piedmont. Lixisols are dominant on the Peneplane (ridge summits, ridge slopes with red soils) and on the flats with red soils. Floodplains, some parts of the piedmont and some parts of Flats with red soils are dominated with Calcisols. Flats with sandy soils and some parts of valley bottoms are dominated by Fluvisols while Vertisols are dominant in Mbuga.

Table 8. Summary of morphological and diagnostic features of studied soils according to the WRB system

Profile	Diagnostic horizons	Other diagnostic features. properties/ materials
NYN-P1	Ochric horizon Argic horizon	Profondic. Rhodic
NYN-P2	Mollic horizon	Mollic, Hypereutric
NYN-P3	Ochric horizon Cambic Horizon	Hyperferralic. Hypereutric
NYN-P4	Mollic horizon Cambic horizon	Calcaric. Hypereutric
NYN-P5	Ochric horizon Vertic horizon	Hypereutric. Pellic. Endosodic
NYN-P6	Mollic horizon	Mollic. Calcaric. Endosodic. Hypereutric
NYN-P7	Ochric horizon Argic horizon	Profondic. Chromic
NYN-P8	Ochric horizon Cambic horizon	Rhodic. Chromic. Hypereutric
NYN-P9	Ochric horizon Calcic horizon	Endosodic, Hypocalcic
NYN-P10	Ochric horizon Argic horizon Calcic horizon	Hypocalcic, Haplic
NYN-P11	Ochric horizon Cambic horizon Calcic horizon	Hypocalcic. Haplic
NYN-P12	Ochric horizon Argic horizon	Rhodic, Chromic, Profondic

Table 9. Summary of morphological and diagnostic features of studied soils according to the USDA Taxonomy system

Profile	Diagnostic horizons	Other diagnostic features
NYN-P1	Ochric epipedon, Argillic horizon	Ustic SMR, Isohyperthermic STR
NYN-P2	Mollic epipedon	Ustic SMR, Isohyperthermic STR
NYN-P3	Ochric epipedon, Cambic horizon	Ustic SMR, Isohyperthermic STR
NYN-P4	Mollic epipedon, Cambic horizon	Ustic SMR, Isohyperthermic STR
NYN-P5	Ochric epipedon	Ustic SMR, Isohyperthermic STR, Slickensides, gilgai micro-relief
NYN-P6	Mollic epipedon	Ustic SMR, Isohyperthermic STR
NYN-P7	Ochric epipedon, Argillic horizon	Ustic SMR, Isohyperthermic STR
NYN-P8	Ochric epipedon, Cambic horizon	Ustic SMR, Isohyperthermic STR
NYN-P9	Ochric epipedon, Calcic horizon	Ustic SMR, Isohyperthermic STR
NYN-P10	Ochric epipedon, Argillic horizon, Calcic horizon	Ustic SMR, Isohyperthermic STR
NYN-P11	Ochric epipedon, Cambic horizon, Calcic horizon	Ustic SMR, Isohyperthermic STR
NYN-P12	Ochric epipedon, Argillic horizon	Ustic SMR, Isohyperthermic STR

Table 10. Classification of the studied soils

Profile	FAO Classification system			USDA Taxonomy system			
	Level-1	Level-2	Level-3	Order	Suborder	Greatgroup	Subgroup
NYN-P1	LIXISOLS (LX)	Profondic Lixisols	Rhodi-Profondic Lixisols (Haplic)	Alfisols	Ustalfs	Rhodustalfs	Kanhaplic Rhodustalfs
NYN-P2	FLUVISOLS (FL)	Mollic Fluvisols	Hypereutri-Mollic Fluvisols (Haplic)	Mollisols	Ustolls	Haplustolls	Fluventic Haplustolls
NYN-P3	CAMBISOLS (CM)	Ferralic Cambisols	Hypereutri-Ferralic Cambisols (Haplic)	Inceptisols	Ustepts	Haplustepts	Udic Haplustepts
NYN-P4	CAMBISOLS (CM)	Mollic Cambisols	Calcari-Mollic Cambisols (Hypereutric)	Mollisols	Ustolls	Haplustolls	Typic Haplustolls
NYN-P5	VERTISOLS (VR)	Pellic Vertisols	Endosodi-Pellic Vertisols (Hypereutric)	Vertisols	Usterts	Haplusterts	Sodic Haplusterts
NYN-P6	FLUVISOLS (FL)	Mollic Fluvisols	Calcari-Mollic Fluvisols (Endosodic, Hypereutric)	Mollisols	Ustolls	Haplustolls	Fluventic Haplustolls

Table 10. Continued.

Profile	FAO classification system			USDA Taxonomy system			
	Level-1	Level-2	Level-3	Order	Suborder	Greatgroup	Subgroup
NYN-P7	LIXISOLS (LX)	Profondic Lixisols	Chromi-Profondic Lixisols (Haplic)	Alfisols	Ustalfs	Haplustalfs	Kanhaplic Haplustalfs
NYN-P8	CAMBISOLS (CM)	Rhodic Cambisols	Chromi-Rhodic Cambisols (Hypereutric)	Inceptisols	Ustepts	Haplustepts	Udic Haplustepts
NYN-P9	CALCISOLS (CL)	Endosodic Calcisols	Hypocalci-Endosodic Calcisols (Haplic)	Inceptisols	Ustepts	Calciustepts	Udic Calciustepts
NYN-P10	CALCISOLS (CL)	Hypocalcic Calcisols	Hapli-Hypocalcic Calcisols	Alfisols	Ustalfs	Haplustalfs	Calcic Haplustalfs
NYN-P11	CALCISOLS (CL)	Hypocalcic Calcisols	Hapli-Hypocalcic Calcisols	Inceptisols	Ustepts	Calciustepts	Typic Calciustepts
NYN-P12	LIXISOLS (LX)	Profondic Lixisols	Rhodi-Profondic Lixisols (Chromic)	Alfisols	Ustalfs	Rhodustalfs	Kanhaplic Rhodustalfs

4.4 Land suitability evaluation

4.4.1 Socio-economic setting

In the study area people live as a family composed of a man, his wife (wives) and children. People in the area are engaged on subsistence food production to feed the members of the family and only the surplus, if available is sold to earn cash to buy other necessities such as clothes, salt, sugar, kerosine and healthy services (medicine). Labour is normally contributed by the members of the family mostly adults. The age group between 16 and 25 years old have moved to town centres to look for employment so as they may get some cash earnings for purchasing basic material requirements. Generally the level of education and technical knowledge in the study area is low, but most of the farmers have adult or primary level of education. However, many farmers are willing to receive and adopt new farming practices brought in by research and extension staffs.

This is proved by the fact that few farmers in the area are currently practicing furrow cultivation as opposed to flat cultivation. This practice helps to reduce the ground water table thus providing favourable conditions for maize and cassava crops. Also at Sokoine village farmers are practicing mixed farming (maize and cassava).

4.4.2 Land use alternatives in Wami Plains

Three systems of land use have been selected for evaluation in this study and are presented in Table 11. The selection of these land use alternatives has been made on the basis of observations of farmers practice in the area. The choice of the set of LUTs to be evaluated within those land use alternatives and management levels are based on social

Table 11. Description of land utilisation types in Wami Plains

Land Utilisation Type (LUT)	Produce	Farming System	Labour intensity (MD/ha)	Level of technical knowledge	Farm size (ha)	Land tenure	Range of observed yield (kg/ha)
Low input farming maize cultivation	Maize; local varieties	Mixed/sequential and single cropping	Low 50-70	Low; (extension, credit, marketing required)	0.5-17	Family farm	1250-5000
Low input farming rice cultivation	Rice; local varieties	Single (monoculture)	High 133-210	Low; (extension, credit, marketing required)	1-7	Family farm	1200-3000
Low input extensive grazing	Grazing of local breeds	Grazing of cattle, goats and sheep	High 469 MD/farmer/yr	Low; (extension, credit, marketing required)	8-900	Family farm	**Meat** 4950 kg/farmer/year **Milk** 203 litres/farmer/year

preferences for type of occupation and consumption in the area. The crops which have been considered for suitability assessment are those that are actually grown in the district.

Low input rainfed maize production (LIRMP)

Maize is grown in many parts of the area except in those areas where there is water-logging condition e.g. in Mbuga. It is characterised by low capital and labour input and is one of the main staple food crops. Most farmers use hand hoe and family labour in land preparation, planting and weeding. Planting is done in February/March and harvested in June/July. The average maize grain yields ranges between 1.25-5.0 tonnes per ha (Table 12) in which maize yields in a monocropping system are generally higher than those in an intercropping system. No any fertiliser application be it in the form of chemical or manure. The average labour involved in maize production per season is about 60 MD/ha.

Low input rainfed rice production (LIRRP)

Rice is grown in many parts of the study area especially in Mbuga, Floodplains and Flats. These bottomlands are mostly present in flat terrain. Rice is also one of the main staple food crops. It is characterised by low capital and labour input. Most farmers use hand hoe and family labour in land preparation. The average labour is 172 MD/ha (Table 13). Planting starts in December through February while harvesting is done in May/June. The average yield is between 1.2 - 3.0 tonnes per ha.

Table 12. Agro-economic survey results for low input maize production in Wami Plains

Economic component	Unit	Smallholder low-input rainfed Maize	
		Range	Calculation based on maximum attainable yield
Yield	kg/ha	1250-5000	....
Maximum attainable yield	kg/ha	....	6250
Farm gate price of product	TShs/kg	100.00	100.00
Returns	TShs/ha	125,000.00-500,000.00	625,000.00
Annual costs			
1. Labour inputs			
(i) Land preparation	MD/ha	16-26	21
(ii) Planting	MD/ha	4-14	9
(iii) Weeding	MD/ha	8-16	12
(iv) Harvesting	MD/ha	8-18	13
(v) Shelling and pesticide application	MD/ha	4-8	6
Total labour input	MD/ha	50-70	60
Sub-total labour cost at 1000 TShs/MD	TShs/ha	50,000.00-70,000.00	60,000.00
2. Material input costs			
(i) Seeds (local variety)	TShs/ha	1,000.00-2,000.00	1,500.00
(ii)Pesticides	TShs/ha	9,000.00-15,000.00	12,000.00
Sub-total input costs	TShs/ha	10,000.00-17,000.00	13,500.00
Total costs	TShs/ha	60,000.00-87,000.00	73,500.00
Gross margin (net benefit)	TShs/ha	65,000.00-413,000.00	....
Maximum gross margin	TShs/ha	....	551,500.00

Table 13. Agro-economic survey results for low input rice production in Wami Plains

Economic component	Unit	Smallholder low-input rainfed Rice: Range	Smallholder low-input rainfed Rice: Calculation based on maximum attainable yield
Yield	kg/ha	1200-3000	....
Maximum attainable yield	kg/ha	....	5000
Farm gate price of product	TShs/kg	187.50	187.50
Returns	TShs/ha	225,000.00-562,500.00	937,500.00
Annual costs			
1. Labour inputs			
(i) Land preparation	MD/ha	25-40	33
(ii) Planting	MD/ha	7.5-35	21
(iii) Weeding	MD/ha	35-70	53
(iv) Thinning	MD/ha	10-35	23
(v) Harvesting	MD/ha	35-75	55
Total labour input	MD/ha	133-210	172
Sub-total labour cost at 1,000 Tsh/MD	TShs/ha	133,000.00-210,000.00	172,000.00
2. Material input costs			
(i) Seeds (Local variety)	TShs/ha	10,000.00	
Sub-total input costs	TShs/ha	10,000.00	10,000.00
Total costs	TShs/ha	143,000.00-220,000.00	182,000.00
Gross margin (net benefit)	TShs/ha	82,000.00-342,500.00	....
Maximum gross margin	TShs/ha	....	755,500.00

MD= Mandays; ha = Hectare; kg = Kilogram; TShs = Tanzanian shillings

Extensive grazing (E)

Extensive grazing is an important land use in the area. Cattle is primarily kept as bank account and as source of meat and milk for the family. Sheep and goats are kept primarily for meat production. The grazing lands are used in their present unimproved state. It is an important land use type in most of the surveyed area. Some of the farmers who keep livestock, also grow crops mainly rice and maize. It is characterised by low capital and labour input. Vertinary services are not available. Livestock is mainly perceived as material wealth in which large numbers are aimed at, even at the sacrifice of the health and milking quality of the animals. The herd sizes are not in consideration of the carrying capacity of the available grazing lands which normally results in an overgrazing problem.

The livestock is kept in the homesteads at night and the animals have to shuttle every day to the grazing lands. Water are few and frequently long distances from homesteads. The animals are communally grazed within or outside the village area, and in charge of herdsmen during the day; they return to the homestead for the night.

Grazing is generally uncontrolled. Mostly herds are walking over long distances from one grazing area to another and to and from scarce water points, thus trampling large areas and causing erosion. After the harvest of field crops, the animals are led over the fields to feed on crop residues (maize, cow peas and rice stubble). In dry season herds may be grazed at very long distances from the homesteads e.g. from Wami Plains to Kingolwira and Pangawe areas to seek for pastures.

4.4.3 ALES suitability evaluation results

ALES physical suitability results

The ALES physical suitability results for maize, rice and extensive grazing in the study area are summarised in Table 14. ALES yields predictions are presented in Table 15.

Of nine mapping units identified in the area, three units are moderately suitable for maize production with yield prediction of 5,000 kg/ha and annual returns of 500,000 TShs $ha^{-1}yr^{-1}$ Table 15). These units includes PL1, Pe1, Pe3 and some parts of Pi1. The factors slightly limiting are nutrients availability, nutrients retention, erosion hazard and moisture availability. Three units classify as marginally suitable (i.e. PL2, PL3 and Pe2; and some parts of mapping unit Pi1) with yield prediction of 2,500 kg/ha and annual returns of 250,000 TShs $ha^{-1}yr^{-1}$. They have moderate limitations due to nutrient availability and oxygen availability to roots. Two mapping units are presently not suitable for maize production (Pe4 and PL4). They have severe limitations due to flooding hazards and oxygen availability to roots as major limitations.

With regards to rice production, five mapping units were classified as marginally suitable (i.e. PL1, PL3, PL4, Pe1 and Pe2) and some parts of mapping units Pe4 and Pi1. The yields predicted by ALES for these mapping unit is 2000 kg/ha and annual returns of 196,274.00 TShs $ha^{-1}yr^{-1}$. Nutrients availability, temperature regime in growing period and soil wetness are slightly limiting factors to the productivity of these soils for rice production.

Table 14. ALES physical suitability subclasses

LMUs	SOIL TYPE	MAIZE	RICE	EXTENSIVE GRAZING	AREA
		RATING			ha
Pi1	Chromi-Rhodic Cambisols	3na	4tg	3acc	920
	Hapli-Hypocalcic Calcisols	2m/na	3tr/wt	3acc	613
Pe1	Rhodi-Profondic Lixisols	2na/nr	3na/tr/wt	2acc/bh/clm/m	3029
Pe2	Rhodi-Profondic Lixisols	3na	3na/tr/wt	2acc/bh/clm/m	2508
Pe3	Hypereutri-Ferralic Cambisols	2e/na/nr	4na	2acc/bh/clm	4331
Pe4	Hypereutri-Mollic Fluvisols	4df	4na	2bh/clm	2422
	Calcari-Mollic Cambisols	4df	3na/tr	3acc	1038
PL1	Chromi-Profondic Lixisols	2df/na/nr	3na/tr	2acc/bh/clm/dwa	4409
	Hapli-Hypocalcic Calcisols	2df/m/na/nr	3tr	2acc/bh/clm/dwa/m	1102
PL2	Calcari-Mollic Fluvisols	3na	4na	2acc/bh/clm/dwa/m	8767
PL3	Hypocalci-Endosodic Calcisols	3o	3na/tr	2bh/clm/m	4152
PL4	Endosodi-Pellic Vertisols	4df/o	3na/tr	3bh	3181

m = moisture availability, na = nutrients availability, nr = nutrients retention, df = duration of flooding, o = oxygen availability to roots, tr = temperature regime , wt = soil wetness, tg = temperature in growing period, acc = accessibility of animals to grazing lands, bh = biological hazards (tsetse ticks), clm = climatic conditions, dwa = drinking water availability.

Table 15. ALES predicted yields [kg ha^{-1}]

LMUs	SOIL TYPE	MAIZE		RICE		EXTENSIVE GRAZING			
		Maize grain		Rice		Meat (kg/farmer/yr)		Milk (litres/farmer/yr)	
		Individual soil	Overall	Individual soil	Overall	Individual soil	Overall	Individual soil	Overall
Pi1	Chromi-Rhodic Cambisols	2500		0		1980		29565	
	Hapli-Hypocalcic Calcisols	5000	3500	2000	800	1980	1980	29565	29565
Pe1	Rhodi-Profondic Lixisols	5000	5000	2000	2000	3960	3960	59130	59130
Pe2	Rhodi-Profondic Lixisols	2500	2500	2000	2000	3960	3960	59130	59130
Pe3	Hypereutri-Ferralic Cambisols	5000	5000	0	0	3960	3960	59130	59130
Pe4	Hypereutri-Mollic Fluvisols	0	0	0		3960		59130	
	Calcari-Mollic Cambisols	0	0	2000	600	1980	3366	29565	50261
PL1	Chromi-Profondic Lixisols	5000		2000		3960		59130	
	Hapli-Hypocalcic Calcisols	5000	5000	2000	2000	3960	3960	59130	59130
PL2	Calcari-Mollic Fluvisols	2500	2500	0	0	3960	3960	59130	59130
PL3	Hypocalci-Endosodic Calcisols	2500	2500	2000	2000	3960	3960	59130	59130
PL4	Endosodi-Pellic Vertisols	0	0	2000	2000	1980	1980	29565	29565

The rest of the mapping units (i.e. PL2, Pe3) and some parts of Pe4 and Pi1 are physically not suitable for rice production due to severe limitations associated with nutrients availability and unfavourable temperature in growing period.

As far as extensive grazing is concerned, six mapping units (i.e. PL1, PL2, PL3, Pe1, Pe2, Pe3) and some parts of Pe4 are classified as moderately suitable. The yield predictions of these mapping are 3969 kg per farmer per year for meat and 59130 litres per farmer per year. The annual returns expected by the farmers in these mapping units is about 10,057,500.00 TShs per farmer per year. The following factors are slightly limiting: poor accessibility of animals to grazing lands, poor climatic conditions (temperature), biological hazards (tsetse and ticks infestation), poor availability of drinking water and moisture availability for the production of enough pasture for the livestock throughout the year. Two mapping units (i.e. PL4, Pi1) and some parts of Pe4 are marginally suitable for extensive grazing with the yield predictions of 1980 kg per farmer per year for meat and 29565 litres per farmer per year and annual returns of 5,028,750.00 TShs per farmer per year. They have moderate limitation due to bushy coverage which hinders accessibility of animals to grazing lands and biological hazards especially tsetse and ticks infestation.

The results of physical suitability evaluation can be summarised as follows: About 38% (13,477 ha) of the study area has been classified as moderately suitable, 44% (15,777 ha) marginally suitable and 18% (6,565 ha) physically not suitable for low input rainfed maize production.

For low input rainfed rice production, about 55% (19,904 ha) of the study area is classified as marginally suitable and 45% (15,922 ha) are physically not suitable for the mentioned LUT.

About 84% (30,143 ha) of the study area has been classified as moderately suitable for extensive grazing while only 16% (5,675 ha) are marginally suitable for the LUT.

ALES economic suitability results

The results of economic suitability evaluation are presented in Table 16. The gross margins for each LUT are summarised in Table 17.

Table 16. Economic suitability classes

LMUs	SOIL TYPE	MAIZE	RICE	EXTENSIVE GRAZING
				RATING
Pi1	Chromi-Rhodic Cambisols	s3	n1	s3
	Hapli-Hypocalcic Calcisols	s2	s3	s3
Pe1	Rhodi-Profondic Lixisols	s2	s3	s1
Pe2	Rhodi-Profondic Lixisols	s3	s3	s1
Pe3	Hypereutri-Ferralic Cambisols	s2	n1	s1
Pe4	Hypereutri-Mollic Fluvisols	n1	n1	s1
	Calcari-Mollic Cambisols	n1	n1	s1
PL1	Chromi-Profondic Lixisols	s2	s3	s1
	Hapli-Hypocalcic Calcisols	s2	s3	s1
PL2	Calcari-Mollic Fluvisols	s3	n1	s1
PL3	Hypocalci-Endosodic Calcisols	s3	s3	s1
PL4	Endosodi-Pellic Vertisols	n1	s3	s3

Three mapping units (PL1, Pe1 and Pe3) were rated as moderately suitable (s2) economically for maize production. Also some parts of mapping unit Pi1 are found to be economically moderately suitable for maize. The farmers involved in maize production in these mapping units are likely to receive a gross margin of about 415,402.50 TShsha^{-1}yr^{-1} (Table 17).

Other three mapping units (PL2, PL3, Pe2) and some parts of Pi1 are classified as marginally suitable (s3) economically for maize production with gross margin of about 165,402.50 TShs ha^{-1}yr^{-1}. Two mapping units (PL4 and Pe4) are found to be economically not suitable (n1).

Most parts of the study area was classified as marginally suitable (s3) economically for rice production with gross margin of 196,274.00 TShs ha^{-1}yr^{-1}. These mapping units include PL1, PL3, PL4, Pe1, Pe2 and some parts of Pe4 and Pi1. Land mapping units (PL2, Pe3) and some parts of Pe4 and Pi1 are classified as economically not suitable (n1) for rice production.

Seven mapping units were classified as highly suitable (s1) economically for extensive grazing with gross margins of 9,563,085.00 TShs/farmer/yr. The mapping units are PL1, PL2, PL3, Pe1, Pe2, Pe3 and Pe4. Two mapping units (PL4 and Pi1) were found to be marginally suitable (s3) economically for extensive grazing with a gross margin of 4,534,335.00 TShs/farmer/yr.

Table 17. Gross margins [TShs $ha^{-1}yr^{-1}$]

LMUs	SOIL TYPE	MAIZE		RICE		EXTENSIVE GRAZING TShs/farmer/year	
		Individual soil	Overall	Individual soil	Overall	Individual soil	Overall
Pi1	Chromi-Rhodic Cambisols	165,402.50		0		4,534,335.00	
	Hapli-Hypocalcic Calcisols	415,402.50	265,402.50	196,274.00	78,509.60	4,534,335.00	4,534,335.00
Pe1	Rhodi-Profondic Lixisols	415,402.50	415,402.50	196,274.00	196,274.00	9,563,085.00	9,563,085.00
Pe2	Rhodi-Profondic Lixisols	165,402.50	165,402.50	196,274.00	196,274.00	9,563,085.00	9,563,085.00
Pe3	Hypereutri-Ferralic Cambisols	415,402.50	415,402.50	0	0	9,563,085.00	9,563,085.00
Pe4	Hypereutri-Mollic Fluvisols	0	0	0	0	9,563,085.00	
	Calcari-Mollic Cambisols	0	0	196,274.00	196,274.00	4,534,335.00	8,054,460.00
PL1	Chromi-Profondic Lixisols	415,402.50		196,274.00		9,563,085.00	
	Hapli-Hypocalcic Calcisols	415,402.50	415,402.50	196,274.00	196,274.00	9,563,085.00	9,563,085.00
PL2	Calcari-Mollic Fluvisols	165,402.50	165,402.50	0	0	9,563,085.00	9,563,085.00
PL3	Hypocalci-Endosodic Calcisols	165,402.50	165,402.50	196,274.00	196,274.00	9,563,085.00	9,563,085.00
PL4	Endosodi-Pellic Vertisols	0	0	196,274.00	196,274.00	4,534,335.00	4,534,335.00

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on field observations, laboratory and ALES results the following conclusions are made:

i) Climate, landform patterns and parent materials have had profound influence on types and distribution of soils in the study area. The piedmont slopes and peneplanes with colluvial materials have deep to very deep soils. This is due to addition of new soils, *in-situ* weathering of soil materials and low rate of erosion. Valley bottoms and plains have medium textures and are stratified as a result of cyclic deposition of materials of diverse origin.

ii) Soils of Wami Plains are mostly sandy clay loams and are well drained except on the valley bottoms, floodplains and mbuga where they are poorly drained. Soil reaction of the soils range between slightly acid to alkaline and are generally poor in chemical fertility. The level of micronutrients in these soils is adequate except for Zn which is rated as inadequate for most crops.

iii) The soils of the study area classify into five soil units namely: Lixisols, Fluvisols, Vertisols, Cambisols and Calcisols.

iv) Soils on the piedmont, peneplane (ridge summits and ridge slopes with sandy soils) and those of plain (flats with red soils) are moderately suitable for maize production while those of peneplane (ridge slopes with red soil) plain (flats with sandy soils and floodplain) have poor potential for maze production. The soils of peneplane (valley bottoms) and plain (mbuga) are physically not suitable for maize. The soils on the plain (flats with red soils, floodplains and mbuga), peneplane (ridge summits, ridge slopes with red soils and valley bottoms) and those of the piedmont are classified as marginally suitable for rice production. Soils on plain (flats with sandy soils) and peneplane (ridge slopes with sandy soils) are physically not suitable for rice production. As far as extensive grazing is concerned, seven mapping units were classified as moderately suitable. The soils include those of plain (flats with red soils, flats with sandy soils, floodplains) and peneplanes. Soils on the plain (mbuga) and those on piedmont were classified as marginally suitable for extensive grazing. The most unfavourable conditions limiting suitability of the soils in the study area for the production of maize, rice and extensive grazing are nutrients availability, nutrients retention capacity, moisture availability, tsetse and ticks infestation, availability of drinking water and accessibility of animals to grazing lands.

5.2 Recommendations

i) Field conditions and rainfall especially during the start and end of growing period can make planning of agricultural operations difficult. Although on average Wami area receives sufficient rain for the production of maize, rice and natural pastures for livestock still yields are low for most farmers. This may probably be due to unreliability of rainfall, thus, the timely planting and use of drought resistance maize varieties is highly recommended.

ii) Soil fertility is a major limiting land quality that poses problem to agricultural productivity in these soils. It is strongly suggested that emphasis should be put on the use of inorganic fertilisers and afforestation using agroforestry tree species especially in those areas recently under arable agriculture. Alley-cropping systems whereby crops are planted between rows of multi-purpose shrubs and trees (e.g. *Leucaena* spp.) should be encouraged. The shrubs and trees will among other things, provide mulch and manure, biologically fix nitrogen for companion crops, suppress weeds and also form barriers for control of soil erosion. Use of indigenous fertilisers such as rock phosphate could immediately contribute to the improvement of soil fertility of these soils. Furthermore, organic matter levels have to be increased and maintained by ploughing in all plant residues as much as possible. Grazing in the arable fields after harvest should not be allowed. Stubble and other plant residues should be left on the fields and ploughed in when preparing the fields for the next growing season. This will also protect the soil against erosion.

iii) Low soil moisture due to inadequate and unreliable rainfall and low water holding capacity of the soils due to low organic matter and poor supply of major nutrients which form the major limitation to agricultural production in the area can be eliminated through water harvesting techniques (e.g use of artificial dams), growing of drought tolerant crops and use of organic fertilisers to improve sustainability of agricultural production in these soils.

iv) Valley bottoms and plains (especially in mbuga and floodplains) have poor soil drainage, unfavourable levels of salinity and poor workability of the soils particularly Vertisols. Provision of drainage systems in these areas will control and keep the ground water low and enhance regular flushing of the soils thus avoiding the building up of harmful levels of soluble salts. Saline soils could also be managed through proper crop selection and planting of salt tolerant crops such as sorghum which withstands poor drainage conditions and can cope very well with drought and saline environments. Agricultural mechanisation and use of organic fertilisers will in the long run improve soil structure of these soils and ultimately enhance soil workability.

v) Since soil pH values of some of the studied soils are high (alkaline soils) an effort should be made to lower and maintain the soil pH at an optimal level. This can be achieved through the use of acidifying fertilisers such as sulphate of ammonia, ammonium sulphate-nitrate, ammonium nitrate in order to correct alkalinity. On saline/sodic soils gypsum is a useful soil amendment for the removal of sodium (Na).

vi) Further studies to establish the exact number of livestock in the District is highly recommended. This will assist in the quantification of livestock carrying capacities of various areas in the District.

vii) Furthermore, study on the nutritive values of natural pastures in the study area is important as this will give a rational basis for pasture improvement in the grazing lands.

viii) Within the grazing lands, there should be proper grazing rotation. Example, animals could be allowed on all grazing lands during the rainy season, but in the dry season grazing should be restricted to the mbuga and floodplains (which have a higher vegetation regeneration rate), and in any case grazing should not be continued in any one area to the extent of leaving the land bare.

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APPENDICES

Appendix 1. Soil profile description

Profile number : NYN-P1 Mapping unit: Pe2

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 35' 16" E/ 6° 37' 30" S

Location : About 30 km from Morogoro town (Mkundi Maili Kumi na Nane).

Elevation : 480 m.a.s.l. Parent material: Colluvium mainly red clays derived from ba muscovite biotite migmatites of Nguru ya Ndege mountains. Landform: peneplane-backslopes; g undulating. Slope: 2 %; convex. Natural vegetation: Thickets, bushes, remnants of miombo wood with grass undergrowth's. Land use: Grazing. Human influences: Animal trampling, bush clearing charcoal burning.

Surface characteristics : Erosion: severe sheet erosion. Deposition: none.

Described by E.P. Kileo, B.M. Msanya, D.N. Kimaro and S.B. Mwango on 19/12/1999

Soils are very deep, well drained dark reddish brown sandy clays, with thick very dark reddish b sandy clay loam topsoils.

Ah 0 - 17/20 cm: very dark brown (7.5YR2.5/2) dry, dark reddish brown (5YR3/2) moist; s clay loam; friable moist, slightly sticky and slightly plastic wet; moderately weak medium suban blocks; many very fine and few medium pores; many fine and few medium roots; clear wavy bour to

Bt 17/20 - 114 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/3) moist; sandy hard dry, friable moist, sticky and plastic wet; moderate medium and coarse subangular blocks medium and many very fine pores; few fine and common medium roots; abrupt smooth boundary

C 114 - 170 cm: dark reddish brown (2.5YR3/4) dry, dark reddish brown (2.5YR3/3) moist; s clay; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; structureless massive; few fine root; many medium and coarse angular and spherical fresh quartz and banded musc biotite migmatitic fragments; fine roots

SOIL CLASSIFICATION: WRB (FAO 1998): **Rhodi-Profondic Lixisols (Haplic)**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Kanhaplic Rhodustalfs**

Profile number : NYN-P2 Mapping unit: Pc4

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 34' 27" E/ 6° 38' 50" S

Location : About 3 km west of Morogoro-Dodoma road (Dr. Fungo's junction)

Elevation : 420 m asl. Parent material: Fluvial materials mainly sandy derived from banded muscovite-biotite migmatites of Nguru ya Ndege mountains. Landform: peneplane-valley bottom; gently undulating. Slope: 2 %; concave. Natural vegetation: Acacia woodland and few scattered miombo trees. Land use: Grazing. Human influences: Trees clearing for charcoal burning, animal trampling. Surface characteristics : Erosion: Severe sheet erosion. Deposition: Alluvial materials.

Natural drainage class : moderately well drained

Described by B.M. Msanya, E.P. Kileo, S.B. Mwango and D.N. Kimaro on 19/12/1999

Soils are shallow, moderately well drained, black sandy clay loams, over very dark grey to dark yellowish brown saprolite.

Ah 0 - 25 cm: black (10YR2/1) moist; sandy clay loam; very friable moist, non-sticky and non-plastic wet; weak medium and coarse subangular blocks; few medium and many very fine pores; common very fine roots; gradual smooth boundary to

C1 25 - 80 cm: very dark grey (10YR3/1) moist; sandy clay loam; very friable moist, sticky and plastic wet; structureless massive; common fine pores; few medium and common fine roots; gradual smooth boundary to

C2 80 - 100 cm: brown (10YR4/3) moist; sandy clay loam; very friable moist, slightly sticky and slightly plastic wet; structureless massive; few medium and common fine pores; few medium and fine roots; clear smooth boundary to

C3 100 - 140 cm: dark yellowish brown (10YR4/6) moist; sandy clay loam; very friable moist, slightly sticky and slightly plastic wet; structureless massive; few medium and common fine pores; few medium roots

SOIL CLASSIFICATION: WRB (FAO 1998): **Hypereutri-Mollic Fluvisols (Haplic)**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Fluventic Haplustolls**

Profile number : NYN-P3 Mapping unit: Pe3

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 37' 02.2" E/ 6° 39' 09.9" S

Location : Mkundi, 150 m west of Morogoro-Dodoma road (Dr.Kimbi's Farm)

Elevation : 530 m asl. Parent material: Colluvial-alluvial materials derived from banded muscovite-biotite migmatites of Nguru ya Ndege mountains. Landform: peneplane-backslopes; gently undulating. Slope: 3 %; straight. Natural vegetation: Secondary miombo woodland, thickets, bushes and grass under growths.

Land use: Cultivation of maize, oranges, cashew nuts, bananas. Human influences: Land clearing, animal trampling and charcoal burning.

Surface characteristics : Erosion: Severe sheet erosion. Deposition: none.

Natural drainage class : well drained

Described by E.P. Kileo, B.M. Msanya, D.N. Kimaro and S.B. Mwango on 19/12/1999

Soils are moderately deep, well drained, dark brown sandy loams, with very thick very dark grey sandy loam topsoils.

Ap 0 - 32/40 cm: very dark grey (7.5YR3/1) moist; sandy loam; very friable moist, non-sticky and non-plastic wet; weak fine subangular blocks; many very fine pores; many very fine and few medium roots; gradual wavy boundary to

Bw 3240 - 64/72 cm: dark brown (7.5YR3/2) moist; sandy loam; very friable moist, slightly sticky and slightly plastic wet; weak medium and coarse subangular blocks; few medium and many very fine pores; common very fine and few medium roots; abrupt wavy boundary to

Cm 64/72 - 120 cm: brown (7.5YR4/4) moist; sandy clay loam; extremely hard dry, friable moist, slightly sticky and slightly plastic wet; structureless massive; many very fine pores; very few medium and very fine roots; common fine and medium angular and spherical fresh quartz and iron fragments; medium and very fine roots

SOIL CLASSIFICATION: WRB (FAO 1998): **Hypereutri-Ferralic Cambisols (Haplic)**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Udic Haplustepts**

Profile number : NYN-P4 Mapping unit: Pc4

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 35' 07" E/ 6° 37' 57" S

Location : About 2.5 km west of Morogoro-Dodoma road from Mkundi Maili Kumi na Nane.

Elevation : 440 m asl. Parent material: Fluvial deposits derived from banded muscovite-biotite migmatites of Nguru ya Ndege mountains. Landform: peneplane-valley bottom; flat to almost flat. Slope: 0.5 %; straight. Natural vegetation: Secondary miombo woodland, bushes, thickets and grass undergrowth's. Land use: Grazing. Human influences: Clearing of trees for charcoal burning. animal trampling. Erosion: slight sheet erosion. Deposition: Fluvial materials (3 cm).

Natural drainage class : moderately well drained

Described by E.P. Kileo, B.M. Msanya, D.N. Kimaro and S.B. Mwango on 20/12/1999

Soil are deep, moderately well drained, dark brown to brown sandy clay loams, with thick black sandy clay loam topsoils.

Ah 0 - 12/24 cm: black (7.5YR2.5/1) moist; sandy clay loam; friable moist, sticky and plastic wet; weak medium subangular blocks; few medium and many fine pores; many fine and few medium roots; slightly calcareous; clear wavy boundary to

AB 12/24 - 40/50 cm: dark brown (7.5YR3/2) moist; sandy clay loam; friable moist, sticky and plastic wet; weak medium subangular blocks; few medium and many fine pores; common fine and medium roots; no reaction with HCl; abrupt wavy boundary to

Bw(m) 40/50 - 95 cm: brown (7.5YR4/3) moist; sandy clay loam; very hard dry, firm moist, sticky and plastic wet; weak medium structureless massive; few medium and common fine pores; few fine and medium roots; moderately strong calcareous; abrupt smooth boundary to

Cmk 95 - 145+ cm: white (7.5YR8/1) moist; sandy clay loam; very hard dry, friable moist, sticky and plastic wet; structureless massive; very fine and few fine pores; few fine and medium; many medium and common subangular fresh mixed rock fragments; few fine and medium roots; strongly calcareous

SOIL CLASSIFICATION: WRB (FAO 1998): **Calcari-Mollic Cambisols (Hypereutric)**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Typic Haplustolls**

Profile number : NYN-P5 Mapping unit: PL4

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 30' 15" E/ 6° 32' 36" S

Location : About 6 km west of Morogoro-Dodoma road (at Sokoine junction)

Elevation : 420 m asl. Parent material: Recent alluvium materials mainly clay derived from banded muscovite-biotite migmatites of Nguru ya Ndege mountains. Landform: Mbuga; flat or almost flat. Slope: 1 %; concave. Natural vegetation. Acacia woodland and grass undergrowth. Land use: Grazing and rice cultivation.

Surface characteristics : Surface sealing: 1-2 mm. Cracks: very deep cracks (>100 cm); 3-10 cm wide with gilgai micro-relief. Erosion: none or slight. Deposition: Alluvial materials.

Natural drainage class : poorly to very poorly drained

Described by E.P. Kileo, B.M. Msanya, D.N. Kimaro and S.B. Mwango on 21/12/1999

Soils are deep, poorly to very poorly drained very dark grey sandy clays, with very thick black sandy clay topsoils.

Ah 0 - 25/45 cm: black (N2.5/0) sandy clay; firm moist, sticky and plastic wet; weak coarse and medium subangular blocks; medium and many fine pores; many fine roots; clear wavy boundary to

ACk 25/45 - 100 cm: very dark grey (N3/0) moist; sandy clay; very firm moist, very sticky and very plastic wet; moderate coarse angular wedge-shaped blocks and angular prismatic blocks; continuous thick slickensides/press cutans; very fine pores; abundant medium spherical hard carbonates nodules; common fine roots; moderately calcareous; abrupt smooth boundary to

Ck 100 - 160+ cm: greyish brown (2.5Y5/2) moist; clay; very firm moist, very sticky and very plastic wet; weak very coarse prisms; very few moderately thick slickensides/press cutans; common very fine pores; diffuse fine and medium spherical hard carbonates nodules; strongly calcareous

SOIL CLASSIFICATION: WRB (FAO 1998): **Endosodi-Pellic Vertisols (Hypereutric)**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Sodic Haplusterts**

Profile number : NYN-P6 Mapping unit: PL2

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 33' 56.9" E/ 6° 33' 16.6" S

Location : About 1 km west of Morogoro-Dodoma road (Kibaoni Dakawa Ranch)

Elevation : 420 m asl. Parent material: Recent alluvium derived from banded muscovite-biotite migmatites of Nguru ya Ndege mountains. Landform: flats; flat to almost flat. Slope: 0.5 %; straight Natural vegetation: Remnants of miombo woodland, thickets, bushes and grasses. Land use: Extensive grazing. Human influences: Animal trampling, tree clearing for charcoal burning.

Surface characteristics : Cracks: fine cracks (<1 cm wide and 20cm deep), very closely spaced cracks. Erosion: moderate sheet erosion. Deposition: Alluvial materials. Natural drainage class : well drained Described by E.P. Kileo, S.B. Mwango, B.M. Msanya and D.N. Kimaro on 06/02/2000

Soils are shallow, stratified, well drained very dark greyish brown sandy clay loams, over dark greyish brown to dark yellowish brown saprolite.

Ah 0 - 26 cm: very dark greyish brown (10YR3/2) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; weak medium and fine subangular blocks; many fine and common medium pores; many fine and few medium roots; clear smooth boundary to

2C 26 - 46 cm: dark greyish brown (10YR4/2) dry, dark yellowish brown (10YR3/4) moist; sandy clay loam; many fine prominent sharp mottles; very hard dry, very firm moist, sticky and plastic wet; structureless massive; few fine and medium pores; few medium and coarse roots; clear smooth boundary to

3Ck 46 - 110 cm: dark yellowish brown (10YR4/4) dry, brown (10YR4/3) moist; sandy clay; hard dry, friable moist, sticky and plastic wet; structureless massive; many fine and medium pores; very few fine roots; slightly to extremely calcareous.; clear smooth boundary to

4Ck 110 - 150 cm: dark yellowish brown (10YR3/6) dry, dark yellowish brown (10YR3/4) moist; clay; hard dry, firm moist, sticky and plastic wet; structureless massive; many fine and medium pores; extremely calcareous

SOIL CLASSIFICATION: WRB (FAO 1998): **Calcari-Mollic Fluvisols (Endosodic, Hypereutric)**
USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Fluventic Haplustolls**

Profile number : NYN-P7 Mapping unit: PL1

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 35' 14.3" E/ 6° 35' 40.9" S

Location : About 1 km west Morogoro-Dodoma road (kwa Mwarabu). Elevation : 420 m asl.

Parent material: Colluvium mainly red clays derived from banded muscovite-biotite migmatites of Nguru ya Ndege mountains. Landform: Red flats; flat or almost flat. Slope: 0.5 %; straight. Natural vegetation: Secondary miombo woodland, thickets, bushes and grasses. Land use: Extensive grazing. Human influences: Charcoal burning.

Surface characteristics : Cracks: Fine (<1 cm wide; 60 cm deep and closely spaced cracks); Erosion: Moderate sheet erosion. Deposition: Alluvial materials. Natural drainage class : well drained

Described by E.P. Kileo, S.B. Mwango, B.M. Msanya and D.N. Kimaro on 06/02/2000

Soils are very deep, well drained reddish brown to yellowish red sandy clay to clays, with thick dark brown sandy clay loam topsoils.

Ah 0 - 20 cm: dark brown (7.5YR3/2) dry, red dark grey (7.5YR3/1) moist; sandy clay loam; soft dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine and few medium pores; many fine and medium roots; clear smooth boundary to

Bts1 20 - 40 cm: yellowish red (5YR5/6) dry, reddish brown (5YR4/3) moist; sandy clay; hard dry, friable moist, sticky and plastic wet; moderate coarse subangular blocks; continuous moderately thick clay cutans; many fine and common medium pores; many fine and few medium roots; gradual wavy boundary to

Bts2 40 - 125 cm: yellowish red (5YR5/8) dry, yellowish red (5YR4/6) moist; clay; slightly hard dry, friable moist, very sticky and very plastic wet; moderately strong medium and fine subangular blocks; continuous moderately thick clay cutans; many fine and medium pores; common very fine and few medium roots; abrupt smooth boundary to

BCk 125 - 160 cm: yellowish red (5YR5/8) dry, yellowish red (5YR4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderately strong fine and medium subangular blocks; few fine and common medium pores; very many fine and medium angular and irregular slightly weathered quartz fragments; very few very fine and medium roots; slightly calcareous

SOIL CLASSIFICATION: WRB (FAO 1998): **Chromi-Profondic Lixisols (Haplic)**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Kanhaplic Haplustalfs**

Profile number : NYN-P8 Mapping unit: Pi1

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 35' 00" E/ 6° 40' 17" S

Location : MKUNDI

Elevation : 465 m asl. Parent material: Banded muscovite-biotite sediments and superficial sands derived from Nguru ya Ndege mountains. Landform: Alluvial fan; undulating. Slope: 6 %; convex

Surface characteristics : Erosion: none or slight. Deposition: none.

Natural drainage class : well drained

Described by B.M. Msanya, D.N. Kimaro, E.P. Kileo and S.B. Mwango on 23/12/1999

Soils are very deep, well drained reddish brown to dark reddish brown loamy sand to sandy clay loams, with thick reddish brown loamy sand topsoils.

Ah 0 - 15 cm: yellowish red (5YR4/6) dry, reddish brown (5YR4/4) moist; loamy sand; slightly hard dry, friable moist, non-sticky and non-plastic wet; weak medium subangular blocks; many fine and medium pores; common fine and very fine roots; gradual smooth boundary to

BA 15 - 35 cm: yellowish red (5YR4/6) dry, reddish brown (5YR4/4) moist; loamy sand; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; weak fine and medium subangular blocks; patchy thin clay cutans; many fine and medium pores; very few small angular slightly weathered quartz fragments; few medium and coarse roots; gradual smooth boundary to

Bw1 35 - 75 cm: red (2.5YR4/6) dry, dark reddish brown (2.5YR3/4) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate medium subangular blocks; patchy thin clay cutans; common fine pores; frequent small angular slightly weathered quartz fragments; few very fine and medium roots; gradual smooth boundary to

Bw2 75 - 160+ cm: reddish brown (2.5YR4/4) dry, dark reddish brown (2.5YR3/4) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium subangular blocks; common fine pores; very frequent medium angular slightly weathered quartz fragments; few very fine and medium roots

SOIL CLASSIFICATION: WRB (FAO 1998): **Chromi-Rhodic Cambisols (Hypereutric)**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Udic Haplustepts**

Profile number : NYN-P9 Mapping unit: PL3

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 37' 0.1" E/ 6° 34' 59.9" S

Location : About 3.2 km east of Morogoro-Dodoma road along road to Dakawa ranch (30 km from Morogoro town to Kibaoni Dakawa Ranch). Elevation : 450 m asl. Parent material: Post-miocene orange-red Colluvium on undifferentiated Precambrian rocks. Landform: floodplain; flat or almost flat. Slope: 1 %. Surface characteristics : Erosion: none or slight. Deposition: none. Natural drainage class : poorly drained

Described by E.P. Kileo, D.N. Kimaro, B.M. Msanya and S.B. Mwango on 22/12/1999

Soil are very deep, poorly drained dark brown to very dark greyish brown loamy sand to sandy loams, with thin very dark grey sandy clay loam topsoils.

Ah 0 - 6 cm: dark greyish brown (10YR4/1) dry, very dark grey (10YR3/1) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine and medium subangular blocks; many fine pores; many fine roots; clear smooth boundary to

BA 6 - 23 cm: brown (10YR4/3) dry, dark brown (10YR3/4) moist; loamy sand; soft dry, friable moist, non-sticky and non-plastic wet; weak fine and medium subangular blocks; many fine pores; many fine roots; abrupt irregular boundary to

Bg1 23 - 40 cm: dark yellowish brown (10YR4/4) dry, dark yellowish brown (10YR3/4) moist; loamy sand; fine distinct mottles; extremely hard dry, friable moist, sticky and plastic wet; moderate medium and coarse prisms; many fine and medium pores; few fine roots; moderately calcareous; abrupt smooth boundary to

Bg2 40 - 64 cm: very dark greyish brown (2.5Y3/2) moist; loamy sand; many fine distinct diffuse2.5YR4/4 mottles; extremely hard dry, friable moist, sticky and plastic wet; moderate medium and coarse prisms; slightly to moderately calcareous; clear smooth boundary to

BC 64 - 90 cm: olive brown (2.5Y4/4) moist; sandy loam; extremely hard dry, extremely firm moist, sticky and plastic wet; weak medium and coarse angular blocks; slightly calcareous; clear smooth boundary to

C1 90 - 126 cm: light olive brown (2.5Y5/4) moist; loamy sand; structureless massive; extremely calcareous; clear smooth boundary to

C2 126 - 165 cm: light yellowish brown (2.5Y6/4) moist; sandy loam; structureless massive; extremely calcareous.

SOIL CLASSIFICATION: WRB (FAO 1998): **Hypocalci-Endosodic Calcisols**

(Calcaric, Chromic, Orthieutric)

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Udic Calciustepts**

Profile number : NYN-P10 **Mapping unit: PL1**

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 36' 0.0" E/ 6° 34' 59.9" S

Location : About 1 km east of Morogoro-Dodoma road to Dakawa ranch Head Office. Elevation : 440 m asl. Parent material: Post-miocene orange red Colluvium on undifferentiated Precambrian rocks. Landform: Red flats; nearly flat to gently undulating. Slope: 1 %; straight. Erosion: none or slight: Natural drainage class : well drained

Described by D.N. Kimaro, S.B. Mwango, E.P. Kileo and B.M. Msanya on 23/12/1999

Soils are very deep, well drained dark reddish brown sandy clay to clays, with thin dark reddish brown sandy clay loam topsoils.

Ah 0 - 6 cm: dark reddish brown (5YR3/3) dry, dark reddish brown (5YR3/2) moist; sandy clay loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine and few medium pores; many fine and few medium roots; clear smooth boundary to

BA 6 - 13 cm: reddish brown (5YR4/4) dry, dark reddish brown (5YR3/4) moist; sandy clay; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine and few medium pores; many fine and few medium roots; slightly calcareous gradual smooth boundary to

Bt1 13 - 26 cm: dark reddish brown (2.5YR3/4) dry, dark reddish brown (2.5YR2.5/4) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; few fine and medium pores; few fine and medium roots; strongly calcareous diffuse smooth boundary to

Bt2 26 - 58 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; patchy thin clay cutans; many fine and few medium pores; fine roots; slightly to strongly calcareous diffuse smooth boundary to

Bts1 58 - 104 cm: reddish brown (2.5YR4/4) dry, dark red (2.5YR3/6) moist; clay; soft dry, friable moist, sticky and plastic wet; moderate fine and fine subangular blocks; many fine and few medium pores; very fine and coarse roots; diffuse smooth boundary to

Bts2 104 - 150+ cm: red (2.5YR4/8) dry, red (2.5YR4/6) moist; clay loam; soft dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine and few medium pores; very fine and coarse roots

SOIL CLASSIFICATION: WRB (FAO 1998): **Hapli-Hypocalcic Calcisols**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Calcic Haplustalfs.**

Profile number : NYN-P11 Mapping unit: Pi1

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 37' 0.1" E/ 6° 40' 0.1" S

Location : Mkundi, about 18 km from Morogoro town on the road to Dodoma; 100 m west of the road (Mohammed Fuko's Farm).

Elevation : 580 m asl. Parent material: metamorphic rocks. Landform: Alluvial fan; flat to almost flat. Slope: 1.5 %; straight

Surface characteristics : Erosion: none or slight. Deposition: none.

Natural drainage class : well drained

Described by B.M. Msanya, E.P. Kileo, D.N. Kimaro and S.B. Mwango on 22/12/1999

Soil are deep, well drained very dark grey to dark brown sandy clay loams, with thick very dark grey sandy clay topsoils.

Ap 0 - 13 cm: very dark grey (10YR3/1) dry, very dark grey (7.5YR3/0) moist; clay loam; soft dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine and few medium roots; clear smooth boundary to

ABm 13 - 40 cm: very dark grey (10YR3/2) dry, very dark grey (10YR3/1) moist; clay loam; very hard dry, very firm moist, sticky and plastic wet; weak medium and coarse angular blocks; few fine and common medium roots; moderately calcareous; gradual smooth boundary to

Bw(m) 40 - 90 cm: dark brown (7.5YR4/4) dry, dark brown (7.5YR3/2) moist; sandy clay; very hard dry, very firm moist, slightly sticky and slightly plastic wet; moderate medium and coarse angular breaking into subangular blocks; few fine and few medium roots; moderately calcareous;.

SOIL CLASSIFICATION: WRB (FAO 1998): **Hapli-Hypocalcic Calcisols**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Typic Calciustepts**

Profile number : NYN-P12 Mapping unit: Pc1

Region : MOROGORO

District : MOROGORO RURAL

Map sheet no. : 183/1

Coordinates : 37° 36' 0.0" E/ 6° 37' 0.1" S

Location : Mkundi (Mawasiliano) east of Morogoro-Dodoma road.

Elevation : 460 m asl. Parent material: Colluvium material derived from banded muscovite biotite migmatites of Nguru ya Ndege mountains . Landform: Peneplane-summit; nearly flat to undulating. Slope: 2 %; straight: Surface characteristics : Erosion: none or slight. Deposition: none: Natural drainage class : well drained

Described by D.N. Kimaro, B.M. Msanya, S.B. Mwango and E.P. Kileo on 22/12/1999

Soils are moderately deep, well drained dark reddish brown to dark red sandy clay to clays, with thin dark reddish brown sandy clay topsoils.

Ah 0 - 10 cm: dark reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3) moist; sandy clay; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine pores; many fine roots; clear smooth boundary to

BA 10 - 26 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; sandy clay; soft dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; patchy thin clay cutans; many fine and few medium pores; many fine roots; gradual smooth boundary to

Bts1 26 - 53 cm: reddish brown (2.5YR4/4) dry, dark red (2.5YR3/6) moist; clay; soft dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; patchy thin clay cutans; many fine and few medium pores; very few small irregular fresh quartz fragments; common fine roots; gradual smooth boundary to

Bts2 53 - 80 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; soft dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; many very fine and medium pores; very few small irregular weathered quartz fragments; many very fine and medium roots.

SOIL CLASSIFICATION: WRB (FAO 1998): **Rhodi-Profondic Lixisols (Chromic)**

USDA-Soil Taxonomy (Soil Survey Staff, 1998): **Kanhaplic Rhodustalfs**

Appendix 2. Land attribute data base for Wami Plains

LC	Soil unit	Alt (m)	MAT (°C)	MAR	RGP	LGP	SI	ESD (cm)	D RC	Tseisc risks	AW C	Surf (pH)	CEC	O.C	N	P	BS	ESP	ECe	Dt w
LMU																				
Pl1	NYN-P8	465	24.6	768	596	5.1	6	160	WD	Slight	130	7.0	5.9	0.52	0.07	3.7	100	0.67	0.02	1.5
	NYN-P11	580	24.6	768	596	5.2	1.5	>100	WD	Slight	96.0	6.5	20	1.20	0.13	12.8	86	0.54	0.03	3
Pe1	NYN-P12	460	24.0	1036	846	6.9	2	80	WD	Slight	82.5	6.2	17.4	1.29	0.13	1.46	53	1.12	0.06	2
Pe2	NYN-P1	480	24.6	768	596	5.1	2	170	WD	Slight	84.8	6.9	18.4	1.39	0.11	1.53	93.4	1.14	0.08	4
Pe3	NYN-P3	530	24.6	768	596	5.2	3	120	WD	Slight	135	6.8	3.3	0.59	0.06	6.8	93.4	4.4	0.03	5
Pe4	NYN-P2	420	24.6	768	596	5.1	2	140	MWD	Slight	89.4	6.7	5.6	0.79	0.07	1.95	90	0.96	0.03	7
	NYN-P4	420	24.6	768	596	5.1	0.5	145	MWD	Modr	97.6	7.8	15.6	1.70	0.17	7.4	130	0.96	0.14	5
PL1	NYN-P7	420	24.0	1036	846	6.8	0.5	>125	WD	Slight	164	6.1	6.1	0.97	0.06	2.4	70.2	2.7	0.03	2
	NYN-P10	440	24.0	1036	846	6.8	1	>150	WD	Slight	112	6.6	10.6	1.22	0.12	8.3	80	1.01	0.03	3
PL2	NYN-P6	420	24.0	1036	846	6.8	0.5	110	WD	Modr	112	6.2	4.4	0.71	0.04	2.29	73.5	20.4	0.182	4
PL3	NYN-P9	450	24.0	1036	846	6.9	1	90	PD	Slight	132	6.1	3.0	0.56	0.06	3.7	78.9	1.7	0.02	1.5
PL4	NYN-P5	420	24.0	1036	846	6.8	1	100	PVPD	Modr	113	7.7	21.2	0.79	0.08	0.96	123	4.25	0.09	5

Alt = Altitude, MAT = Mean annual temperature, MAR = mean annual rainfall, RGP = Rainfall during growing period, ESD = Effective soil depth, MDR = moderately drained, WD = well drained, PD = poorly drained, PVPD = poorly to very poorly drained, DRC= Drainage class, AWC = Available water capacity, Surf pH= Surface pH, P= available P., Dtw= Distance to drinking water (km). Sl = Slope (%). Modr = moderate

Appendix 3. Land characteristics specifications

LC Id *Code*	*class*	LC Name *Class Name*	*Classes (Upper Limit)*	*Unit*
sl		*Dominant slope classes*		%
1	1	Flat	0-0.2	
2	2	Level	0.2-0.5	
3	3	Nearly level	0.5-1.0	
4	4	Very gently slopping	1.0-2.0	
5	5	Gently slopping	2.0-5.0	
6	6	Slopping	5.0-10	
7	7	Strongly slopping	10-15	
8	8	Moderately steep	15-30	
9	9	Steep	30-60	
10	10	Very steep	>60	
T-an		*Mean annual temperature*		°C
		Very cool	15-17.5	
		Cool	17.5-20	
		Moderately cool	20-22.5	
		Moderately warm	22.5-25	
		Warm	25-30	
		Very warm	30-40	
		Extremely warm	40-60	
T-GP		*Mean temperature in growing period*		°C
1	1	Very cool	10-15	
2	2	Cool	15-17.5	
3	3	Moderately cool	17.5-20	
4	4	Moderately warm	20-22.5	
5	5	Warm	22.5-25	
6	6	Very warm	25-27.5	
Tex-p		*Average soil texture of profile*		Class
1	1	Clay		
2	2	Sandy clay		
3	3	Silty clay		
4	4	Clay loam		
5	5	Sandy clay loam		
6	6	Silty loam		
7	7	Silty clay loam		
8	8	Sandy loam		
9	9	Sand		
10	10	Loamy sand		

Tex-t		*Average soil texture within 0-30 cm*		Class
1	1	Clay		
2	2	Sandy clay		
3	3	Silty clay		
4	4	Clay loam		
5	5	Sandy clay loam		
6	6	Silty loam		
7	7	Silty clay loam		
8	8	Sandy loam		
9	9	Sand		
10	10	Loamy sand		
Dr		*Soil drainage class*		
1	1	Excessively drained		
2	2	Somewhat excessively drained		
3	3	Well drained		
4	4	Moderately well drained		
5	5	Imperfectly drained		
6	6	Poorly drained		
7	7	Very poorly drained		
FL		*Frequency of flooding*		
1	1	None		
2	2	Daily		
3	3	Weekly		
4	4	Monthly		
5	5	Annually		
6	6	Biennially		
LGP		*Reference length of growing period*		Days
1	1	Very short	120-150	
2	2	Short	150-180	
3	3	Medium	180-210	
4	4	Long	210-240	
5	5	Very long	240-270	
6	6	Extremely long	270-300	
7	7	Almost continuous	300-365	
Sd		*Effective soil depth*		cm
1	1	Very shallow	<20	
2	2	Shallow	20-40	
3	3	Moderately deep	40-80	
4	4	Deep	80-120	
5	5	Very deep	>120	
Sd-T		*Topsoil thickness*		
1	1	Thin	<10	cm
2	2	Thick	10-20	

AWC		*Available water capacity*		mm/m
1	1	Extremely low	<25	
2	2	Very low	25-50	
3	3	Low	50-100	
4	4	Medium	100-150	
5	5	High	150-200	
6	6	Very high	>200	
P-an		*Mean annual precipitation*		mm
1	1	Very low	300	
2	2	Low	500	
3	3	Moderate	750	
4	4	High	1500	
5	5	Very high	2000	
6	6	Extremely high	>2000	
Rgs		*Rainfall in growing season (last 4 months)*		mm
1	1	very low	0-100	
2	2	Low	100-200	
3	3	Medium	200-400	
4	4	High	400-600	
Rgp		*Rainfall in growing period*		
1	1	very low	100-200	mm
2	2	Low	200-400	
3	3	Medium	400-600	
4	4	High	600-1000	
pH-t		*Soil pH (H_2O) within 0-30 cm*		
1	1	Extremely acid	<4.5	
2	2	Very strongly acid	4.5-5.0	
3	3	Strongly acid	5.1-5.5	
4	4	Moderately acid	5.6-6.0	
5	5	Slightly acid	6.1-6.5	
6	6	Neutral	6.6-7.3	
7	7	Mildly alkaline	7.4-7.8	
8	8	Moderate alkaline	7.9-8.4	
9	9	Strongly alkaline	8.5-9.0	
10	10	Very strongly alkaline	>9.0	
pH-P		*Soil reaction throughout profile*		
1	1	Extremely acid	<4.5	
2	2	Very strongly acid	4.5-5.0	
3	3	Strongly acid	5.1-5.5	
4	4	Moderately acid	5.6-6.0	
5	5	Slightly acid	6.1-6.5	
6	6	Neutral	6.6-7.3	

7	7	Mildly alkaline	7.4-7.8	
8	8	Moderate alkaline	7.9-8.4	
9	9	Strongly alkaline	8.5-9.0	
10	10	Very strongly alkaline	>9.0	
CEC		*CEC within 0-30 cm*		cmol(+)/kg
1	1	Very low	<6.0	
2	2	Low	6.0-12.0	
3	3	Medium	12.1-25.0	
4	4	High	25.0-40.0	
5	5	Very high	>40.0	
N		*Nitrogen content within 0-30 cm*		%
1	1	Very low	<0.10	
2	2	Low	0.10-0.20	
3	3	Medium	0.21-0.50	
4	4	High	>0.50	
P-Br		*Available P- Bray-1 within 0-30 cm*		mgP/kg
1	1	Low	<7.0	
2	2	Medium	7-20	
3	3	High	>20	
P-Ols		*Available P-Olsen within 0-30 cm*		
1	1	Low	<5.0	
2	2	Medium	5-10	
3	3	High	>10	
K-cl		*Potassium within 0-30 cm (clay soils)*		cmol(+)/kg
1	1	Very low	<0.2	
2	2	Low	0.2-0.4	
3	3	Medium	0.41-1.2	
4	4	High	1.21-2.0	
5	5	Very high	>2.0	
K-loa		*Potassium within 0-30 cm (loam soils)*		
1	1	Very low	<0.13	
2	2	Low	0.13-0.25	
3	3	Medium	0.26-0.8	
4	4	High	0.81-1.35	
5	5	Very high	>1.35	
K-sa		*Potassium within 0-30 cm (sandy soils)*		
1	1	Very low	<0.05	
2	2	Low	0.05-0.10	
3	3	Medium	0.11-0.40	
4	4	High	0.41-0.70	
5	5	Very high	>0.7	

OC		*OC content within 0-30 cm.*		%
1	1	Very low	<0.6	
2	2	Low	0.6-1.25	
3	3	Medium	1.26-2.50	
4	4	High	2.51-3.50	
5	5	Very high	>3.50	
ESP		*Soil sodicity*		%
1	1	Non-sodic	<6	
2	2	Slightly sodic	6-10	
3	3	Moderately sodic	11-15	
4	4	Strongly sodic	16-25	
5	5	Very strongly sodic	26-35	
6	6	Extremely sodic	>35	
ECe		*Soluble salts*		mS/cm
1	1	Non-saline	0-2	
2	2	Slightly saline	2-8	
3	3	Moderately saline	8-15	
4	4	Strongly saline	>15	
BS		*Base saturation*		%
1	1	Very low	<20	
2	2	Low	20-40	
3	3	Medium	41-60	
4	4	High	61-80	
5	5	Very high	>80	
Dstdw		*Distance to drinking water*		km
1	1	Very near	0-2	
2	2	Near	2-5	
3	3	Moderately far	6-9	
4	4	Far	10-12	
5	5	Very far	>12	
Ps& ds		*Pests and diseases*		
1	1	None		
2	2	Slightly		
3	3	Moderate		
4	4	Severe		
Bsc		*Bush coverage*		%
		non bushy	0-20	
		slightly bushy	20-40	
		Moderately bushy	40-80	
		Bushy	80-100	

Appendix 4. Coding of land attributes database for Wami Plains

LMU	Soil unit	Mtgp	MAR	Rgp	LGP	FL	SI	ESD	DRC	Surf Text	Prof Text	AWC	Surf pH	Prof pH	CEC	BS	ESP	OC	N	P	ECe	Df	Bh	Dwa	Acc	Rf 4	Mat
Pi1	NYN-P8	6	3	3	2	1	6	7	3	3	5	4	6	7	2	5	1	2	3	3	1	1	2	2	3	4	4
	NYN-P11	6	3	3	2	1	4	6	3	2	5	3	5	5	3	5	1	4	3	4	1	1	2	2	3	4	4
Pe1	NYN-P12	6	4	4	2	1	4	5	3	5	2	3	5	6	3	3	1	5	3	1	1	1	2	2	2	4	4
Pe2	NYN-P1	6	4	4	2	1	4	7	3	5	1	3	5	7	2	5	1	5	3	1	1	1	2	2	2	4	4
Pe3	NYN-P3	6	3	4	2	1	5	6	3	2	8	4	6	6	1	5	1	2	2	2	1	2	2	2	2	4	4
Pe4	NYN-P2	6	3	3	2	5	4	7	4	2	5	3	6	6	2	5	1	3	2	1	1	4	2	2	1	4	4
	NYN-P4	6	3	3	2	5	2	7	4	2	5	3	7	8	3	5	1	5	3	3	1	4	2	2	3	4	4
PL1	NYN-P7	6	3	3	3	5	2	7	3	2	1	5	5	4	2	5	1	3	2	1	1	3	2	3	2	4	4
	NYN-P10	6	4	3	3	5	3	7	3	1	1	4	6	4	2	4	1	4	3	3	1	3	2	3	2	4	4
PL2	NYN-P6	6	4	4	3	5	2	6	3	2	2	4	5	8	2	5	5	3	2	1	1	2	2	3	2	4	4
PL3	NYN-P9	6	4	4	3	5	3	6	5	3	10	4	5	6	2	4	1	2	3	2	1	4	2	1	1	4	4
PL4	NYN-P5	6	4	4	3	5	3	6	6	1	2	4	7	9	3	5	3	3	3	2	1	4	3	1	1	4	4

Mtgp = Mean temperature in growing period, MAR = mean annual rainfall, Rgp = Rainfall during growing period, FL = Frequency of flooding, ESD = Effective soil depth, DRC= Drainage class, AWC = Available water capacity, Surf pH= Surface pH, Prof. pH = Profile pH, CEC = Cation exchange capacity, BS = Base saturation, ESP = Exchangeable sodium percentage, Df = Duration of flooding, Bh = Biological hazards, Dwa = Drinking water availability P= available P., Sl = Slope (%), N = Nitrogen, OC = Organic carbon.

APPENDIX 5.
Questionnaires for socio-economic data collection in Wami Plains

General information
Number of respondent..
Village..
Ward: Wami Luhindo
District: Morogoro rural
Region: Morogoro
GPS Coordinates:
Name of enumerator...
Date:..
SECTION A: FARMER'S BACKGROUND
(a) Sex
1. Male...........2. Female............
(b) Age (years)..
(c) Marital status:
1. Single
2. Married
3. Divorced
4. Widowed
5. Other (specify)..
(d) Household composition (number)

Category	Members (number)	How many contribute to work on the farm?	Off-farm work
Adults			
Male	....	....	
Female	....	....	
Children			
Male	....	....	
Female	....	....	
Dependants			
Male	....	....	
Female	....	....	
Total			

(e) What is your belief (religion)?
1. Pagan
2. Catholic
3. Lutheran
4. ERIC
5. Pentecost
7. Moravian
8. Islamic
9. SDA
10. Other (specify).......................................
(f) What is your ethnic group (tribe)?..

SECTION B: FARMER'S SOCIO-ECONOMIC STATUS

(a) What is your highest level of education?

1. No formal education
2. Adult education
3. Primary education
4. Secondary
5. Other (specify)..

(b) What is your social position?

1. Peasant/ small scale farmer
2. Political leader
3. Traditional leader
4. Employee (specify)...

(c) What is the major source of your income?

1. Farming activities
2. Non-farm activities
3. Both 1&2.
4. Other (specify)..

(d) What is your average monthly income?...........................

SECTION C: LAND ACQUISITION AND USE

(a) Since when have you been residing at this village?

(b) How did you acquire your farmland?

i. Purchased
ii. Inherited
iii. Given by village government
iv. Hired
v. Other (specify)...

c). What is the size of your farm?.................ha or.................acres.

d). How far is the farm(s) from home?

i. Around homestead..........ha or...........acres
ii. Away from the homestead...........ha or.......acres.

e). What crops do you grow on your farm?

Crop	Main Use
1. Maize	
2. Rice	
3. Cassava	
4. Beans	
5. Sorghum	
6. Peas	
7. Others (specify)	

(f) Do you keep any livestock?

Livestock type		Number
Cattle:	Exotic............................	
	Local............................	....
		....
Goats:	Exotic...........	
	Local...........	....
		....
Sheep	....	....
Chickens:	Exotic............	
	Local.............	....
		....
Others	....	....

(g). Information on livestock and /or livestock products marketing

Livestock	Product	Price per product	Market name and distance (km)
1. Cattle	Live animal		
	Hides/ skin		
	milk		
	meat		
2. Goats	Live animal		
	Hides/ skin		
	milk		
	meat		
3. Sheep	Live animal		
	Hides/ skin		
	milk		
	meat		
5. Others			

SECTION D: SERVICE RELATED, POLITICAL AND CULTURAL INFORMATION

(a). Do you have access to the following services?

i) Crop seeds Yes/ No
ii) Livetock dip or spray Yes/No
iii) Farm implements (eg. Tractor, harrow) Yes/No
iv) Vertinary services Yes/ No
v) Fertiliser Yes/ No

How does the above situation affect farming activities?..
....
....
....

(b). Do you get advice in the following activities?

	Yes	No	Source:
Crop husbandry	....	....	....
Livestock husbandry	....	....	....
Other (specify)..			

(c) How frequent do you get extension services? ....Per week/month/year (specify).....................

Do you think the visits are adequate? Yes/ No
How do village or Ward government leaders promote farming activities in this area?

SECTION E: FARM CHARACTERISTICS

(a) What is the main soil constraint?

Waterlogging
Weed
Stoniness
Pests
Other (specify)

(b) Is this plot permanently used for this crop? Yes/No
(c) What is the estimated yield per plot?............kg/plot.

SECTION F: GENDER ROLES

(i). Resource Analysis

Between man and woman, who has access to the following resources?

Resource	Man	Women
Land		
Capital		
Credit		

(ii). Activity Analysis

(a) Division of labour

12. (i) Among members of the family who does the following activities?

M = Male, F = Female, MA =Male adult, FA = Female adult, MC = Male child, FC = Female child.

	M		F	
Activity	**MC**	**MA**	**FC**	**FA**
Land preparation				
Hoeing				
Seed sowing/ transplanting				
Weeding				
Harvesting				
Transporting crops home				
Treshing				
Fodder collection				
Livestock feeding				
milking				

(b) Decision making

13. Between the husband (H) and (W) who decides to carry out the following activities?

Note: 'B' = both husband and wife

	Decision maker		
Activity	**H**	**W**	**B**
Type of crop to grow			
When to plant			
When to weed			
When to harvest			
What to sell			
When to sell			
Type of livestock to keep			
When to slaughter			

(iii). Benefit Analysis

Who owns the following benefits?

	M		F	
Benefit	**MC**	**MA**	**FC**	**FA**
Farm crops	....	....	....	....
Livestock products				
meat	....	....	....	....
milk	....	....	....	....
skin	....	....	....	....

SECTION G: CROP INFORMATION

Crop	Where is the best place to grow this crop	Total area per crop (ha)	Cop production system: Monoculture, Mixed, Intercropping, Agroforestry	Residues after harvesting: removed, Left, Burnt, others.	Yield (kg/ha, bag/ha)	Percent of yield that is used for home consumption	Percent of yield that is sold on farm or market	Price obtained on farm or market per unit (/,kg/bag)
1								
2								
3								

Total benefit: (T. Shillings)
Sales in: Field/ farmhouse/local market
What is the most important crop to you?
Why?

SECTION H: SPECIFIC INFORMATION PER CROP

Crop:

Variety;

Crops sequence in one year:

If multiple cropping, which crops?

If perennial crop lifetime of Crop:

Age of crop:

name all harvesting years (1, 2, 3, 4, 5,....)

What are the main difficulties concerning this crop?.

1. Management level: Input. Low/Medium/High.

2. Initial package:

(i) **Seeds: Local/Improved**

Do you use improved seed?: Yes/No:

Where do you get?

Material required: kg,............ price (per kg):............TShs

Own labour required: mandays,....... cost per manday:........TShs

Hired labour required: mandays,....... cost per manday:........TShs

Total cost of labour: Cost of transport.....................TShs

Total cost:................TShs.

(ii) **Planting/Replanting**

Do you practice: Yes/No:

When:

How: manual/:

Material used:

Own labour required: mandays,....... cost per manday:........TShs

Hired labour required: mandays,....... cost per manday:........TShs

Total cost of labour: Cost of transport.....................TShs

Total cost:................TShs.

iii) **Pesticide /Herbicides**

Do you apply: Yes/ No:

Type:

When:

Material required: Price (per kg).................TShs

Own labour required: mandays,....... cost per manday:........TShs

Hired labour required: mandays,....... cost per manday:........TShs

Total cost of labour: Cost of transport.....................TShs

Total cost:................TShs.

Are you aware of any impact of this on the environment?

Have already noticed this?

3. Production package

(i) **Land preparation**

Do you practice: Yes/No:

When:

How: Manual/Animal traction/Tractor/Others (specify):

Own labour required: mandays,....... cost per manday:........TShs

Hired labour required: mandays,....... cost per manday:........TShs

Total cost of labour:...................TShs

Total cost:................TShs.

(ii) Weeding

Do you practice : Yes/No:
When:
How: manual:
Material used:
Own labour required: mandays,....... cost per manday:........TShs
Hired labour required: mandays,....... cost per manday:........TShs
Total cost of labour:...................TShs
Total cost:................TShs.

(iii) Pruning/thinning:

Do you practice : Yes/No:
When:...........days or......weeks after planting
How: manual/:
Material used:
Own labour required: mandays,....... cost per manday:........TShs
Hired labour required: mandays,....... cost per manday:........TShs
Total cost of labour:...................TShs
Total cost:................TShs.

(iv) Irrigation

Do you practice : Yes/No:
If Yes, When:
How:
Material used: Cost of material (each year):
Own labour required: mandays,....... cost per manday:........TShs
Hired labour required: mandays,....... cost per manday:........TShs
Total cost of labour:...................TShs
Total cost:................TShs.

4. Soil Conservation

Have you ever experienced erosion in any of your plots?
What kind of erosion?
Do you practice soil conservation: Yes/No:
Why?
When:
Type:
How: manual:
Material used: Cost?
Own labour required: mandays,....... cost per manday:........TShs
Hired labour required: mandays,....... cost per manday:........TShs
Total cost of labour:...................TShs
Total cost:................TShs.

5. Land improvement activities:

Fertiliser:

Do you practice: Yes/No:
When:
How: manual:
Kind of fertiliser: N/ P/ K/ Manure/ Lime
Material used:
Own labour required: mandays,....... cost per manday:........TShs
Hired labour required: mandays,....... cost per manday:........TShs
Total cost of labour: Cost of transport.....................TShs
Transport: Total cost:................TShs.

	Quantity (kg)	Price /kg (Tshs)	Total cost (TShs)
N:			
P:			
K:			

6) Other farm characteristics

How far is from farm to market:.......m or .....km
Do you have credit? Yes/No.
If Yes; Purpose:
Conditions:
Sources: Bank/ Co-operative/Family/Middleman:
Where do you get your firewood from?...........km Cost?...........TShs
Where do you get your water from?............km Cost?.................TShs

7) Harvesting/ Post-harvesting

(i) Harvesting

When:
How: manual/:
Material used:
Own labour required: mandays,....... cost per manday:........TShs
Hired labour required: mandays,....... cost per manday:........TShs
Total cost of labour:...................TShs
Transport: Cost of Transport:........................TShs
Total cost:................TShs.

(ii) Post-harvesting

Do you practice: Yes/No:
When:
How: manual/:
Material used:
Own labour required: mandays,....... cost per manday:........TShs
Hired labour required: mandays,....... cost per manday:........TShs
Total cost of labour:...................TShs
Transport: Cost of Transport:........................TShs
Total cost:................TShs.

(iii) Prospects:

Are the yields improving (+) or declining (-)?
What are the causes of this trend?
Is your farm area adequate? Would you like more land?
If Yes or No Why?
What are your future expectations?
(i) To use improved seeds
(ii) To change cropping system
(iii) Other (specify)...

THANKS FOR YOUR CO-OPERATION.

Appendix 6. Rating of land use requirements for maize production in Wami Plains

Land use requirements (Land quality)	Land characteristics (Diagnostic factor)	Unit	Factor Rating: Highly suitable (s1)	Moderately suitable (s2)	Marginally suitable (s3)	Not suitable (n)
Moisture availability	Total rainfall in growing period	(mm)	600-1000	400-600	200-400	<200
Temperature regime	Mean temperature in growing period	°C	24-30	20-24; 30-32	15-20; 32-35	<15; >35
Oxygen availability to roots	Soil drainage	class	well	Moderately well	Imperfect	Poor, very poor
Rooting conditions	Effective soil depth	(cm)	>120	75-120	30-75	<30
	Soil texture	class	L, SCL, CL, SiCL.	SC, C, SL.	LS, SiC.	S
Nutrient availability	Soil reaction	pH	6.0-6.5	5.5-6.0; 6.5-7.0	5.0-5.5; 7.0-8.2	<5.0; >8.2
	Topsoil OC	%	>2.0	1.0-2.0	0.5-1.0	<0.5
	Topsoil N. content	%	>0.2	0.1-0.2	0.02-0.1	<0.02
	Topsoil avail. P.	mg/kg	>40	10-40	3-10	<3
Nutrient retention capacity	Base saturation	%	>80	40-80	20-40	<20
	Topsoil CEC_{soil}	cmol(+)/kg	>25	13-25	6-12	<6
Salinity and alkalinity	ECe	dS/m	0-4	4-6	6-8	>12
	ESP	%	0-15	15-20	20-25	>25
Wetness	Frequency of flooding		none	biannually	annually	daily, weekly, monthly
	Duration of flooding	days	0-1	1-5	5-15	>15
Erosion hazard	Slope angle	%	<4	4-8	8-16	>16

Appendix 7. Rating of land use requirements for rice production in Wami Plains

Land use requirements (Land quality)	Land characteristics (Diagnostic factor)	Unit	Factor Rating: Highly suitable (s1)	Moderately suitable (s2)	Marginally suitable (s3)	Not suitable (n)
Moisture availability	Total rainfall in growing period	(mm)	550-1000	400-550	200-400	<200
Temperature regime	Mean temperature in growing period	°C	24-28	22-24; 28-30	18-22; 30-35	<18; >35
Moisture retention	Topsoil texture	class	C, SiC, CL.	SC, SiCL, SiL.	SL, L and SCL.	S, LS.
Rooting conditions	Effective soil depth	(cm)	>75	50-75	25-50	<25
Nutrient availability	Soil reaction	pH	5.5-6.0	5.0-5.5; 6.0-7.0	4.0-5.0; 7.0-8.0	<4.0; >8.0
	Topsoil organic carbon	%	2.0-4.0	1.0-2.0	0.5-1.0	<0.5 >5.0
	Topsoil Nitrogen content	%	>0.2	0.1-0.2	0.05-0.1	<0.05
	Topsoil available P.	Mg/kg	>40	20-40	10-20	<10
Nutrient retention capacity	Base saturation	%	>75	50-75	30-50	<30
	Topsoil CEC_{soil}	cmol(+)/kg	>25	13-25	6-13	<6
Salinity and alkalinity	ECe	dS/m	0-4	4-8	8-15	>15
	ESP	%	0-10	10-15	15-20	>20
Topography	Slope angle	%	<1	1-2	2-4	>4
Wetness	Duration of flooding	days	>15	5-15	1-5	0-1

C= Clay; CL= Clay loam; L= Loam; LS= Loamy sand; S= Sand; SC= Sandy clay; SCL= Sandy clay loam; SL= Sandy loam; SiC= Silty clay; SiCL= Silty clay loam; SiL= Silt loam.

Appendix 8. Rating of land use requirements for extensive grazing in Wami Plains

Land use requirements (Land quality)	Land characteristics (Diagnostic factor)	Unit	Factor Rating			
			Highly suitable (s1)	Moderately suitable (s2)	Marginally suitable (s3)	Not suitable (n)
Climatic limitations	Daytime temperatures	°C	15-20	20-30	30-40	>40
	Mean annual rainfall	(mm)	600-800	450-600	200-450	<200
Drinking water availability	Distance to drink water	(km)	<2	2-5	6-9	>10
Biological hazards	Pests and diseases		none	Slightly to moderate	Moderate to severe	Severe
Tolerance to erosion	Slope angle	%	<4	4-8	8-16	>16

Appendix 9. ALES decision trees for small holder low input rainfed maize

```
Wami (Wami automated land evaluation)                              Decision Trees
DtId Type                          Where Used
----------------------------------------------------------------------------------
1     Severity Level               SLIRM,df
 > frl (frequence of flooding)
   1 (none)................ : 1 (good)
   2 (daily)............... : 4 (very poor)
   3 (weekly) > drf (duration of flooding)
      1 (very short) [0-1 days : 1 (good)
      2 (short) [1-5 days].... : 2 (moderate)
      3 (medium) [5-15 days].. : 4 (very poor)
      4 (long) [15-20 days]... : 4 (very poor)
      ?....................... : ?
   4 (monthly) > drf (duration of flooding)
      1 (very short) [0-1 days : 1 (good)
      2 (short) [1-5 days].... : 2 (moderate)
      3 (medium) [5-15 days].. : 3 (poor)
      4 (long) [15-20 days]... : 4 (very poor)
      ?....................... : ?
   5 (annualy) > drf (duration of flooding)
      1 (very short) [0-1 days : 1 (good)
      2 (short) [1-5 days].... : 1 (good)
      3 (medium) [5-15 days].. : 2 (moderate)
      4 (long) [15-20 days]... : 4 (very poor)
      ?:...................... : ?
   6 (biennualy)........... : =5
   ?....................... : ?

2     Severity Level               SLIRM,s
 > sl (dominant slope)
   1 (flat) [0-.2 %]....... : 1
   2 (level) [.2-.5 %]..... : 1
   3 (nearly level) [.5-1 % : 1
   4 (very gently sloping)  : 1
   5 (gently sloping) [2-5  : 2
   6 (sloping) [5-10 %].... : 2
   7 (strongly sloping) [10 : ?
   8 (moderately sloping) [ : ?
   9 (steep) [30-60 %]..... : ?
   10 (very steep) [60-65 % : ?
   ?....................... : ?

3     Severity Level               SLIRM,m
 > rgp (rainfall during the growing period)
   1 (very low) [0-200 mm]. : 4
   2 (low) [200-400 mm] > awc (available water capacity)
      1 (extremely low) [0-25  : 4
      2 (very low) [25-50 mm/m : 3
      3 ( low) [50-100 mm/m].. : 3
      4 (medium) [100-150 mm/m : 3
      5 (high) [150-200 mm/m]. : 2
      6 (very high) [200-300 m : 2
      ?....................... : ?
   3 (moderate) [400-600 mm] > awc (available water capacity)
      1 (extremely low) [0-25  : 2
      2 (very low) [25-50 mm/m : 2
      3 ( low) [50-100 mm/m].. : 2
      4 (medium) [100-150 mm/m : 2
      5 (high) [150-200 mm/m]. : 1
      6 (very high) [200-300 m : 1
      ?....................... : ?
   4 (high) [600-800 mm]... : 1
   ?....................... : ?
```

```
Wami (Wami automated land evaluation)
DtId Type                          Where Used
----------------------------------------------------------------------------------
4     Severity Level               SLIRM,na
(continued)
 > pH-p (soil reaction throughout profile)
   1 (extremely acid) [0-4. : 4
   2 (very strongly acid) [4.5-5 pH] > oc (organic carbon)
      1 (extremely low) [0-.49 : 3
      2 (very very low) [.49-. : 3
      3 (very low) [.59-1 %].. : 3
      4 (low) [1-1.25 %]...... : 3
      5 (medium) [1.25-2 %]... : 3
      6 (high) [2-2.5 %] > N (nitrogen content)
         1 (extremely low) [0-.02 : 3
         2 (very low) [.02-.1 %]. : 3
         3 (low) [.1-.2 %]....... : 2
         4 (medium) [.2-.5 %] > P (available phosphorus)
            1 (extremely low) [0-3 m : 3
            2 (very low) [3-6.9 mg P : 2
            3 (low) [6.9-10 mg P/kg] : 2
            4 (medium) [10-20 mg P/k : 2
            5 (high) [20-40 mg P/kg] : 2
            6 (very high) [40-60 mg  : 2
            ?....................... : ?
         5 (high) [.5-.8 %]...... : =4
         ?....................... : ?
      7 (very high) [2.5-3.5 % : =6
      ?....................... : ?
   3 (strongly acid) [5-5.5 pH] > oc (organic carbon)
      1 (extremely low) [0-.49 : 3
      2 (very very low) [.49-. : 3
      3 (very low) [.59-1 %].. : 3
      4 (low) [1-1.25 %]...... : 3
      5 (medium) [1.25-2 %] > N (nitrogen content)
         1 (extremely low) [0-.02 : 3
         2 (very low) [.02-.1 %]. : 3
         3 (low) [.1-.2 %] > P (available phosphorus)
            1 (extremely low) [0-3 m : 3
            2 (very low) [3-6.9 mg P : 3
            3 (low) [6.9-10 mg P/kg] : 2
            4 (medium) [10-20 mg P/k : 2
            5 (high) [20-40 mg P/kg] : 2
            6 (very high) [40-60 mg  : 2
            ?....................... : ?
         4 (medium) [.2-.5 %].... : 2
         5 (high) [.5-.8 %]...... : 2
         ?....................... : ?
      6 (high) [2-2.5 %] > N (nitrogen content)
         1 (extremely low) [0-.02 : 3
         2 (very low) [.02-.1 %]. : 3
         3 (low) [.1-.2 %]....... : 3
         4 (medium) [.2-.5 %].... : 2
         5 (high) [.5-.8 %]...... : 2
         ?....................... : ?
      7 (very high) [2.5-3.5 % : =6
      ?....................... : ?
   4 (moderately acid) [5.5-6 pH] > oc (organic carbon)
      1 (extremely low) [0-.49 : 3
      2 (very very low) [.49-.59 %] > N (nitrogen content)
         1 (extremely low) [0-.02 : 3
         2 (very low) [.02-.1 %]. : 2
         3 (low) [.1-.2 %] > P (available phosphorus)
            1 (extremely low) [0-3 m : 2
            2 (very low) [3-6.9 mg P : 2
```

```
Wami (Wami automated land evaluation)                    Decision Trees
DtId Type                           Where Used
------------------------------------------------------------------------
4    Severity Level                 SLIRM,na
(continued)
              3 (low) [6.9-10 mg P/kg] : 2
              4 (medium) [10-20 mg P/k : 2
              5 (high) [20-40 mg P/kg] : 2
              6 (very high) [40-60 mg  : 1
              ?....................... : ?
            4 (medium) [.2-.5 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 2
              2 (very low) [3-6.9 mg P : 2
              3 (low) [6.9-10 mg P/kg] : 2
              4 (medium) [10-20 mg P/k : 1
              5 (high) [20-40 mg P/kg] : 1
              6 (very high) [40-60 mg  : 1
              ?....................... : ?
            5 (high) [.5-.8 %]...... : =4
            ?....................... : ?
          3 (very low) [.59-1 %].. : =2
          4 (low) [1-1.25 %]...... : =2
          5 (medium) [1.25-2 %]... : =2
          6 (high) [2-2.5 %] > N (nitrogen content)
            1 (extremely low) [0-.02 : 3
            2 (very low) [.02-.1 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3
              2 (very low) [3-6.9 mg P : 3
              3 (low) [6.9-10 mg P/kg] : 3
              4 (medium) [10-20 mg P/k : 2
              5 (high) [20-40 mg P/kg] : 2
              6 (very high) [40-60 mg  : 2
              ?....................... : ?
            3 (low) [.1-.2 %]....... : 2
            4 (medium) [.2-.5 %].... : 2
            5 (high) [.5-.8 %]...... : 2
            ?....................... : ?
          7 (very high) [2.5-3.5 % : =6
          ?....................... : ?
        5 (slightly acid) [6-6.5 pH] > oc (organic carbon)
          1 (extremely low) [0-.49 : 3
          2 (very very low) [.49-.59 %] > N (nitrogen content)
            1 (extremely low) [0-.02 : 3
            2 (very low) [.02-.1 %]. : 2
            3 (low) [.1-.2 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 2
              2 (very low) [3-6.9 mg P : 2
              3 (low) [6.9-10 mg P/kg] : 2
              4 (medium) [10-20 mg P/k : 2
              5 (high) [20-40 mg P/kg] : 2
              6 (very high) [40-60 mg  : 1
              ?....................... : ?
            4 (medium) [.2-.5 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 2
              2 (very low) [3-6.9 mg P : 2
              3 (low) [6.9-10 mg P/kg] : 2
              4 (medium) [10-20 mg P/k : 2
              5 (high) [20-40 mg P/kg] : 2
              6 (very high) [40-60 mg  : 1
              ?....................... : ?
            5 (high) [.5-.8 %]...... : =4
            ?....................... : ?
          3 (very low) [.59-1 %].. : =2
          4 (low) [1-1.25 %]...... : =2
          5 (medium) [1.25-2 %] > N (nitrogen content)
```

```
Wami (Wami automated land evaluation)
DtId Type                           Where Used
------------------------------------------------------------------------
4    Severity Level                 SLIRM,na
(continued)
            1 (extremely low) [0-.02 : 3
            2 (very low) [.02-.1 %]. : 2
            3 (low) [.1-.2 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 2
              2 (very low) [3-6.9 mg P : 2
              3 (low) [6.9-10 mg P/kg] : 2
              4 (medium) [10-20 mg P/k : 2
              5 (high) [20-40 mg P/kg] : 2
              6 (very high) [40-60 mg  : 1
              ?....................... : ?
            4 (medium) [.2-.5 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 2
              2 (very low) [3-6.9 mg P : 2
              3 (low) [6.9-10 mg P/kg] : 2
              4 (medium) [10-20 mg P/k : 2
              5 (high) [20-40 mg P/kg] : 2
              6 (very high) [40-60 mg  : 1
              ?....................... : ?
            5 (high) [.5-.8 %]...... : =4
            ?....................... : ?
          6 (high) [2-2.5 %] > N (nitrogen content)
            1 (extremely low) [0-.02 : 3
            2 (very low) [.02-.1 %]. : 2
            3 (low) [.1-.2 %]....... : 2
            4 (medium) [.2-.5 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 2
              2 (very low) [3-6.9 mg P : 2
              3 (low) [6.9-10 mg P/kg] : 2
              4 (medium) [10-20 mg P/k : 2
              5 (high) [20-40 mg P/kg] : 2
              6 (very high) [40-60 mg  : 1
              ?....................... : ?
            5 (high) [.5-.8 %]...... : =4
            ?....................... : ?
          7 (very high) [2.5-3.5 % : =6
          ?....................... : ?
        6 (neutral) [6.5-7.3 pH] : =4
        7 (mildly alkaline) [7.3 : =3
        8 (moderately alkaline)  : =2
        9 (strongly alkaline) [8 : =2
        10 (very strongly alkali : =1
        ?....................... : ?
```

```
Wami (Wami automated land evaluation)                              Decision Trees
DtId Type                                    Where Used
--------------------------------------------------------------------------------
5    Severity Level                          SLIRM,nr
 > CSC (cation exchange capacity)
   1 (very low) [0-6 cmol(+)/kg] > bs (base saturation)
     1 (very low) [0-20 %]... : 4
     2 (low) [20-40 %]....... : 3
     3 (medium) [40-60 %].... : 2
     4 (high) [60-80 %]...... : 2
     5 (very high) [80-150 %] : 2
     ?....................... : ?
   2 (low) [6-12 cmol(+)/kg] > bs (base saturation)
     1 (very low) [0-20 %]... : 3
     2 (low) [20-40 %]....... : 3
     3 (medium) [40-60 %].... : 2
     4 (high) [60-80 %]...... : 2
     5 (very high) [80-150 %] : 2
     ?....................... : ?
   3 (medium) [12-25 cmol(+)/kg] > bs (base saturation)
     1 (very low) [0-20 %]... : 2
     2 (low) [20-40 %]....... : 2
     3 (medium) [40-60 %].... : 2
     4 (high) [60-80 %]...... : 1
     5 (very high) [80-150 %] : 1
     ?....................... : ?
   4 (high) [25-40 cmol(+)/kg] > bs (base saturation)
     1 (very low) [0-20 %]... : 2
     2 (low) [20-40 %]....... : 2
     3 (medium) [40-60 %].... : 1
     4 (high) [60-80 %]...... : 1
     5 (very high) [80-150 %] : 1
     ?....................... : ?
   5 (very high) [40-100 cm : =4
   ?....................... : ?

6    Severity Level                          SLIRM,o
 > dr (soil drainage class)
   1 (excessively drained). : 1
   2 (somewhat excessively  : 1
   3 (well drained)........ : 1
   4 (moderately well drain : 2
   5 (somewhat poorly drain : 3
   6 (poorly drained)...... : 4
   7 (very poorly drained). : 4
   ?....................... : ?

7    Severity Level                          SLIRM,r
 > sd (effective soil depth)
   1 (extremely shallow) [0 : 4
   2 (very shallow) [20-30 cm] > txp (profile soil texture)
     1 (clay)................ : 3
     2 (sandy clay).......... : 3
     3 (silty clay).......... : 3
     4 (clay loam)........... : 3
     5 (sandy clay loam)..... : 3
     6 (silty loam).......... : 3
     7 (silty clay loam)..... : 3
     8 (sandy loam).......... : 3
     9 (sand)................ : 4
     10 (loamy sand)......... : 3
     ?....................... : ?
   3 (shallow) [30-40 cm] > txp (profile soil texture)
     1 (clay)................ : 2
     2 (sandy clay).......... : 2
```

```
Wami (Wami automated land evaluation)
DtId Type                                    Where Used
--------------------------------------------------------------------------------
7    Severity Level                          SLIRM,r
(continued)
     3 (silty clay).......... : 3
     4 (clay loam)........... : 2
     5 (sandy clay loam)..... : 2
     6 (silty loam).......... : 2
     7 (silty clay loam)..... : 2
     8 (sandy loam).......... : 2
     9 (sand)................ : 4
     10 (loamy sand)......... : 3
     ?....................... : ?
   4 (slightly deep) [40-75 cm] > txp (profile soil texture)
     1 (clay)................ : 2
     2 (sandy clay).......... : 2
     3 (silty clay).......... : 2
     4 (clay loam)........... : 2
     5 (sandy clay loam)..... : 2
     6 (silty loam).......... : 2
     7 (silty clay loam)..... : 2
     8 (sandy loam).......... : 2
     9 (sand)................ : 4
     10 (loamy sand)......... : 3
     ?....................... : ?
   5 (moderately deep) [75-80 cm] > txp (profile soil texture)
     1 (clay)................ : 1
     2 (sandy clay).......... : 1
     3 (silty clay).......... : 2
     4 (clay loam)........... : 1
     5 (sandy clay loam)..... : 1
     6 (silty loam).......... : 2
     7 (silty clay loam)..... : 2
     8 (sandy loam).......... : 1
     9 (sand)................ : 4
     10 (loamy sand)......... : 2
     ?....................... : ?
   6 (deep) [80-120 cm] > txp (profile soil texture)
     1 (clay)................ : 1
     2 (sandy clay).......... : 1
     3 (silty clay).......... : 2
     4 (clay loam)........... : 1
     5 (sandy clay loam)..... : 1
     6 (silty loam).......... : 2
     7 (silty clay loam)..... : 1
     8 (sandy loam).......... : 1
     9 (sand)................ : 3
     10 (loamy sand)......... : 1
     ?....................... : ?
   7 (very deep) [120-180 c : =6
   ?....................... : ?
```

```
Wami (Wami automated land evaluation)                          Decision Trees
DtId Type                              Where Used
------------------------------------------------------------------------------
8    Severity Level                    SLIRM,sa
 > sa (salinity)
   1 (non-saline) [0-2 mS/c : 1
   2 (slightly) [2-8 mS/cm] > sdc (soil sodicity)
      1 (non- sodic) [0-6 %].. : 1
      2 (slightly sodic) [6-10 : 1
      3 (moderately sodic) [10 : 1
      4 (strongly sodic) [15-2 : 2
      5 (very strongly sodic)  : 3
      6 (extremely sodic) [35- : 4
      ?....................... : ?
   3 (moderately saline) [8-15 mS/cm] > sdc (soil sodicity)
      1 (non- sodic) [0-6 %].. : 2
      2 (slightly sodic) [6-10 : 2
      3 (moderately sodic) [10 : 2
      4 (strongly sodic) [15-2 : 3
      5 (very strongly sodic)  : 4
      6 (extremely sodic) [35- : 4
      ?....................... : ?
   4 (strongly saline) [15- : 4
   ?....................... : ?

9    Severity Level                    SLIRM,tr
 > t-gp (mean temperature in growing period)
   1 (very cool) [15-17.5 d : 3
   2 (cool) [17.5-20 degree : 3
   3 (moderately cool) [20- : 2
   4 (moderately warm) [22. : 2
   5 (warm) [25-27.5 degree : 1
   6 (very warm) [27.5-32 d : 1
   7 (extremely warm) [32-4 : 3
   ?....................... : ?

10   Severity Level                    SHLIRR,m
 > rgs (rainfall in growing season (last 4 months))
   1 (very low) [0-100 mm]. : 4
   2 (low) [100-200 mm].... : 3
   3 (medium) [200-400 mm]. : 2
   4 (high) [400-600 mm]... : 1
   ?....................... : ?
```

Appendix 10. ALES decision trees for small holder low input rainfed rice

```
Wami (Wami automated land evaluation)                      Decision Trees
DtId Type                                   Where Used
--------------------------------------------------------------------------
11   Severity Level                         SHLIRR,r
 > sd (effective soil depth)
   1 (extremely shallow) [0 : 4 (very poor)
   2 (very shallow) [20-30  : 3 (poor)
   3 (shallow) [30-40 cm].. : 3 (poor)
   4 (slightly deep) [40-75 : 2 (moderate)
   5 (moderately deep) [75- : 1 (good)
   6 (deep) [80-120 cm].... : 1 (good)
   7 (very deep) [120-180 c : 1 (good)
   ?....................... : ?
12   Severity Level                         SHLIRR,sa
 > sa (salinity)
   1 (non-saline) [0-2 mS/c : 1 (good)
   2 (slightly) [2-8 mS/cm] : 2 (moderate)
   3 (moderately saline) [8 : 2 (moderate)
   4 (strongly saline) [15-20 mS/cm] > sdc (soil sodicity)
     1 (non- sodic) [0-6 %].. : 2 (moderate)
     2 (slightly sodic) [6-10 : 2 (moderate)
     3 (moderately sodic) [10 : 3 (poor)
     4 (strongly sodic) [15-2 : 3 (poor)
     5 (very strongly sodic)  : 4 (very poor)
     6 (extremely sodic) [35- : 4 (very poor)
     ?....................... : ?
   ?....................... : ?

13   Severity Level                         SHLIRR,tr
 > t-gp (mean temperature in growing period)
   1 (very cool) [15-17.5 d : 4 (very poor)
   2 (cool) [17.5-20 degree : 3 (poor)
   3 (moderately cool) [20- : 2 (moderate)
   4 (moderately warm) [22. : 2 (moderate)
   5 (warm) [25-27.5 degree : 1 (good)
   6 (very warm) [27.5-32 d : 3 (poor)
   7 (extremely warm) [32-4 : 4 (very poor)
   ?....................... : ?

14   Severity Level                         SHLIRR,nr
 > CEC (cation exchange capacity)
   1 (very low) [0-6 cmol(+)/kg] > bs (base saturation)
     1 (very low) [0-20 %]... : 4 (very poor)
     2 (low) [20-40 %]....... : 4 (very poor)
     3 (medium) [40-60 %].... : 3 (poor)
     4 (high) [60-80 %]...... : 3 (poor)
     5 (very high) [80-150 %] : 2 (moderate)
     ?....................... : ?
   2 (low) [6-12 cmol(+)/kg] > bs (base saturation)
     1 (very low) [0-20 %]... : 4 (very poor)
     2 (low) [20-40 %]....... : 3 (poor)
     3 (medium) [40-60 %].... : 2 (moderate)
     4 (high) [60-80 %]...... : 2 (moderate)
     5 (very high) [80-150 %] : 2 (moderate)
     ?....................... : ?
   3 (medium) [12-25 cmol(+)/kg] > bs (base saturation)
     1 (very low) [0-20 %]... : 3 (poor)
     2 (low) [20-40 %]....... : 2 (moderate)
     3 (medium) [40-60 %].... : 2 (moderate)
     4 (high) [60-80 %]...... : 2 (moderate)
     5 (very high) [80-150 %] : 1 (good)
     ?....................... : ?
   4 (high) [25-40 cmol(+)/kg] > bs (base saturation)
     1 (very low) [0-20 %]... : 3 (poor)
     2 (low) [20-40 %]....... : 2 (moderate)
     3 (medium) [40-60 %].... : 1 (good)
     4 (high) [60-80 %]...... : 1 (good)
     5 (very high) [80-150 %] : 1 (good)
     ?....................... : ?
   5 (very high) [40-100 cm : =4
   ?....................... : ?

15   Severity Level                         SHLIRR,na
 > pH-p (soil reaction throughout profile)
     1 (extremely acid) [0-4.5 pH] > oc (organic carbon)
```

```
Wami (Wami automated land evaluation)
DtId Type                            Where Used
-----------------------------------------------
15   Severity Level                  SHLIRR,na
(continued)
     1 (extremely low) [0-.49 %] > N (nitrogen
       1 (extremoly low) [0-.02 %] > P (availa
         1 (extremely low) [0-3 m : 4 (very p
         2 (very low) [3-6.9 mg P : 4 (very p
         3 (low) [6.9-10 mg P/kg] : 4 (very p
         4 (medium) [10-20 mg P/k : 3 (poor)
         5 (high) [20-40 mg P/kg] : 3 (poor)
         6 (very high) [40-60 mg  : 3 (poor)
         ?....................... : ?
       2 (very low) [.02-.1 %] > P (available
         1 (extremely low) [0-3 m : 4 (very p
         2 (very low) [3-6.9 mg P : 4 (very p
         3 (low) [6.9-10 mg P/kg] : 3 (poor)
         4 (medium) [10-20 mg P/k : 3 (poor)
         5 (high) [20-40 mg P/kg] : 3 (poor)
         6 (very high) [40-60 mg  : 2 (modera
         ?....................... : ?
       3 (low) [.1-.2 %] > P (available phosph
         1 (extremely low) [0-3 m : 3 (poor)
         2 (very low) [3-6.9 mg P : 3 (poor)
         3 (low) [6.9-10 mg P/kg] : 3 (poor)
         4 (medium) [10-20 mg P/k : 3 (poor)
         5 (high) [20-40 mg P/kg] : 2 (modera
         6 (very high) [40-60 mg  : 2 (modera
         ?....................... : ?
       4 (medium) [.2-.5 %] > P (available pho
         1 (extremely low) [0-3 m : 3 (poor)
         2 (very low) [3-6.9 mg P : 3 (poor)
         3 (low) [6.9-10 mg P/kg] : 3 (poor)
         4 (medium) [10-20 mg P/k : 2 (modera
         5 (high) [20-40 mg P/kg] : 2 (modera
         6 (very high) [40-60 mg  : 2 (modera
         ?....................... : ?
       5 (high) [.5-.8 %]...... : =4
       ?....................... : ?
     2 (very very low) [.49-. : =1
     3 (very low) [.59-1 %].. : =1
     4 (low) [1-1.25 %] > N (nitrogen content)
       1 (extremely low) [0-.02 %] > P (availa
         1 (extremely low) [0-3 m : 4 (very p
         2 (very low) [3-6.9 mg P : 4 (very p
         3 (low) [6.9-10 mg P/kg] : 3 (poor)
         4 (medium) [10-20 mg P/k : 3 (poor)
         5 (high) [20-40 mg P/kg] : 3 (poor)
         6 (very high) [40-60 mg  : 2 (modera
         ?....................... : ?
       2 (very low) [.02-.1 %]. : =1
       3 (low) [.1-.2 %] > P (available phosph
         1 (extremely low) [0-3 m : 3 (poor)
         2 (very low) [3-6.9 mg P : 3 (poor)
         3 (low) [6.9-10 mg P/kg] : 3 (poor)
         4 (medium) [10-20 mg P/k : 2 (modera
         5 (high) [20-40 mg P/kg] : 2 (modera
         6 (very high) [40-60 mg  : 2 (modera
         ?....................... : ?
       4 (medium) [.2-.5 %] > P (available pho
         1 (extremely low) [0-3 m : 3 (poor)
         2 (very low) [3-6.9 mg P : 3 (poor)
         3 (low) [6.9-10 mg P/kg] : 2 (modera
         4 (medium) [10-20 mg P/k : 2 (modera
```

```
Wami (Wami automated land evaluation)                              Decision Trees
DtId Type                              Where Used
----------------------------------------------------------------------------------
15   Severity Level                    SHLIRR,na
(continued)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           5 (high) [.5-.8 %]...... : =4
           ?....................... : ?
         5 (medium) [1.25-2 %]... : =4
         6 (high) [2-2.5 %] > N (nitrogen content)
           1 (extremely low) [0-.02 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 3 (poor)
              4 (medium) [10-20 mg P/k : 3 (poor)
              5 (high) [20-40 mg P/kg] : 3 (poor)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           2 (very low) [.02-.1 %]. : =1
           3 (low) [.1-.2 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 3 (poor)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           4 (medium) [.2-.5 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 2 (moderate)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           5 (high) [.5-.8 %]...... : =4
           ?....................... : ?
         7 (very high) [2.5-3.5 % : =6
         ?....................... : ?
      2 (very strongly acid) [ : =1
      3 (strongly acid) [5-5.5 pH] > oc (organic carbon)
        1 (extremely low) [0-.49 %] > N (nitrogen content)
           1 (extremely low) [0-.02 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 4 (very poor)
              2 (very low) [3-6.9 mg P : 4 (very poor)
              3 (low) [6.9-10 mg P/kg] : 3 (poor)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           2 (very low) [.02-.1 %]. : =1
           3 (low) [.1-.2 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 2 (moderate)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           4 (medium) [.2-.5 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 3 (poor)
```

```
Wami (Wami automated land evaluation)
DtId Type                              Where Used
----------------------------------------------------------------------------------
15   Severity Level                    SHLIRR,na
(continued)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           5 (high) [.5-.8 %]...... : =4
           ?....................... : ?
        2 (very very low) [.49-. : =1
        3 (very low) [.59-1 %].. : =1
        4 (low) [1-1.25 %] > N (nitrogen content)
           1 (extremely low) [0-.02 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 4 (very poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 3 (poor)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           2 (very low) [.02-.1 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 2 (moderate)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           3 (low) [.1-.2 %]....... : =2
           4 (medium) [.2-.5 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 2 (moderate)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 1 (good)
              ?....................... : ?
           5 (high) [.5-.8 %]...... : =4
           ?....................... : ?
        5 (medium) [1.25-2 %]... : =4
        6 (high) [2-2.5 %] > N (nitrogen content)
           1 (extremely low) [0-.02 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 2 (moderate)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           2 (very low) [.02-.1 %]. : =1
           3 (low) [.1-.2 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 3 (poor)
              3 (low) [6.9-10 mg P/kg] : 2 (moderate)
              4 (medium) [10-20 mg P/k : 2 (moderate)
              5 (high) [20-40 mg P/kg] : 2 (moderate)
              6 (very high) [40-60 mg  : 2 (moderate)
              ?....................... : ?
           4 (medium) [.2-.5 %] > P (available phosphorus)
              1 (extremely low) [0-3 m : 3 (poor)
              2 (very low) [3-6.9 mg P : 2 (moderate)
              3 (low) [6.9-10 mg P/kg] : 2 (moderate)
              4 (medium) [10-20 mg P/k : 2 (moderate)
```

```
Wami (Wami automated land evaluation)                            Decision Trees
DtId Type                                         Where Used
-------------------------------------------------------------------------------
15   Severity Level                               SHLIRR,na
(continued)
                5 (high) [20-40 mg P/kg]  : 2 (moderate)
                6 (very high) [40-60 mg   : 1 (good)
                ?.......................  : ?
              5 (high) [.5-.8 %]...... : =4
              ?....................... : ?
          7 (very high) [2.5-3.5 % : =6
          ?....................... : ?
      4 (moderately acid) [5.5-6 pH] > oc (organic carbon)
          1 (extremely low) [0-.49 %] > N (nitrogen content)
              1 (extremely low) [0-.02 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 3 (poor)
                3 (low) [6.9-10 mg P/kg] : 2 (moderate)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 2 (moderate)
                6 (very high) [40-60 mg  : 2 (moderate)
                ?....................... : ?
              2 (very low) [.02-.1 %]. : =1
              3 (low) [.1-.2 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 3 (poor)
                3 (low) [6.9-10 mg P/kg] : 2 (moderate)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 2 (moderate)
                6 (very high) [40-60 mg  : 2 (moderate)
                ?....................... : ?
              4 (medium) [.2-.5 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 2 (moderate)
                3 (low) [6.9-10 mg P/kg] : 2 (moderate)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 2 (moderate)
                6 (very high) [40-60 mg  : 1 (good)
                ?....................... : ?
              5 (high) [.5-.8 %]...... : =4
              ?....................... : ?
          2 (very very low) [.49-. : =1
          3 (very low) [.59-1 %].. : =1
          4 (low) [1-1.25 %] > N (nitrogen content)
              1 (extremely low) [0-.02 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 3 (poor)
                3 (low) [6.9-10 mg P/kg] : 3 (poor)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 2 (moderate)
                6 (very high) [40-60 mg  : 2 (moderate)
                ?....................... : ?
              2 (very low) [.02-.1 %]. : =1
              3 (low) [.1-.2 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 3 (poor)
                3 (low) [6.9-10 mg P/kg] : 2 (moderate)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 2 (moderate)
                6 (very high) [40-60 mg  : 2 (moderate)
                ?....................... : ?
              4 (medium) [.2-.5 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 2 (moderate)
                3 (low) [6.9-10 mg P/kg] : 2 (moderate)
```

```
Wami (Wami automated land evaluation)
DtId Type                                         Where Used
-------------------------------------------------------------------------------
15   Severity Level                               SHLIRR,na
(continued)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 1 (good)
                6 (very high) [40-60 mg  : 1 (good)
                ?.......................   ?
              5 (high) [.5-.8 %]...... : =4
              ?....................... : ?
          5 (medium) [1.25-2 %]... : =4
          6 (high) [2-2.5 %] > N (nitrogen content)
              1 (extremely low) [0-.02 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 3 (poor)
                3 (low) [6.9-10 mg P/kg] : 2 (moderate)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 2 (moderate)
                6 (very high) [40-60 mg  : 2 (moderate)
                ?....................... : ?
              2 (very low) [.02-.1 %]. : =1
              3 (low) [.1-.2 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 3 (poor)
                3 (low) [6.9-10 mg P/kg] : 2 (moderate)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 2 (moderate)
                6 (very high) [40-60 mg  : 2 (moderate)
                ?....................... : ?
              4 (medium) [.2-.5 %] > P (available phosphorus)
                1 (extremely low) [0-3 m : 3 (poor)
                2 (very low) [3-6.9 mg P : 2 (moderate)
                3 (low) [6.9-10 mg P/kg] : 2 (moderate)
                4 (medium) [10-20 mg P/k : 2 (moderate)
                5 (high) [20-40 mg P/kg] : 1 (good)
                6 (very high) [40-60 mg  : 1 (good)
                ?....................... : ?
              5 (high) [.5-.8 %]...... : =4
              ?....................... : ?
          7 (very high) [2.5-3.5 % : =6
          ?....................... : ?
      5 (slightly acid) [6-6.5 : =1
      6 (neutral) [6.5-7.3 pH] : =1
      7 (mildly alkaline) [7.3 : =2
      8 (moderately alkaline)  : =1
      9 (strongly alkaline) [8 : =1
      10 (very strongly alkali : =1
      ?....................... : ?

16   Severity Level                               SHLIRR,tg
 > sl (dominant slope)
      1 (flat) [0-.2 %]....... : 1
      2 (level) [.2-.5 %]..... : 1
      3 (nearly level) [.5-1 % : 1
      4 (very gently sloping)  : 2
      5 (gently sloping) [2-5  : 3
      6 (sloping) [5-10 %].... : 4
      7 (strongly sloping) [10 : 4
      8 (moderately sloping) [ : 4
      9 (steep) [30-60 %]..... : 4
      10 (very steep) [60-65 % : 4
      ?....................... : ?
17   Severity Level                               SHLIRR,wc
 > drf (duration of flooding)
      1 (very short) [0-1 days : 3 (poor)
      2 (short) [1-5 days].... : 2 (moderate)
      3 (medium) [5-15 days].. : 2 (moderate)
      4 (long) [15-20 days]... : 1 (good)
      ?....................... : ?
```

Appendix 11. ALES decision trees for low input extensive grazing

```
Wami (Wami automated land evaluation)                          Decision Trees
DtId Type                                 Where Used
------------------------------------------------------------------------------
18    Severity Level                      LIEXG,acc
 > bc (bush coverage)
   1 (good) [0-20 %]....... : 1 (good)
   2 (moderate) [20-40 %].. : 2 (moderate)
   2.1 (moderately poor) [4 : =2
   3 (poor) [60-80 %]...... : 3 (poor)
   4 (very poor) [80-100 %] : 4 (very poor)
   ?....................... : ?

19    Severity Level                      LIEXG,bh
 > pd (pests and diseases)
   1 (none)................ : 1 (good)
   2 (slight).............. : 2 (moderate)
   3 (moderate)............ : 3 (poor)
   4 (severe).............. : 4 (very poor)
   ?....................... : ?

20    Severity Level                      LIEXG,clm
 > t-an (mean annual temperature)
   1 (very cool) [15-17.5 d : 1
   2 ( cool) [17.5-20 degre : 1
   3 (moderately cool) [20- : 2
   4 (moderately warm) [22. : 2
   5 ( warm) [25-27.5 degre : 2
   6 (very warm) [27.5-32 d : 3
   7 (extremely warm) [32-4 : 3
   ?....................... : ?

21    Severity Level                      LIEXG,dwa
 > dst (distance to drinking water)
   1 (very near) [0-2 km].. : 1
   2 (near) [2-5 km]....... : 1
   3 (moderately far) [5-9  : 2
   4 (far) [9-12 km]....... : 3
   5 (very far) [12-15 km]. : 4
   ?....................... : ?

22    Severity Level                      LIEXG,e
 > sl (dominant slope)
   1 (flat) [0-.2 %]....... : 1
   2 (level) [.2-.5 %]..... : 1
   3 (nearly level) [.5-1 % : 1
   4 (very gently sloping)  : 1
   5 (gently sloping) [2-5  : 1
   6 (sloping) [5-10 %].... : 2
   7 (strongly sloping) [10 : 3
   8 (moderately sloping) [ : 4
   9 (steep) [30-60 %]..... : 4
   10 (very steep) [60-65 % : 4
   ?....................... : ?
23    Severity Level                      LIEXG,m
 > p-an (mean annual precipitation)
   1 (very low) [0-300 mm]. : 3
   2 (low) [300-500 mm].... : 1
   3 (moderate) [500-750 mm : 1
   4 (high) [750-1500 mm].. : 2
   5 (very high) [1500-2000 : 2
   6 (extremely high) [2000 : 3
   ?....................... : ?
```

Appendix 11. ALES decision trees for low input extensive grazing

Appendix 12. Guide to general evaluation of some chemical and physical soil properties Compiled from Msanya *et al.* (1996), Baize (1993), Landon (1991), Sys (1993) and EUROCONSULT (1989).

1. Organic matter and total nitrogen

	Very low	Low	Medium	High	Very high
Organic matter %	< 1.0	1.0-2.0	2.1-4.2	4.3-6.0	> 6.0
Organic carbon %	< 0.6	0.60-1.25	1.26-2.50	2.51-3.50	>3.5
Total nitrogen %	< 0.10	0.10-0.20	0.21-0.50	> 0.50	

C/N ratios give an indication of the quality of organic matter:

C/N 8-13: good quality
C/N 14-20: Moderate quality
C/N > 20: Poor quality.

2. Soil reaction

Extremely acid	pH <4.5	Neutral	pH 6.6 to 7.3
Very strongly acid	pH 4.5 to 5.0	mildly alkaline	pH 7.4 to 7.8
Strongly acid	pH 5.1 to 5.5	moderate alkaline	pH 7.9 to 8.4
Medium acid	pH 5.6 to 6.0	strongly alkaline	pH 8.5 to 9.0
Slightly acid	pH 6.1 to 6.5	very strongly alkaline	pH > 9.0

3. Available phosphorus

mg/kg	Low	Medium	High
Avail. P (Bray-Kurtz I	< 7	7-20	> 20
Avail. P (Olsen)	< 5	5-10	> 10

NB. Available phosphorus is determined by the Bray-Kurtz 1 method if the pH H_2O of the soil is less than 7.0. In soils with a pH H_2O of more than 7.0 the Olsen method is used.

4. Cation exchange capacity (CEC)

cmol(+)/kg	Very low	Low	Medium	High	Very high
CEC	< 6.0	6.0-12.0	12.1-25.0	25.0-40.0	> 40.0

CEC is determined using 1 M ammonium acetate in soils with pH less than 7.5. In soils with pH greater than 7.5 CEC is determined using 1 M sodium acetate.

5. Electrical conductivity (ECe)

ECe	< 1.7 dS/m	no yield reduction
ECe	1.7 - 2.5 dS/m	up to 10% yield reduction
ECe	2.5 - 3.8 dS/m	up to 25% yield reduction
ECe	3.8 - 5.9 dS/m	up to 50% yield reduction
ECe	5.9 - 10 dS/m	up to 100% yield reduction

6. Exchangeable calcium

cmol(+)/kg	Very low	Low	Medium	High	Very high
Ca (clayey soils rich in 2:1 clays)	< 2.0	2.0-5.0	5.1-10.0	10.1-20.0	> 20.0
Ca (loamy soil)	< 0.5	0.5-2.0	2.1-4.0	4.1-6.0	> 6.0
Ca (kaolinitic and sandy soils)	< 0.2	0.2-0.5	0.6-2.5	2.6-5.0	> 5.0

7. Exchangeable magnesium (Mg)

cmol(+)/kg	Very low	Low	Medium	High	Very high
Mg (clayey soils)	< 0.3	0.3-1.0	1.1-3.0	3.1-6.0	> 6.0
Mg (loamy soils)	< 0.25	0.25-0.75	0.75-2.0	2.1-4.0	> 4.1
Mg (sandy soils)	< 0.2	0.2-0.5	0.5-1.0	1.1-2.0	> 2.0

The desired saturation level of exchangeable Mg is 10 to 15 percent; for sandy and kaolinitic soils 6 to 8 percent Mg saturation is still sufficient.
Ca/Mg ratios of 2 to 4 are favourable.

8. exchangeable potassium (K)

cmol(+)/kg	Very low	Low	Medium	High	Very high
K (clayey soils)	< 0.20	0.20-0.40	0.41-1.20	1.21-2.00	> 2.00
K (loamy soils)	< 0.13	0.13-0.25	0.26-0.80	0.81-1.35	> 1.35
K (sandy soils)	< 0.05	0.05-0.10	0.11-0.40	0.41-0.70	> 0.70

The desired saturation level of exchangeable K is 2 to 7 percent.
Favourable Mg/K ratios for most crops are in the range of 1 to 4.

9. Exchangeable sodium (Na)

cmol(+)/kg	Very low	Low	Medium	High	Very high
Na	< 0.10	0.10-0.30	0.31-0.70	0.71-2.00	> 2.00

More important than the absolute level of exchangeable Na is the exchangeable sodium percentage (ESP) calculated by dividing exchangeable Na by CEC (x 100). ESP values are a measure of the sodicity of the soil.

10. Soil sodicity

	Non-sodic	Slightly sodic	moderately sodic	Strongly sodic	Very strongly sodic	Extremely sodic
ESP %	< 6	6-10	11-15	16-25	26-35	> 35

ESP < 15% -up to 50 percent yield reduction of sensitive crops (maize, beans)
ESP 16-25% -up to 50 percent yield reduction of semi-tolerant crops (rice, wheat, sorghum, sugarcane)
ESP 35% - up to 50 percent yield reduction of tolerant crops (barley, cotton).

11. Basic infiltration rate (IR)

IR < 0.1 cm/h	extremely slow
IR 0.1-0.3 cm/h	very slow
IR 0.3-0.5 cm/h	slow
IR 0.5-2.0 cm/h	moderately slow
IR 2.0-6.5 cm/h	moderate
IR 6.5-12.5 cm/h	moderately rapid
IR 12.5-25.0 cm/h	rapid
IR > 25.0 cm/h	very rapid

Basic infiltration rate is the constant at which water enters the (pre-wetted) soil and which develops after 3 to 5 hours of infiltration.

12.0 Available water capacity (AWC)

AWC	< 25 mm/m	extremely low
AWC	25-50 mm/m	very low
AWC	50-100 mm/m	low
AWC	100-150 mm/m	medium
AWC	150-200 mm/m	high
AWC	> 200 mm/m	very high

Available water capacity is the capacity of the soil to store water that is readily available for uptake by plant roots; usually expressed in millimetres of water per metro depth of soils; technically the difference between the percentage of soil water at field capacity (normally taken as the water content at pF 2.0) and the percentage at wilting point (taken as the water content at pF 4.2). This is applicable for most tropical soils.

13. Aluminium saturation

	Very low	low	Medium	High	Very high
Al saturation %	< 10	10-30	31-50	51-80	> 80

Aluminium saturation as measure of toxicity is calculated by dividing exchangeable Al by the sum of exchangeable bases and exchangeable Al.