LAND EVALUATION USING FAO FRAMEWORK FOR RAINFED CROPS: A CASE STUDY OF LITI-TENGERU FARM

By

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ABSTRACT

A detailed land evaluation by using the FAO (1976) Framework and resource survey for 380 ha was carried out at Tengeru Livestock Training Institute (LITI) farm. The major objectives of this study were: (a) to test the adaptability of the FAO (1976) Framework for land evaluation in the area for rainfed field crops, vegetables, perennial crops, and pastures; (b) to establish the land resources inventory of the LITI farm; and (c) to assess the land suitabilities and limitations of the major land units in the farm for different land uses.

The concepts and principles in the FAO (1976) Framework were found to work well in this area. However, some of the methodologies and procedures outlined in the FAO (1984) guidelines had to be refined in order to match with the actual local conditions and crops performance. Different approaches from those proposed in the FAO (1984) guidelines were used for reliable assessment of moisture availability, temperature regime and soil erosion hazard.

Three soil types, namely, Mollic Andosols, Eutric Fluvisols and Pellic Vertisols, were identified in the area according to the FAO-Unesco (1974, 1988) legend. These soils were mapped at a scale of 1:10 000.

The land evaluation results indicated that the major limitations in all soils of the study area are: moisture availability for perennial crops and pastures; Nitrogen deficiency; and land degradation through soil erosion and /or soil compaction. The major limitations for using Mollic Andosols in land mapping unit 34B1 are: severe soil erosion hazard, and buried stones which may limit tillage by using tractors. This

land unit is very fertile and highly suitable for pasture production. It is highly suitable for vegetable and other field crops considered if soil erosion is controlled. The Eutric Fluvisols represented in mapping land unit 14C1, are highly fertile and suitable for all crops and pastures considered. However, like other land units in this farm, supplementary irrigation is necessary for optimum yield of perennial crops and pastures.

The Pellic Vertisols in land unit 11C2 is not suitable for banana , citrus and coffee production. It is currently not suitable for maize, sunflower, tomato, Siratro, and elephant grass. It is suitable for rhodes and buffel grass. It is marginally suitable for the rest of crops and pastures considered in this study. The major limitations in using this land unit are: unfavourable soil structure and texture; poor drainage; shallow soil depth; presence of toxic layer ($CaCO_3$) below 75 cm; high Sodium level; and deficiency of major nutrient elements (N, P, K).

Economic analysis showed that pasture seeds production gave the highest farm net income in the area. Other crops which are highly economically suitable are vegetables, banana, citrus, coffee, and pasture fodder production. Beans, sunflower, sorghum and maize are marginally suitable in terms of farm net income.

DECLARATION

I, MAHENYE N.C. MUYA, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my own work and that it has not been submitted for a higher degree in any other University.

Date 15.11.1996

Signature

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ABBREVIATIONS

ACU	Arusha Cooperation Union
DALDO	District Agricultural and Livestock Development Officer
DLDO	District Livestock Development Officer
FAO	Food and Agricultural Organisation
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit (German Agency for Technical Co-operation)
HORTI	Horticultural Research and Training Institute
LITI	Livestock Training Institute
NSS	National Soil Survey
SACCAR	Southern African Centre for Co-operation in Agricultural & Natural Resource Research & Training
TFA	Tanganyika Farmer's Association

1. INTRODUCTION

1.1 Background information on FAO Framework for Land Evaluation

According to the study by FAO (1981), Africa has enough land to produce food for her present and future population. However, the precarious food situation experienced by most African countries indicates that, the mere availability of land is not enough to attain self-sufficiency in food production. It is essential that differences in land resource endowment in crop production potential be fully appreciated. This is because, different crops require different environmental conditions for optimum productivity. Moreover, land productivity vary considerably depending on the soils, climate and other endowments of each agro-ecological region and land unit.

Thus, knowledge of land resources and their limitations is the basis for agricultural development and technological transfer for any nation. It forms the prime key for determining research priorities and development alternatives for sustained productivity and profitability (Dudal, 1988). Therefore, the need for land evaluation system to achieve optimum utilization of land resources, has been felt by all land users since time immemorial. In early days, land evaluation for sustained performance of the chosen use, evolved through experiences gained by trial and error over generations. This is no longer possible in modern agriculture due to competing uses for the same land, and the urgent need to feed the fast increasing population. As a result, by late sixties, most countries had already developed their own systematic land evaluation systems according to their level of knowledge (Dent and Young, 1981) in order to plan most effectively the cropping production and land use.

The international need for detailed standard principles, methodology and procedures for carrying out the land evaluation necessitated the formulation of the FAO (1976) "Framework for land evaluation" and the FAO (1984) "Guidelines for land evaluation for rainfed agriculture". The land evaluation according to FAO (1976, 1984) is conducted according to the following six major principles:

- it must be made in terms of a specified kind of use;
- the evaluation must take into account the level of technology which is being envisaged;
- the evaluation must be based on a multidisciplinary approach which covers the different components of the land;
- the economic and social factors must be taken into consideration;
- the suitability rating must aim at a land utilization on the sustained basis; and
- the evaluation must involve the comparison of alternative kinds of use.

Since the FAO (1976) formulation, many African countries including Tanzania opted for its use immediately (FAO,1980, 1988). However, a number of reports from the East and Southern African countries (FAO, 1978, 1980, 1983, 1985, 1988) show that, things had not been easy in translating some of the Framework principles into practical land evaluation. In these studies, the approach and methodologies used often differ from country to country. In addition only few land qualities are being assessed in these studies. Furthermore, reports on land evaluation conducted in

Tanzania by using the Framework (NSS, 1980-1991; Mushi,1983; Mpepo, 1986; Kaaya, 1989) show that, most of land evaluation conducted in the country are limited to semi-quantitative physical evaluation. In addition they are strongly based on soil characteristics. Hence, the Framework concepts have not been rigorously and exhaustively applied in our country. There is therefore a need to test the adaptability of the FAO (1976) principles and the FAO (1984) guidelines as a tool for land evaluation in our local conditions, using detailed information and strictly adhering to the Framework.

1.2 Background information on the study area

Farming systems research and the agricultural development programme as stipulated in Tanzania agricultural policy document (MALD, 1983,1991) are based on agro-ecological zoning. Subsequently, agricultural research and training institutes are organized in zones.

The Northern Agricultural Research and Training zone is composed of the following Institutions: Selian Agricultural Research Institute (SARI) in Arusha; Lyamungu Agricultural Research Institute (LARI), Moshi; Livestock Training Institute (LITI); and Horticultural Research and Training Institute (HORTI) both at Tengeru, Arusha.

LITI and HORTI Tengeru are involved in training extension workers and farmers. Therefore they have the mandate for disseminating appropriate improved agro-technology in this zone. According to Kayombo (1988), effective training can be achieved by establishing and using demonstration farms , where the target groups can see the practical difference, and therefore be able to study and compare the benefits of the old and new technologies. Therefore LITI and HORTI Tengeru are using the study area - in this case referred to as LITI Farm - for training, demonstration, research and production purposes.

Regrettably, this LITI farm had no systematic land resource inventories. The lack of sufficient knowledge of the LITI farm land resources and their distribution was the fundamental constraint in: understanding and classifying the potential and limitations of the land resources; agro- technological transfer; and planning of optimum management and land use of the farm. In addition, without land resource inventory it was not possible to correlate training and research in this farm with other areas. There was therefore a need to conduct land evaluation at LITI farm to augment LITI's and HORTI's training, demonstration and research efforts.

1.3 Objectives

The main objective of this study was to test the adaptability of the FAO Framework for land evaluation using LITI Tengeru farm. The specific objectives were:

1. To demonstrate use of FAO Framework for land evaluation;
2. To identify the major soils and land units at LITI farm;
3. To identify suitability for different land utilization types for each major land unit at the farm ; and
4. To establish resource inventories and limitations of major land units.

2. LITERATURE REVIEW

2.1 Land evaluation

2.1.1 Land Evaluation General

Land evaluation is the process of estimating the potential of land for alternative kinds of use (Dent and Young, 1981; FAO, 1984). FAO (1976) defined land evaluation as an assessment of land performance when used for a specified purpose. According to FAO (1976), land evaluation involves the execution and interpretation of basic surveys of climate, soils, vegetation and other relevant physical aspects of land in terms of the requirements of alternative forms of land use, taking into consideration the economics and social context of the area considered of the proposed enterprises, the future social consequences, beneficial or adverse for the environment.

The definition implies that, not all land can be used for agricultural purposes, because production is limited by physical constraints such as unfavourable conditions of climate, topography, hydrology or soils. Also the social, economic and political constraints are important . The proposed land use can be very suitable physically, but may be disqualified by factors such as poverty and illiteracy of farmers or lack of infrastructure or market for products. In some cases, agricultural produce prices are fixed by local government or world market, sometimes these prices may be so low that there is no benefit to continue with agricultural production even though optimum output can be attained . As a result, sometimes the role of socio-economic, or/and political constraints are often more important in making decisions on land use in many developing countries than physical constraints.

Hence, the task of land evaluation is not of recent origin although the concept

"Land evaluation" has gained much popularity with the introduction of the FAO framework for land evaluation in 1976. In the early days, the only land practice alternative was agriculture. However, the urgent need for food to feed the rapid increasing population in 1930's brought about the introduction of new crops in local areas from abroad, this necessitated the development of soil survey for easy correlation. Suddenly soil scientists unearthed too detailed information in forms not often easily understood or usable by land users i.e. planners, foresters, extension workers, farmers. This constraint necessitated the need to interpret the soil survey data for land use planning purposes.

These soil survey interpretations came in the form of land capability classification or land suitability classifications. These classifications formed the first stage towards systematic land evaluation we are having today (Landon, 1991).

The earliest and perhaps best known systematic land evaluation attempt is the Land Capability System of the Soil Conservation Service of the US Department of Agriculture (Klingebiel and Montomery, 1961). This system commonly known as USDA Land Capability System used the limitation approach for judging the value of a tract of land. The system rated permanent physical land characteristics that limit or impose risk of erosion or other hazards or limitations. Slope, soil texture, depth, permeability, water holding capacity and clay types were interpreted. Eight capability classes were created on their assumed capability to produce common crops or other uses. Limitations or erosion risks in land use progressively increased from class I to class VIII. Groups were identified as arable (classes I - IV), and non-arable (classes V-VIII). In this approach the value of a tract of land decreases with increased number or magnitude of limitations.

The major limitation of the system is that it does not define the crops needed in terms of land utilization types. In addition, this system is not a land evaluation tool per se, as it was designed primarily for soil conservation rather than for economic purposes. Its assessment criterion puts more emphasis on environmental factors or physical features than chemical characteristics which can equally affect the land use.

The USDA assumption that the best land for one crop is also best for another crop and vice versa is practically not always true. In addition, there is no provision to consider social and economic factors directly (Young and Dent, 1981).

Together with these shortcomings, the USDA land capability classification system is widely used and applied in the United States where it was developed and in some other countries with abundant land (Woods, 1981). Due to lack of widely applicable systematic system for land evaluation and the need for land evaluation from populated areas where there is high competition from non-agricultural uses of land, many countries tried to establish their local systems and others tried to modify the USDA system to fit into their local conditions (Davidson, 1980).

The best known contribution to improve upon the limitations approach above the level attained by the USDA land capability system has been done by the land use capability classification of the UK (Bibby and Mackney, 1969) , and the standard classification system of Iran (Mahler, 1970 cited by Dent and Young, 1981). The UK system has a slight deviation from the USDA land capability system by putting weights on a few land characteristics that have a greater diagnostic value for specific kinds of land use (LUTs) intensities. The Iranian system incorporates many soil and land characteristics which are then taken into account as criteria for land evaluation. The rating is of a qualitative nature, where each rating is weighted according to the importance that the characteristic has on a defined land utilization. Unlike the USDA land capability system where the starting point is optimum usage, the standard land classification system of Iran is based on the existing soil and land conditions while the irrigability land classification is based on uncorrected limitations.

With the advance of technology and world-oriented agricultural production, it was felt that social and economic factors should be considered in addition to physical land evaluation, so as to ensure that the assessed suitability correspond with economic realities (Davidson, 1980).

Among the early land evaluation systems in which economic factors play an important role is the United States Bureau of Reclamation (USBR) irrigation suitability land classification system (USBR, 1951). In this system, land classes are based on the economics of production. The system has four basic classes used to identify the arable lands according to their suitability for irrigated agriculture, one for provisional class and one class to identify the non arable lands. The major disadvantage of the USBR land evaluation system is that the inventory of soil resources is not very important, and the fact that, this system is based on the land suitability for irrigation development in general and not for specific crops.

Due to the high demand for a land evaluation tool, by early 1970's, many countries had developed their own land evaluation systems (Dent and Young 1981). This made the understanding of the basic scientific land evaluation principles vague, resulting in several basic contradictions on land evaluation concepts. As a result, FAO initiated a series of international discussion on land evaluation. The objective was to develop some measure of International standards of terminology and procedures, and to cut down on the several land evaluation concepts that were existing and coming up, as well as to reflect the present status of knowledge. The series of FAO expert consultations which started in 1972, came up with their results in 1976.

These results are incorporated in "A framework for land evaluation" (FAO, 1976), with more guidelines provided in 1984 (FAO, 1984). The guidelines include additional details about evaluation procedures for specific crops and land utilization types. This framework has resolved the confusion between land evaluation and soil survey. The FAO (1976) framework emphasis that land has a broader concept than soil. It indicates that land evaluation is an independent discipline in which soil survey is one of the activities used to collect data for land quality ratings and not the vice versa (Dent and Young, 1981; FAO,1988, Landon, 1991).

The use of the FAO Framework in land evaluation culminates in a land suitability classification. The suitability classification is of a four hierarchical structure consisting of land suitability orders, classes, subclasses and units (FAO,1976). These suitability classes are assessed separately for each kind of land use under consideration, with respect to each land mapping unit in the survey area.

The highest level, which is the suitability order, separate land as suitable (S) from that which is not suitable (N) for the use under consideration. Land can be unsuitable for the proposed use if (a) it is technically impracticable eg. cultivating very thin or rocky soils; (b) it is environmentally undesirable or would lead to severe soil erosion; or (c) it is social or economically unprofitable (Dent and Young, 1981).

The second level is the suitability classes within the order. A land suitability class is defined in terms of degree of limitations to the intended land use. Classes indicate degrees of suitability. Within the order 'suitable' there are three classes: highly (S1); moderately (S2); and marginally (S3) suitable. Within the order 'not suitable' there are two classes: 'Currently not suitable' (N1) and 'permanently not suitable' (N2). The third level is the suitability subclasses which denote the kinds of limitations eg. drainage (d), erosion (e). There are no subclasses to S1. There is no limit to the number of subclass symbols that may be employed in a particular survey. The fourth level is the suitability unit. These units are divisions of subclasses that differ from each other in detailed aspects of their production characteristics or management requirements. They are numbered successively, eg. S2d-1, S2d-2, etc.

The framework is still being tested with further improvement on its limitations and problems of application (Purnell, 1977; FAO, 1988). According to FAO (1980, 1988), the constraints in its application include rating of land qualities, the definition of land characteristics and land qualities, the identification of land characteristics that make up specific land qualities at a particular area, the rating and assessment of land characteristics, and the lack of multidisciplinary approach due to the fact that the land evaluation activities are still under the mandate of soil survey institutions which lack specialists in the socio-economic field.

In addition, the FAO framework is claimed to demand too much data (Veldkamp, 1979). However, investigations, on land evaluation according to the

FAO framework (FAO,1976) conducted in Tanzania reveal that, data used in most of these evaluations were derived from semi- detailed and reconnaissance soil survey or from general purpose soil survey (NSS, 1980-1991, Mushi, 1983; Mpepo, 1986; Kaaya, 1989). As a result, data obtained were not enough for Land evaluation according to FAO (1976, 1984) guidelines (Dent and Young, 1981). However, according to ILRI (1980) and FAO (1984), the land use requirements determine to a greater extent, which land resources data need to be studied and in how much detail.

Therefore, most of the constraints observed above may be eliminated if the special purpose soil survey is used and multidisciplinary approach is adhered to. The development of mathematical models for yield reductions based on simulations and analogue models found on fundamental plant growth requirements (Wit 1978; Feddes et al, 1978) are expected to reduce the amount of data required for land qualities assessment. In addition the development and application of computer software and numerical (parametric) approach in assessment methods are expected to improve on speed, accuracy, variability and rapid utility of the land evaluation system and its correlation (Miller, 1978, Dent and Young 1981, Mpepo 1986).

2.1.2 Land Evaluation in Tanzania

Land evaluation in Tanzania dates back to colonial days when attempts and research were made by farm planning staff to use the land without degradation (Mpepo, 1986). The farm planning evaluation systems gathered information on rainfall probability, topography and soil erosion associated with different land uses

(Temple, 1972; Mpepo, 1986). Land selection and suitability used criteria such as availability and nature of markets, communication, soil fertility, supply and quality of labour, availability and suitability of irrigation water, incidence of pests and diseases in both animals and crops, and flexibility and relationships between enterprises, in farm planning.

The capability classification was on the basis of slopes in relation to erosion. Most of the research on the land evaluation practices occurred in Kenya with recommendations being extrapolated to Tanganyika (Mpepo, 1986). Since 1967, the Bureau of Resource Assessment (IRA) and Land Use Planning has been carrying out broad land evaluations for social and economic planning. The IRA evaluations are mostly on demography, rainfall and communications. Several international organisations have also been carrying out land evaluations often using their own systems (Presant, 1992; Mpepo 1986).

The establishment of a National Soil Service (NSS) with FAO assistance in 1975, was the first step to reorganise land evaluation in the country. The National Soil Service, which is based at Mlingano, in Tanga, uses FAO guidelines for profile description, and the FAO Framework (FAO, 1976) for land evaluation (Samki and Dewan, 1980). This has improved the co-ordination and correlation of the findings tremendously. Most of the land evaluation work is done as part of soil survey. Currently, studies on ratings for land qualities and crop requirements is going on at Mlingano - NSS.

2.2 Soil Survey

2.2.1 Soil Survey and General Appraisal

Land evaluation needs information from three sources namely land, land use and economics (Dent and Young, 1981). Data on land is obtained by natural resource survey. The natural resource survey information required for land evaluation include soils, climate, vegetation, hydrology, relief, and impact of human activities on the environment.

Brady (1984) defined soil survey as the systematic examination, description, classification and mapping of soils in an area. According to Brammer (1967), soil survey means recognizing different soils as they occur in nature and representing the area they cover on maps. According to Soil Survey Staff (1951), soil survey includes those researches which are necessary to:-

(i) determine important characteristics of soils;

(ii) classify soils into defined types and other classification units;

(iii) establish and plot on maps the boundaries among kinds of soils, and;

(iv) correlate and predict the adaptability of soils to various crops, grasses and trees; their behaviour and productivity under different management systems and the yields of adapted crops under defined sets of management practices.

Based on the purpose of soil survey, there are two types of soil surveys, namely, the special purpose and general purpose soil survey. The special purpose soil surveys are carried out with a specific use of land in mind or to answer specific questions about the land (Dent and Young, 1981; Bridges, 1982; Lema, 1987). The general purpose soil surveys are made with the intention of guiding a wide range of land use and evaluation of the land, and, therefore, they are based upon general soil properties and morphology. The soil maps produced for such surveys are pedological in nature (Kaaya, 1989). The major deficiency to any general purpose survey is its failure to serve all purposes equally well (Dent and Young, 1981).

Therefore, for land evaluation purpose for rainfed agriculture , the special purpose soil survey is more appropriate for collecting data required in assessing land characteristics in different land qualities (Dent and Young, 1981).

According to the soil survey intensities, three principal methods of soil survey have been described by Young (1976) and White (1987). These are:

(a) General purpose remote sensing method eg. air photo (API) or Satellite Imagery interpretation method. This method is used for low intensity surveys. The mapped boundaries of soils are largely or entirely inferred from API with a free survey at low intensities of field observations to characterize physiographic units;

(b) General purpose free survey method. This is employed for medium intensity survey using API, but also with a relatively high intensity of field observations. The observation points are sited by judgement of sample representative areas; and

(c) Special purpose grid survey method. This method involves the recording of individual soil properties on a grid pattern and mapping them parametrically. Observation points are commonly located on grid sited to cross the area that is being surveyed.

2.2.2 Soil Classification

Although soil classification started since time immemorial, when man began harvesting roots and searching for other natural foods (Johnson, 1978), the systematic attempts of soil classification began in the nineteenth century (Clayden, 1982). Cline (1949) defined soil classification as the process of organizing the properties of soils so that they may be recalled and their relationships can be communicated.

Soil classification identifies, organizes and names soils in an orderly fashion and it implies the interpretation and formulation of relationships within the soil population (Beinroth, 1978). It also enables soil surveyors to maintain consistency in soil surveys from place to place (Jonhson, 1978). In addition, it serves as a base for transfer, correlation, interpretation and application of soil technology and agro-technology (Beinroth, 1978; Johnson, 1978). In general soil classification assists communication about soils and helps to extrapolate findings about soils in one region to other regions.

Various systems of soil classification and consequently different definitions and nomenclature of soils have been developed (clayden, 1982; FritzPatrick, 1983). Literature on soil classification indicates that even the existing and most popular soil classification systems are regularly modified so as to match with development of new concepts and increasing knowledge of soils (Buringh, 1979; FritzPatrick, 1983).

Although there are several land classification systems in use worldwide (Beinroth, 1978; Buringh, 1979; Buol et al., 1980; Brady, 1984; ILACO, 1985), only two of these systems, namely the US soil Taxonomy (Soil survey staff, 1975) and the FAO-UNESCO (1974, 1988) legend of the soil map of the world are known to enjoy wide international recognition (Msanya, 1987; Kaaya, 1989; Landon 1991). As the science and technology in most of tropical countries is mostly based on adoption and modification of the science developed in developed countries, these two systems are among the most widely used in the tropical areas, as their taxa can be correlated at various categoric levels (Beinroth, 1978).

The US Soil Taxonomy system (USDA) and the FAO-UNESCO Soil Map of the World legend are the most commonly used system in an attempt to correlate the soils of Tanzania (NSS, 1980-1991; Samki and Dewan, 1982; Mushi, 1983; Mpepo, 1986; Sharma, 1987; Kaaya, 1989). The US Soil Taxonomy system is however used as a secondary system to the FAO-UNESCO system (Cline, 1980).

The US Soil Taxonomy (Soil survey staff, 1975) is much more comprehensive and less genetic than earlier systems (Whiteman, 1980). It is placing much more emphasis on actual soil properties (viz. morphological, chemical, etc.) and therefore being desirably less subjective, but often requiring much laboratory work on profile samples before final classification. The major problem, in the practical application of the US Soil Taxonomy is the work required on the soil before accurate identification is possible. Also, the methods used in many laboratories throughout the world often differ from those required in the US Soil Taxonomy. Therefore lack of detailed soil knowledge is a major current drawback in its use worldwide (Whiteman, 1980).

The FAO-UNESCO system is widely used because it is far much simpler to use compared to the US Soil Taxonomy system as well as being international. It is commonly used for communication in facilitating correlation of the soils in the country with those of other countries (Cline, 1980; Kaaya, 1989).

The FAO-UNESCO (1974) legend of the Soil Map of the World classification structure consists of two categories of which the higher one is roughly equivalent to the great groups of the US Soil Taxonomy (Clayden, 1982) and the lower category equivalent to the subgroups of the US Soil Taxonomy. The soil units are defined using the diagnostic properties of soils and horizons whose definitions are most similar to those of the US Soil Taxonomy system.

In the mid 1980's an exhaustive appraisal of the 1974 FAO-UNESCO legend took place, based on its international and national experiences over the previous decade (FAO,1988; Landon, 1991). The appraisal resulted in a revised legend (FAO-UNESCO, 1988). However, the revised legend (FAO-UNESCO, 1988) consists of only minor changes and, therefore the old legend (FAO-UNESCO, 1974) will continue to be used for many years to come (Landon, 1991).

3. MATERIALS AND METHODS

A two stage approach in FAO framework for land evaluation was adopted (FAO, 1976, 1984). The first stage involved a detailed soil survey and climatic data analysis. This was aimed at establishing relevant land characteristics for assessment of land qualities. The requirements of the land utilization types (LUTs) were established from the literature and personal communication with agronomists in the area. The land qualities of each mapping unit and the requirements of the LUTs were then analyzed, interpreted and matched to determine land suitability classification.

In the second stage, the LUTs suitable for different mapping units were analyzed by considering the social and economic factors. The suitability classification was then adjusted accordingly.

3.1 The physical Environment of LITI-Tengeru Farm

3.1.1 Location and Extent

LITI-Tengeru farm is located 3 km south of the Moshi-Arusha highway. It is about 13 km east of Arusha town, (Fig. 3.1). The farm lies at 3° 23' S latitude and Longitude 36° 52' E. Its altitude ranges from 1330 m a.s.l in the North-West to 1190 m a.s.l in South - East (Map.1). Its total area is 375 ha. Out of this, 250 ha are used for agriculture. Catchment forest occupies 47 ha, and residential and office area is 78 ha.

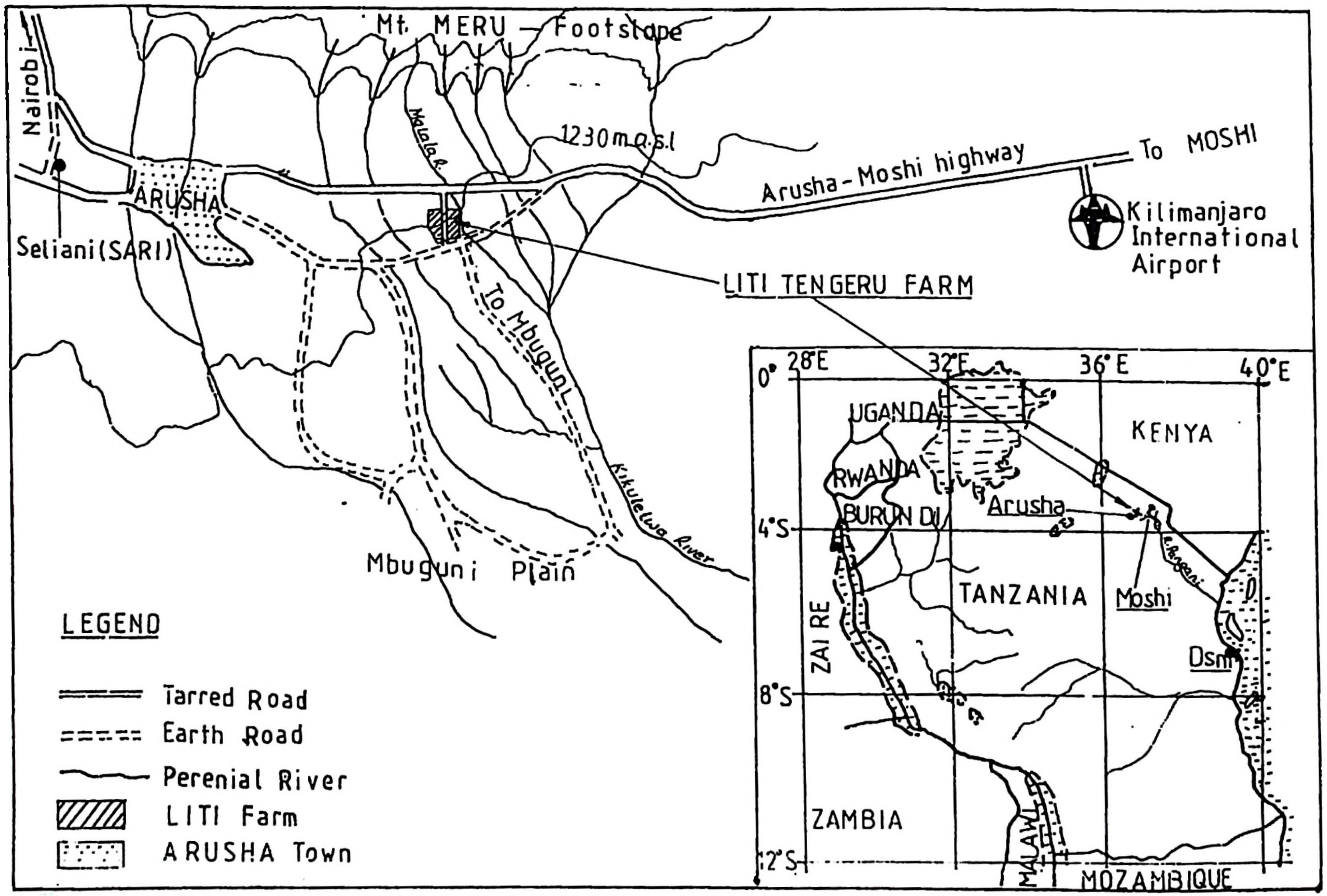


Fig. 3.1 LITI-Farm Location Map

3.1.2. Soils, Geomorphology and Drainage

The farm is divided into two zones geomorphologically: the upland zone with rolling topography and low rounded hills in the north and west, and the lowland zone with the flat to undulating topography in the south east. The upland zone lies between 1250 -1325 m a.s.l while the lowland zone lies between 1190 -1235 m a.s.l. (Map.1.)

The upland zone of Tengeru farm forms the lower part of uplifted area of Mt. Meru. The upland zone is separated from the lowland zone by a steeply dissected minor escarpment. Consequently, the upland zone soils are formed in situ from volcanic ash and other pyroclastic materials from Mount Meru. This zone thus consists of volcanic soils or Andosols (FAO-UNESCO, 1974). The lowland zone forms the upper part of Mbuguni plain, which is part of Pangani river basin. The soils in this zone were formed from alluvium and colluvium materials from upland volcanic soils. They include heavy textured cracking "Mbuga" soils or Vertisols found in the poorly drained depressions, and the dark brown soils or Fluvisols (JICA, 1990; Presant, 1992).

The farm is drained by two perennial streams, Malala River (Fig.3.3) and seasonal streams. Malala River and the two spring streams flow southward to join with other tributaries to form Kikuletwa River (Fig.3.1). Kikuletwa River joins other rivers draining Mt. Kilimanjaro at Nyumba ya Mungu Dam to form Pangani River.

3.1.3 Climate

The climatic data as summarized in Table 3.1 and Fig:3.2:, show that the area is dry during July - September and wet during March - May and November - January. In general, meteorological items such as temperature, relative humidity and evaporation varies widely under the influence of both solar energy and rainfall depth. The mean monthly temperature varies from 17°C in July to 22°C in February and March. The coolest months are June, July and August. The monthly daily mean relative humidity varies from 63% to 80%. During the short light rain season from November to February, the relative humidity is almost constant.

The evaporation at the farm measured by using A-pan and Piche evaporation methods, indicate that the maximum evaporation is in February (5.5 mm/day). The minimum evaporation is in May (2.5 mm/day). From September to January the evaporation seems to be constant (4.0 to 5.0 mm/day. The difference between Piche evaporation and A-pan evaporation seems to be very little, this may be due to the low wind velocity. The winds are light throughout the year ranging from 0.6 m/s to 1.0 m/s. The wind direction is predominantly from South to North-East.

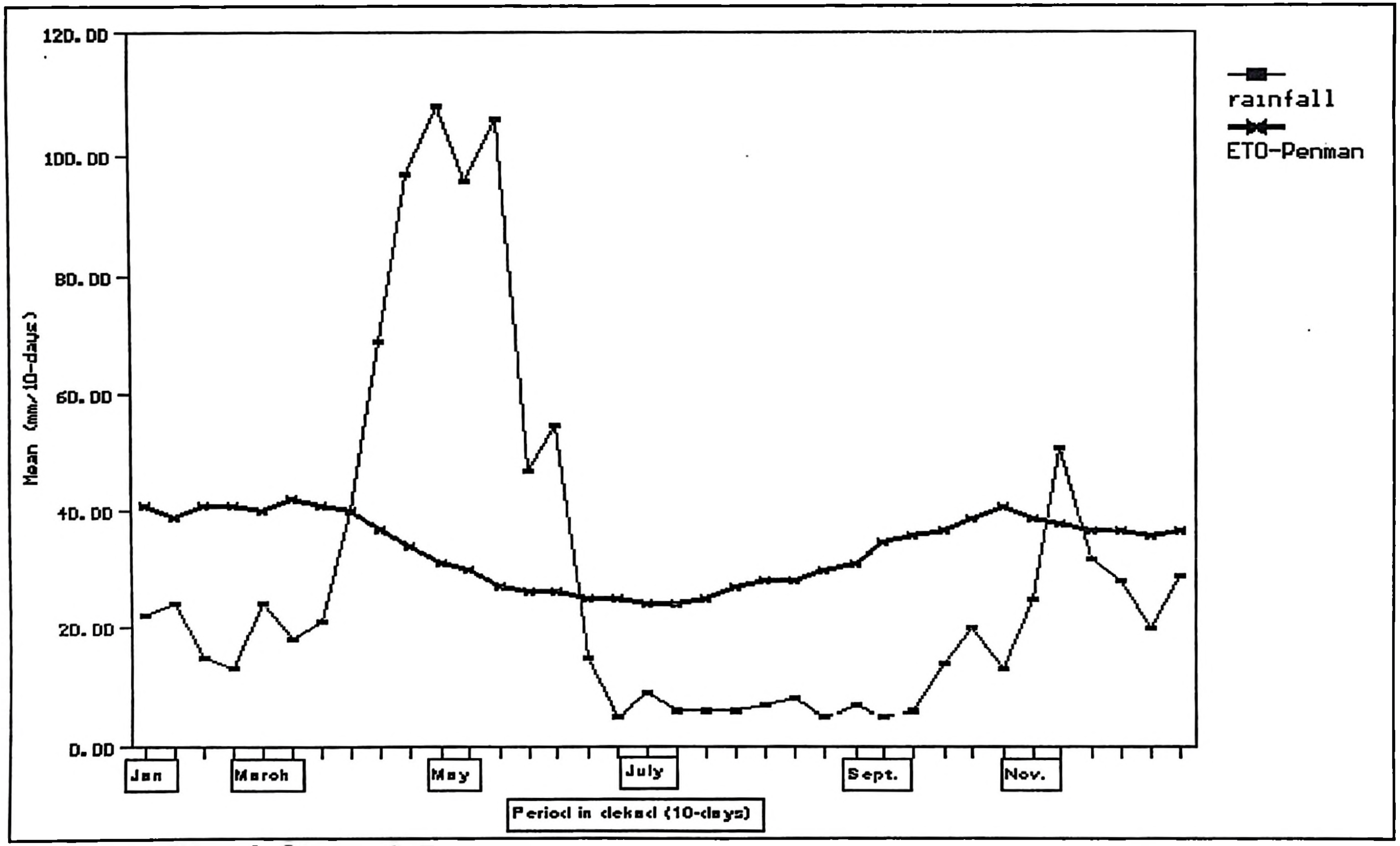


Fig.3.2 Water balance at Tengeru

Table 3.1a Agro-climatological data

Month	Dekad	Rainfall/dekad			Evaporation mm/day		
		mm	Sd%	Cv%	Piche	A-Pan	ETo-Penman
Jan	1	22	26	120	3.7	5.3	4.1
	2	24	28	133	4.8	5.4	3.9
	3	15	19	108	5.4	5.6	4.1
Feb	4	13	14	111	5.4	6.7	4.1
	5	24	30	137	5.6	5.4	4.0
	6	18	23	182	5.6	5.8	4.2
Mar	7	21	29	143	5.9	5.9	4.1
	8	40	48	120	5.1	5.5	4.0
	9	69	65	95	4.2	4.6	3.7
Apr	10	97	74	76	3.5	4.1	3.4
	11	108	74	68	3.1	3.6	3.1
	12	96	68	64	2.8	2.7	3.0
May	13	106	51	48	2.4	2.4	2.7
	14	47	31	70	2.5	2.3	2.6
	15	55	63	116	2.5	2.4	2.6
Jun	16	15	33	226	2.6	2.4	2.5
	17	5	5	102	2.7	2.8	2.5
	18	9	14	150	2.6	2.7	2.4
July	19	6	9	137	3.0	2.4	2.4
	20	6	12	179	3.1	2.5	2.5
	21	6	11	186	3.2	2.9	2.7
Aug.	22	7	11	161	3.4	2.9	2.8
	23	8	11	128	3.4	3.1	2.8
	24	5	7	137	3.5	3.1	3.0
Sept.	25	7	10	145	3.7	3.7	3.1
	26	5	8	152	4.4	4.7	3.5
	27	6	14	230	4.5	4.7	3.6
Oct.	28	14	15	98	4.6	4.6	3.7
	29	20	50	260	4.9	4.7	3.9
	30	13	12	93	4.7	4.8	4.1
Nov.	31	25	25	103	4.7	4.9	3.9
	32	51	52	103	4.2	4.9	3.8
	33	32	47	143	4.1	5.0	3.7
Dec.	34	28	31	108	4.3	4.5	3.7
	35	20	19	95	4.2	4.5	3.6
	36	29	42	145	4.4	4.6	3.7
Total	1072						1233

Table 3.1b Agro- climatological data

Month	Dekad	Tmin. °C	Tmax. °C	Tmean° C	RH% mean	Wind m/s	Sunshine hrs/day
Jan.	1	13.2	29.3	21.3	62	0.8	8.4
	2	13.6	28.8	21.6	67	0.7	8.1
	3	14.3	29.9	21.9	65	0.8	7.5
Feb.	4	13.8	29.7	21.8	64	0.8	7.9
	5	14.2	29.8	22.0	64	0.8	6.6
	6	13.9	30.4	22.2	63	0.8	7.4
Mar.	7	14.7	29.9	22.3	63	0.9	6.6
	8	15.5	29.3	22.4	65	0.9	6.3
	9	15.6	28.5	22.0	68	0.8	5.7
Apr.	10	15.5	27.6	21.6	73	0.7	5.1
	11	15.1	26.1	20.6	77	0.7	4.4
	12	15.2	25.7	20.5	79	0.6	4.1
May	13	14.7	24.8	19.8	82	0.6	3.7
	14	14.2	24.2	19.2	79	0.6	3.3
	15	13.7	23.8	18.8	78	0.6	3.3
Jun	16	13.1	23.3	18.2	78	0.6	3.7
	17	12.3	23.0	17.7	78	0.6	4.4
	18	11.7	22.7	17.2	79	0.6	2.9
July	19	11.4	22.4	16.9	77	0.6	3.4
	20	11.3	22.8	17.1	73	0.6	3.6
	21	11.1	22.9	17.0	73	0.7	4.2
Aug.	22	11.6	23.3	17.5	72	0.7	4.1
	23	11.3	22.7	17.0	72	0.7	3.6
	24	11.5	23.7	17.6	71	0.8	4.6
Sept.	25	11.8	24.2	18.0	67	0.8	4.3
	26	11.5	26.1	18.8	63	0.8	5.8
	27	11.7	26.6	19.2	62	0.9	5.3
Oct.	28	12.6	27.0	19.8	62	1.0	5.7
	29	13.2	27.7	20.5	63	1.0	6.8
	30	13.2	28.4	20.8	64	1.1	7.1
Nov.	31	13.6	28.4	21.0	63	1.0	6.4
	32	13.9	28.0	21.0	68	0.9	6.6
	33	13.7	28.1	20.9	67	0.8	6.8
Dec.	34	14.5	27.9	21.2	66	0.8	6.9
	35	14.3	27.8	21.1	67	0.7	6.0
	36	14.2	28.4	21.3	66	0.7	6.2

From water balance in Fig 3.2:, the area is experiencing bimodal rainfall. Therefore, agro-climate at Tengeru area can be said to be characterized by three seasons: The long rain season from March to early June, contributing 60% (640 mm) of mean annual rainfall; the cool dry season from late June to October; and the light and short rainy season from November to January contributing 25% (250 mm) of annual rainfall.

3.1.4 Vegetation and Current Land Use

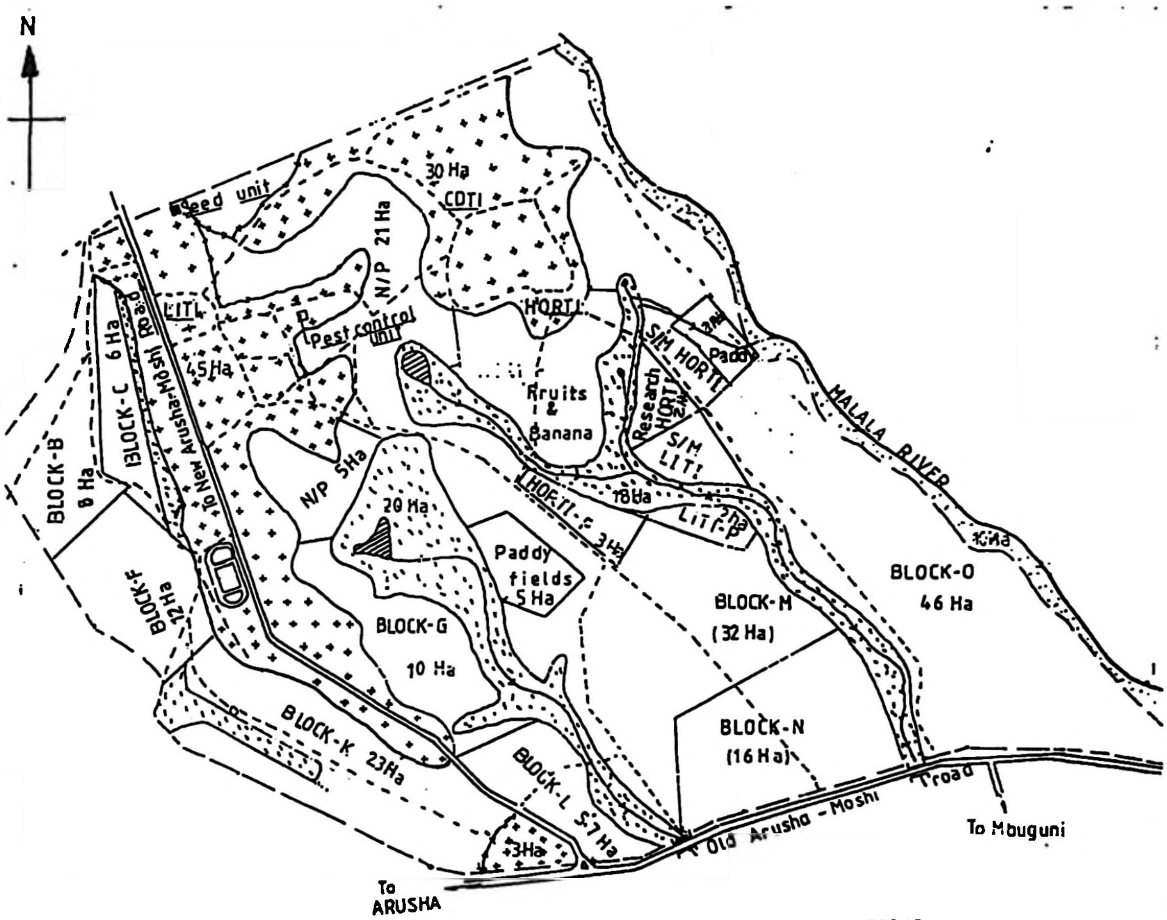
The natural vegetation of this area is tropical semi-deciduous rainforest (FAO-UNESCO, 1974). The major natural forest in the farm comprises of *Acacia spp., Casuarina equisetifolia, Schimis molle, and Gmelina Spp.* Most of the natural forest is found in the protected forest catchment, along the perennial streams and Malala River (Fig.3.3).

Natural grasses are tall savanna grass. The shrub comprises of *Hymenocardia acida, Comelina benhalisis, Lantana camala, Vernonia spp., Psiadia arabika , Chinese lantern, and Sida acuta* (sweeping broom). The steep slopes are planted with trees, such as Silky oak (*Grevelia robusta*), Lucena (*Leucaena Leucocephala*), *Eucalyptus Spp.*, and Neem (*Azadirachta indica*).

As shown in Fig. 3.3:, 200 hectares out of 250 hectares of agricultural land is under grass / legume pasture sward which constitutes the key crop of the farm. The dominant grass species include: Rhodes grass (*Chloris gayana*), Buffel grass (*Cenchrus ciliaris*), *Cynodon Spp.*, Guinea grass (*panicum maximum*), and Kikuyu grass (*Pennisetum clandestinum*). Legumes grown include: Green leaf Desmodium (*Desmodium intortum*), Glycine (*Neonotonia Wightii*), Siratro (*Macroptilium atropurpureum*), and Lucerne or Alfalfa (*Medicago Sativa)*. Grass grown for fodder comprises of Elephant grass (*Pennisetum purpureum*),and Guatemala grass (*Tripsacum Laxum*).

Pasture grown are used to feed the LITI livestock and excess sold to farmers around in the form of fresh pasture and pasture seeds. LITI- Tengeru keeps about 300 dairy cows, 80 small ruminants, 700 chicken (mostly Layers), 100 ducks, 35 rabbits, 8 horses and about 150 pigs on this farm. Due to Management problems and drought, LITI is currently carrying out destocking exercises.

The farm is also used by HORTI- Tengeru for vegetable seed production and Horticultural research plots in vegetables, fruits (Pomology), and flowers (Floriculture). It is also used by LITI staff (small holder) for crop production such as maize, beans and rice paddy.



LEGEND

(dotted box)	Forest / Catment reserve
(crossed box)	Residential / Office area
(blank box)	Pasture / agric. land
BLOCK-N	Pasture block
HORTI-P	Vegetable seed production
LITI-P	Vegetable production
S/M	Small scale model farmer
— —	Farm boundary
- - -	Farm road
═══	Main road
~~	Stream / River
N/P	Night paddock

Fig.3.3: LITI FARM — PRESENT LAND USE

3.2 Land use requirements and utilization types

3.2.1 Land utilization types

A land utilization type consists of a set of technical specifications within a socio-economic and physical setting (Dent and Young, 1981; ILRI, 1981; FAO, 1984). Therefore land utilization types (LUTs) involve individual crops or cropping systems, under broadly specified management level. In this study the land utilization types were defined under the following assumption:

- The LITI-farm is managed by well trained agricultural specialists and its use is intended to demonstrate the benefits of using improved technology and high inputs in livestock and crop production;
- The present and future objectives of Tengeru agricultural centre is to utilize the farm for research and training aimed to improve farming techniques, land husbandry and water management in the surrounding semi-arid and highland agro-ecological zones (MALDC, 1991);
- The climate and soils in the farm allow the growth of crops grown in the highland Agro-ecological zone (1500-3000 m) and in the lowland zone (800-1500 m)

According to ICRA-SARI (1993) the farming system around Mt. Meru agro-ecological zones include:

- the "highland" zone (2000-3000 m), with banana/coffee intercropping, with intensive livestock keeping;
- the "intermediate" zone (1 250 - 2 000 m), with banana/coffee intercropping; maize/bean intercropping, vegetables and intensive to semi-intensive livestock

keeping. Tradition supplementary irrigation using furrows is common in this zone ; and

- the "lowland" or semi-arid zone (800-1250 m), with sole maize, sole bean, maize/bean intercropping, irrigated paddy, vegetables and drought resistant crops eg. cassava, sunflower, groundnut, green gram, chickpea, sorghum, finger millet, and extensive livestock keeping.

As noted in section 3.1.2, this farm comprises of the intermediate agro-ecological features in the upland zone and semiarid features in lowland zone. The provisional land utilization types were based on: the present LITI and HORTI Tengeru activities and the future training requirements based on economic and farming system in the area (MALD, 1983; Laurent and Centres, 1988; Ellman et al., 1989; MALDC, 1991; ICRA/ SARI, 1992, 1993;); the survey on crops and market; consultations with LITI-Tengeru farm planning committee; and local agronomists.

The provisional land utilization types were refined from information delivered from matching the comparison of land resource data with the requirement of the use. The provisional land utilization types include:

(a) Rainfed annual cropping based on sole maize, beans, vegetables, sunflower, sorghum, by smallholder with medium capital resources, using tractor or ox-drawn implements for land preparation only, with high labour intensity, high input, advanced technology on household farms;

(b) Rainfed perennial cropping based on coffee, banana by small holder with medium capital resources, with high labour intensity, high input, and advanced technology for commercial purposes.

(c) Rainfed pasture farming for intensive dairy farm, operated by LITI for training and sale (hay and seeds production) with high capital intensity, high labour intensity, partly mechanised high input and advanced technology. In this case pasture grass considered include: Rhodes grass (*Chloris gayana)*, Elephant grass (*Pennisetum purpureum)*, Guatemala grass (*Tripsacum laxum)*, Giant setaria (*Setaria splendida*). Legume pasture considered are Greenleaf Desmodium (*Desmodium intortum*), Lucerne (*Medicago sativa*), Siratro (*Macroptilium atropurpureum*) and Glycine wightii (*Neonotonia wightii*).

3.2.2 Requirements of crops and land utilization types

Having described and selected the relevant land utilization types, the next step was to define the requirements for their successful operation. The sets of land use requirements are: Crop requirements (the physiological requirements; Management requirements; and conservation requirements) (FAO, 1984). The land use requirements for each LUT selected were established by combining: local experience, field survey observation,and information obtained from literature.

3.3 Basic Land Resource Surveys

3.3.1 General

The process of land evaluation includes the basic land resource survey such as soil survey and analysis of climatic records. The soil survey and climatic records form one of land evaluation major sources of physical data (FAO, 1984). The special purpose soil survey was adopted in this study (Young, 1976; White, 1987). The survey was conducted at intensity level 1 (ILACO, 1985; Landon, 1991).

3.3.2 Soil Survey

3.3.2.1 Pre-field work

The pre-field work included collecting of literature relevant to the area and tentative delineation of soil boundaries. The topographic map of the farm was obtained from Arusha regional agriculture office. This map produced in 1962, at a scale of 1 : 2 500 was used as a base map for this soil survey.

The tentative delineation of soil boundaries was done based on topography of the area that might indicate soil differences. Based on this preliminary soil mapping units, the first field reconnaissance trip to the study area was made. By considering the actual soil morphology, physiography and associated vegetation, the soils boundaries were adjusted in the field. The morphology factors used in this survey were those proposed by Msanya (1987), which included: the topsoil texture , colour, topography and drainage.A base map based on this preliminary reconnaissance findings at a scale of 1:2500 was prepared and a legend was set up.

3.3.2.2 Field Work

The systematic soil survey of the area was done by considering the preliminary soil mapping units established in section 3.3.2.1. The first stage of field survey included preliminary augering and soil description of each mapping unit. The soils were described at two depth levels: 0-30 cm and 30-60 cm. The intensity of checking was greatest along the boundaries and on the most representative sites.

The soil description was done according to the FAO (1977) guidelines. The data were collected by using the soil description forms designed by the National Soil Service (NSS), Mlingano- Tanga. The sample of the NSS form is attached in Appendix 7.1.

The analysis of the soil description information led to the reduction of the soil mapping units established by reconnaissance soil survey. Most of the soil units established on the basis of rolling physiographic position in the upland zone was found to be independent of relief variation, and therefore had the same morphological properties. In the undulating lowland area, the soil boundaries were found to be dictated by relief with its associated influence on drainage. Therefore, soil boundaries were adjusted again.

Based on the new soil mapping units, disturbed composite samples from each mapping unit were collected by augering. The composite sample comprised soil samples from four different representative sites on the same soil mapping unit. Samples were collected at 0-30 cm and 30-60 cm depths. The samples from different sites were combined by quartering method (Landon, 1991) to produce a composite sample. The composite samples were air dried immediately after their collection. A portion of each air dried composite sample was ground to pass through a 2 mm sieve in order to obtain fine earth. The fine earth was then tested for pH (1:25 soil: water suspension) and for electric conductivity at HORTI laboratory . The results were used as a continual check on the apparent uniformity of the soils (Landon, 1991).

The analysis of these laboratory results were used to correlate the soil mapping units and to reduce the number of samples requiring detailed laboratory analysis. A total of 186 samples were collected over an area of 328 ha. This gives an overall intensity of observation of 1 sample per 2 hectares. This intensity is within acceptable range (Landon, 1991).

The pH and electric conductivity results as well as other information in the soil description forms were used to analyze the new soil boundaries. Where necessary supplementary augerhole observations were conducted. At last, the new position of soil boundaries were established. At least one representative soil profile was dug for each soil mapping unit. The profile depth was at least 1.5 m , except where the limiting layer was met. In total, 10 profiles were excavated for the three soil mapping units identified (Map.1). Each profile was described according to FAO (1977) guidelines using NSS soil profile description form. Additional information was collected according to the crop requirements (FAO, 1976, 1984).

Soil colour was determined using the Munsell colour charts (Munsell Color Co., 1975). Both disturbed and undisturbed soil samples were collected from each horizon for determination of physical and chemical properties in the laboratory. Three undisturbed core samples were taken at different depths within each horizon.

A total of 60 core samples were collected. Precautions of soil sampling (FAO, 1979) were taken to avoid contaminations of unrepresentativeness of the soil samples. The undisturbed samples were air-dried for bulk density determination (Blake, 1986). The disturbed samples were then ground and tested for pH and electrical conductivity (ECe).

The soil infiltration rate was determined by the double infiltrometer method (Klute, 1986). Only soil mapping units with high risk for soil erosion were tested for infiltration rate. To minimize error due to variation in infiltration rate produced by changes in the initial soil water content (Landon, 1991), the infiltration rate measurement was done when the soil was at field capacity. This was achieved by conducting a test two days after a heavy rainfall. However, regardless of the precautions taken during measurement, the light fine volcanic ash soils showed a high tendency to produce a thick paste of silt suspension. This caused irregular local infiltration rate, being high at the time of filling and diminishing as the silt concentration increased with falling water level. This problem persisted even after decreasing the water resetting head from the recommended 5 cm to 3 cm (Appendix 7.2). Six sites were tested in the upland volcanic soil mapping unit.

3.3.2.3 Preparation of the soil samples

After field laboratory analysis and profile description, 25 representative soil samples were selected for further analysis. These included composite samples and samples from representative profiles. The selected samples already air dried were ground to pass through a 2 mm sieve. They were then packed in plastic bags. Each sample was at least 1 kg in weight.

The soil chemical and particle size analyses were conducted at Selian Agricultural Research Institute (SARI) soil laboratory - Arusha, on contract basis. The particle size distribution was determined by Bouyoucos hydrometer method (Klute, 1986) after dispersion. The bulk density was determined using the core sample method (Blake, 1986) and the results were expressed in g/cm^3.

Moisture retention characteristics were determined by using undisturbed core samples. The samples were saturated for two to seven days depending on the texture. The saturated samples were weighed and subjected to different tensions by using pressure plate and pressure membrane apparatus, respectively (US Soil Conservation Service, 1967). By using this method the water held at 0.1 bar, 0.3 bar, 0.5 bar and 15.8 bar were determined. Available water content (AWC) was estimated from the difference in water held at 0.3 bar (field capacity) and 15.8 bar (wilting point).

3.3.2.4 Soil Chemical Laboratory Methods

The soil pH was measured potentiometrically in 1:2.5 soil/water suspension and in 1:2.5 soil:1 Mole KCl suspension (Dewis and Freitas, 1970). Organic carbon was determined by the wet combustion method of Walkley Black (Nelson and Sommers, 1982). The cation exchange capacity of the soil was determined by Macro-distillation (Thomas, 1982).Exchangeable cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were determined from NH_4OAc leachate by atomic absorption spectrophotometer (Hesse, 1971).

Available phosphorus was determined by the Olsen method (Thomas, 1982). Electrical conductivity of saturated extracts was determined according to Dewis and Freitas (1970). Total nitrogen content of the soil was determined by the Macro-Kjeldhal method described by Bramner and Mulvaney (1982).

3.3.3 Climatic records and analysis

The climatic records were collected from LITI-Tengeru meteorological station situated at 1280 m above sea level, within LITI farm. The data were collected on dekad (10 day) basis. The records collected were those between 1979 and 1993 and included the following parameters: rainfall, temperature (maximum and minimum), wet and dry bulb temperatures at 9.00 a.m and at 3.00 pm., sunshine hours, wind velocity at 2 metres, A-pan evaporation, Piche evaporation and number of rain days for each decad.

The climatic records analysis was done by using Computer and statistical software packages such as Quattro-Pro and INSTAT. The potential evapotranspiration (ETO) was determined by Penman method (Doorenbos and Pruitt, 1977).

3.4 Soil Classification

By using the field information and Laboratory data, the soils in each soil mapping unit were classified to subclass level of the FAO-UNESCO (1974) legend. The result of this soil classification is presented in a 1:10 000 scale (Map.1.) and explained in section 4.4.

3.5 Land qualities rating and conversion tables

The land suitability classification is done by comparing requirements of a given type of land use with the properties of mapped areas of land by means of land qualities and characteristics (FAO, 1976, 1984). In this study, the four steps proposed by Dent and Young (1981) were used. These steps are:

- to select the land qualities that are relevant to the land use (crop) in consideration;
- to decide on the land characteristics to be used to measure or estimate each of these qualities;
- to determine the values which will form the boundaries of suitability classes for each land quality;
- to determine how the ratings based on individual qualities are to be combined into overall suitabilities.

The land qualities (FAO, 1977,1984) considered for land suitability evaluation for this farm included: radiation regime, temperature regime, moisture availability, oxygen availability to roots (drainage), nutrient availability, nutrient retention capacity, rooting conditions, condition for seedling establishment, condition for ripening, excess of salts, pests and diseases, soil workability, potential for mechanisation, erosion hazard, and soil degradation hazard. The other land qualities proposed in the guidelines were considered as not limiting.

3.6.1 Radiation regime

The solar radiation can be expressed by either of two characteristics; total shortwave radiation or sunshine hours (FAO, 1984). For evaluation in this study, day length based on daily average sunshine hours during growing period were used. By using tables relating radiation data and sunshine hours to dry matter production rate of a 'standard' crop given by FAO (1978/80/81) and Doorenbos and Kassam (1979), the rating for different crops was obtained. This assessment was necessary due to the high altitude of the area and the cloudiness induced by Mt. Meru rain-bearing winds.

3.6.2 Temperature regime

Local information indicates that the temperature effect in the area prolongs the growing length and cause sterility and head damage to sorghum and paddy rice tasselling occur during the cold month in late June and July. These months have the mean monthly temperature below 20°C. Therefore, the temperature data collected from the meteorological station was used to evaluate the effect of temperature during growing season on different crop phenological stages. The rating was based on crop requirements for growing period given in literature.

Table 3.2 Rating of temperature and radiation regime

Land Quality Diagnostic factor	Crop require-ments	Land quality rating			
		S1	S2	S3	N
1.Growing period mean temp.	Temp. range (opt.)/ (abs)	Within opt.	Within abs but 6^0C from opt.	Within abs.	Out-side abs.
2.Growing period sunshine hrs.	Optimum and absolute range	Within opt.	within abs. 2 hrs from opt. range	within abs.	out of abs. range

3.6.3 Soil moisture availability

The moisture availability can be assessed as total moisture, critical period, or as drought hazard (FAO, 1976; 1984). In this study the total moisture was found useful. The total moisture was evaluated through length of the growing period (FAO, 1984, 1988). The length of the growing period is the period during which the plant has enough available soil water to maintain its optimum growth, under favourable temperature. Therefore, the length of the growing period was determined by soil moisture balance analysis. The soil moisture balance was delivered from the general soil water balance equation (Doorenbos and Kassam, 1979):

$$WCi = WCi\text{-}1 + P + I + Ge - ETcrop - Dp\text{-}Ro \quad \text{(3.1)}$$

where: WCi = the soil water content at time i

WCi-1 = the soil water content at time i-1

P = total rainfall in time i

Ro = Rainfall converted into surface run-off

ETcrop = actual crop evapotranspiration

Dp = deep percolation of rainfall

I = Irrigation water (mm),in this case I = 0

Ge = Contribution from ground water table

The effective rainfall was determined as the total rainfall minus surface run-off, presented as:

$$Pe = P\text{-}Ro = (1\text{-}C)p \quad \ldots\ldots\ldots\ldots (3.2)$$

where: Pe = effective rainfall.

C = coefficient of run-off.

P = total rainfall

The run-off coefficient is defined as ratio of surface run-off (mm) over areal rainfall (mm). Due to lack of reliable run-off data from run-off experiments in the area, the average run-off coefficients for different soils were estimated from Table 3.3 below.

Table 3.3 Run-off coefficient (C)

Land unit: Vegetation or land use	Land unit: Slope %	Run- off potential: Low (Sand, loam sand)	Moderate (SL, SCL, SC, L)	High (ZL, C, ZCL)	very high (Heavy clay)
Forest	0 - 5	0.00	0.00	0.05	0.10
	5 - 8	0.00	0.05	0.10	0.15
	8 - 16	0.00	0.05	0.10	0.15
	16 -30	0.00	0.10	0.15	0.20
Natural pasture	0 - 5	0.00	0.05	0.05	0.10
	5 - 8	0.00	0.05	0.10	0.15
	8 - 16	0.00	0.05	0.10	0.20
	16 - 30	0.00	0.10	0.15	0.25
Arable land	0 - 5	0.00	0.05	0.10	0.20
	5 - 8	0.00	0.10	0.15	0.20
	8 - 16	0.05	0.10	0.15	0.25
	16 - 30	0.05	0.15	0.20	0.30

Source: FAO (1988)

The potential evapotranspiration rate (ETo) was computed by using Penman method (FAO, 1977). The ETO was computed for each dekad (10 day). The soil moisture storage capacity (AWC) was computed as a difference between moisture held at field capacity (1/3 bar) and moisture held at wilting point (15 bar) for different soil units and soil profile horizons. Since not all moisture between these zones is available to the plant due to rooting pattern, the Readily Available Moisture (RAM) was taken as 60% of the total available moisture content (AWC). The root zone was taken to be 1.2 metres, which is the common root depth for many crops (FAO, 1988; Kaaya, 1989).

The total root depth AWC (mm) was found by adding the product of the horizon thickness (m) by AWC (v/v %) for all multiple horizons within the potential rooting depth, in this case taken as 1.2 m.

The deep percolation was taken as any moisture in soil water balance above the maximum soil readily available moisture in the root zone.

Consequently, the water balance Equation 3.1 was modified and used under two conditions:

If $(WC_{i-1} + Pe\text{-}ETo_i) < 0.6*AWC = RAM$, then

$WCi = WC_{i-1} + (Pe\text{- }ETO)_i$ . . . . (3.3)

and; If $(WC_{i-1} + Pe - ETo_i) > 0.6*AWC$, then:

$WCi = 0.6 * AWC$ . . . .(3.4)

The growing period length was determined for the two growing seasons namely: season A, with heavy rainfall ranging from March to September; and season B, with light rainfall, ranging from October to February.

The steps for determining the growing period length were as outilined below. Sample calculation is shown in Table 7.7 in Appendix 7.2.

a. calculating the soil moisture water balance for each decad by using equation 3.3 and 3.4, for each soil mapping unit;

b. determining the growing period in days by using the ratio

$$\frac{Pe_i + WC_{i-1}}{ETO_i} \quad (3.5)$$

under the following conditions:

(i) If the result in equation 3.5 is greater or equal to 1: the growing duration was taken as 1 dekad. This condition is represented by the number "1" in the soil moisture balance Table 7.7 and 7.8 (Appendix 7.2).

ii. If $0.5 \leq \frac{PE_i + WC_{i-1}}{ETO_i} < 1$

The growing period was taken as 5 days if this condition occurred on the first or last decad of the growing season. If it occurred between two growing decads, it was counted as one growing decad. It is represented by "0.5" in appendix 7.2 (Table 7.7)

(iii) If the result in equation 3.5 is less than 0.5: It was taken as "1" growing decad if it occurred singly within two growing decads. If occurred more than once consecutively, it was taken as end of growing period. This condition is presented as "0" in Table 7.7.

According to the above method, the condition for the start of the growing season was satisfied when the running 10-day readily available soil moisture became greater than half the ETO. The end of growing season was taken as the first occurrence when the 10-day moisture in the soil got less than the ETO .

The growing period length in days were summed up for each year, and for each season A and B to find the total growing period (Table 7.7 in Appendix 7.2). The growing period for season A and B and for every year were then arranged in descending order, and the probability of exceedence was calculated by using data for 14 year seasons (Table 7.9 in Appendix 7.2). The probability of exceedence was calculated by using the formula:

$$Fa=\frac{100*(2n-1)}{2y} \qquad (3.6)$$

where:

n = rank number;

y = number of years of record.

Fa= probability of exceedence

The crop growing cycle length (Table 4.4) was matched with the growing period length (Table 7.9 in Appendix 7.2) to find the corresponding probability of exceedence (Table 4.4). The perennial crops were ranked by using the probability of exceedence based on the annual total soil moisture. The crop cycle for annual crops were taken to be equal to 210 days x Ky . Where Ky is the crop sensitivity to water supply coefficient as given in Landon (1991). The 210 days (seven month) approach were found to match with rating based on annual crop rainfall requirement

(Table 4.3). The results which is the probability of duration of moisture availability in the soil exceeding the crop growth cycle, was rated by using a conversion Table 3.4 below.

Table 3.4. Rating for growing seasons length

Growing period probability of exceeding crop growth cycle (days)	Rating	Remark
> 75%	S1	Very suitable
75-50%	S2	Suitable
50-30%	S3	Marginally suitable
< 30%	S4	Not suitable

3.6.4 Rating for Oxygen availability to roots

The occurrence of stress due to oxygen shortage depends on the occurrence of rainfall in excess of crop requirements, ability of the site to shed excess water as run-off or by infiltration, the aeration porosity and presence of a ground water table (FAO, 1984). Thus landform, hydrological conditions and soils affect this quality, against a background of the amount of rainfall and run-on. This quality was assessed through three methods: colour and mottling of the soil, inference from natural vegetation, and the hazard of water logging as dictated by land topography in relation to the surrounding area- were used to assign the soil drainage class; infiltration rate; and ground water table. The rating were based on the conversion Table 3.5 below:

Table 3.5 Rating for oxygen availability to roots

Land quality / diagnostic factor	Wt	Rating			
		S1 (3)	S2 (2)	S3 (1)	N (o)
1.Infiltr-ation rate cm/hr	2	>20	10-20	1-10	<1
2.Drainage class	3	Well; no ponding	moderate well ponding less than 3 days	Imperfect; ponding 3-10 days/year	Very poor or ponding more than six days/year
3.Ground water table (cm)	3	>150	50-150	20-100	<20
4.Combined rating index		≥ 20	19-15	14-3	< 3

3.6.5 Nutrient availability

The nutrient availability involves the following aspects: the quantity of nutrients present in the soil, the form in which they are present and the capacity of the soil-vegetation system to restore nutrient supplies during periods of rest from cropping (FAO, 1984).

Consequently, nutrient availability was assessed by using:

(a) quantities of major nutrients present in the root zone from soil chemical analysis for different soil units and soil pH;

(b) indicators of nutrient availability/fixation such as soil pH, Ca: Mg ratio, K: Mg ratio Na: CEC (ESP), K: CEC (EPP) (Landon, 1991);

(c) indicators of capacity for nutrient renewal such as content of weatherable minerals in the soil assessed during field soil profile description, total P,K and soil parent materials.

Rating of nutrient availability was based on values suggested by Landon (1991) and FAO (1983/86) where necessary modifications were done according to crop nutrient requirements. The conversions to get the overall suitability were based on Table 3.6 below.

The assessment was reached after analysis of condition modifiers such as aluminium toxicity, acidity, phosphorus fixation by iron or allophane, potassium reserves and cation exchange capacity. The above rating is valid only where no limitation of substantial effect which requires specific measures of soil management was encountered.

Table 3.6 Rating for nutrient availability

Factor	Unit	Values	Rating
1.pH (1:2.5 H_2O)		5.5-7.0	S1
		7-8.5	S2
		>8.5	S3
		4.5-5.5	S3
2. K (me/100g-soil)		>O.6	S1
		0.6-0.2	S2
		<0.2	S3
3.CEC (buffered 1M KCl at pH of soil)	me/100g soil	>40	S1
		25-40	S2
		15-25	S3
		>15	N
4. Total N.	%	>0.5	S1
		0.2-05	S2
		0.2-0.1	S3
		<0.1	N
5. Available P (Olsen).	ppm	>21	S1 - rich
		12-20	S2 - adequate
		5-11	S3 - marginal
		-<5	N - deficiency
6. Cation imbalance.	ratio		
	K:CEC	<2%	K -deficiency
	Ca: Mg	3:1-5:1	S1
		>5:1 & <3:1	{Possible Mg & P inhibition}
	K:Mg	>2:1	Mg Inhibition
		<1:1	S1 -vegetable
		<3:2	S1-field crop
		<3:5	S1 -fruits
	C: N	>6:1	Normal
5. Sum of cation (unbuffered) soln. 1M KCl at pH of the soil.		>16	S1
		12-16	S2
		6-12	S3
		<6	N

Source: Landon (1991)

3.6.6 Nutrient retention capacity

The quality refers to the capacity of the soil to retain added nutrients as against losses caused by leaching. It is relevant to the assessment of required fertilizer inputs (FAO, 1984).

Because plant nutrients are held in the soil on exchange sites (cation and anion), provided largely by clay particles, organic matter or the clay humus complex (FAO, 1984), the evaluation was based on cation exchange capacity (CEC) and sum of cations at pH 7. This was expressed as total exchangeable bases (TEB), which is the product of CEC and base saturation (expressed as a fraction). The TEB (meq/100g soil) was computed within 100 cm depth or lower horizon only if high organic matter was present. The rating was done according to conversion Table 3.7.

Table 3.7 Nutrient Retention Rating

Diagnostic criteria	Nutrient Status Class			
	High S1	Moderate S2	Low S3	Extremely Low N
CEC me/100g soil	<20	12-20	4-12	<4
Base saturation (%)	>50	50-25	50-25	<25
TEB	>20	10-20	5-10	<5

Source: FAO (1988)

3.6.7 Rooting conditions

Rooting conditions are controlled by soil effective depth and ease of root penetration. Effective depth is depth to a limiting hoziron e.g. rock, gravel, hardpan or toxic layer (FAO, 1984).

In assessment of the soil depth available for root development, the effective depth (cm) was determined through physical presence of roots recorded during profile description, by bulk density of the horizons and the start of C-horizon. The ratings were based on Table 3.8.

Table 3.8 Rating for Rooting Condition

Diagnostic characteristic	S1 Easy (wt.=3)	S2 moderate (2)	S3 Difficulty (1)	N= Very difficulty (0)
1.Bulk density. (wt=4)	<1.2	1.2-1.4	1.4-1.8	>1.8
2.Consistence when moist.(3)	Loose, very friable	Friable, firm	Very firm	Extremely firm
3. effective soil depth from effective crop root zone(3)	more by 50 cm or more	more by 10cm-50cm	more than 75% of effect. crop root depth	less than 75% of the effective crop root depth.
4. Presence of gravels or stones(wt=2).	<5% gravel	5-15%	15-40%	>40%
5.Min. combined rating per horizon.	≥34	33-20	20-10	<10

The effective rooting depth was considered as a sum of horizon depth for those horizons with a minimum combined rating above or equal to 10. The horizon was not considered if it was found to be below water table in some part of the year.

3.6.8 Conditions affecting germination

This condition was assessed based on the difficulty in proper seedbed preparation due to clodness and susceptibility to surface sealing for soils that seal easily after cultivating the land, therefore posing mechanical hindrance to emergence due to large firm clods or crust formation, and less availability of moisture due to a decrease in infiltration of water and increased surface run-off.

The assessment of this quality relied on surface sealing observed during soil survey and soil type and the size of the seed. The smaller the seed the higher the risk. The ratings were based on conversion table 3.9 below.

Table 3.9 Rating for conditions for seedling establishment

Diagnostic factor	S1 Good	S2 Moderate	S3 Marginal	N = Very poor
Soil structure and consistence 0-20 cm	Single grain, fine granular. Moderate fine sub-angular blocky, loose or very friable moist	Course granular. Moderate medium subangular blocky, friable to slightly firm moist.	Course subangular blocky, weak fine subangular blocky slightly hard dry, firm to very firm moist	Strong course angular blocky, massive or strong prismatic, very hard to extremely hard dry; extremely firm moist

3.6.9 Conditions for ripening

All crops require a period, sometimes after growth has ceased, for the seed, fruits or other used part to mature or ripen. Conditions for ripening were assessed by considering the effect of moisture due to rainfall and RH% during ripening or drying. Therefore the drying energy was assessed on the basis of pan evaporation. The result was calibrated in terms of extent of farm rot. Conversion Table 3.10 was used for rating.

Table 3.10: Rating for conditions for ripening

Diagnostic factor	Wt	Unit	Rating S1 (3)	S2 (2)	S3(1)	N(0)
1.Relative humidity %	2	%	< 65%	65 -75	75 -90%	<90%
2.Rainfall at maturity stage	3	decade mean (mm)	Less than 0.5 E-pan	between 0.5-1.0 E-pan or	Between 1.1-2.0 E-pan or	More than twice Pan evaporation
3. Combined index rating			$\geq$13	12 -8	7-3	<3

3.6.10 Excess of salts

This quality refers to the two hazards which may arise through accumulation of salts: salinity or excess of free salts; and sodicity or saturation of the exchange complex with sodium ions (Sodium alkalinity).

The assessment of salinity through electrical conductivity of the saturation extract and assessment of sodicity through exchangeable sodium percentage (ESP), was done based on the laboratory data and their effect on different crops interpreted into corresponding yield reduction for each crop (Table 3.11). The rating was based on salinity and sodicity levels corresponding to different yield reduction in the tropics suggested in Landon (1991) and FAO (1979).

Table 3.11 Rating for salinity and sodicity

land charact.	criteria	wt	S1(3)	S2(2)	S3(1)	N (0)
Salinity in Ece mS/cm	Yield reduction %	1	< 11%	11-25%	26-50%	>50
Sodicity ESP%	Yield reduction%	1	< 11%	11-25	26-50	>50%
Combined rating index			≥ 6	5 - 3	2	< =1

3.6.11 Soil toxicities

These include toxicities due to aluminium, calcium carbonate and gypsum, manganese, acid sulphate and others (FAO, 1984). In this study, most of toxicities components were considered in nutrient availability when checking cation imbalance and pH effect. Therefore, only calcium carbonate was important under this land quality. The rating was based on the presence of calcarious material horizon. In addition to using the conversion table 3.12 below, crop sensitivity to $CaCO_3$ as outlined by Sys and Riquier (1980) was taken into account in the final rating. Tolerant crops eg. sorghum was raised one class higher, very sensitive crops (citrus, banana and coffee) were lowered by one

class.

Table 3.12 Soil toxicities rating

Land characteristic.	Rating			
	S1	S2	S3	N
$CaCO_3$ horizon depth	more than 20 cm below the effective root zone	overlap-ping the root zone by less than 10 cm	covering less than 50% of the root zone	occupy more than 50% of the root zone

3.6.12 **Pests and Diseases**

The assessment was based on local experience on the frequency and effect of particular pests or diseases on production loss. The conversion Table 3.13 below were used in the rating in association with the market value of the crop and the cost involved in controlling the pest/ disease.

Table 3.13 Rating for pests and diseases

Diagnostic	Wt	Loss in Yield %			
		Very low S1	Low S2	High S3	Very high N
plant pest	6	<10	10 -25	25 - 50	>50
plant disease	6	<10	10 - 25	25 - 50	>50
Index of endemic		36	35-24	23-12	<12

3.6.13 Soil Workability

This refers to the ease of tillage or cultivation, regardless of the tool being used. Based on the characteristics of the soils in this farm, this quality was assessed through consistence and occurrence of stones in the surface layer as shown in Table 3.14.

Table 3.14 Rating for Soil Workability

Diagnostic	Wt	S1	s2	s3	N
1.Soil Texture /consistence	5	Light to medium texture with loose to friable consist.	Medium textured and firm to friable	medium to heavy textured and very firm	heavy textured extreme-ly firm and very plastic when wet
2.Occurrence of stones (class)	3	very low < 20%	low 20-30%	high 30-40%	very high > 40%
4.Rock outcrop	4	<10%	10-15%	15-50%	> 50%
5.Combined Index		≥ 29	28 - 23	22 -12	< 12

3.6.14 Potential for mechanisation

This quality refers to condition of the land which specifically affects mechanized agricultural operations. In this case this land quality was evaluated through stoniness and presence of heavy clays, limiting slope for machinery operations and timeliness. Table 3.15 was used for conversion.

Table 3.15 Ratings for potential for mechanisation

Land characteristic	S1	S2	S3	N
Slope % (wt=2)	< 6	6-18	19-45	> 45
Stones, top soil (wt=1)	< 4	4-10	11-25	> 25
% clay content (wt. = 3)	< 40	40-60	61-75	> 75
Combined rating	≥ 17	16-12	11-5	< 5

3.6.15 Soil degradation hazard

This quality refers to physical, chemical and biological degradation of soil properties. Physical degradation of soil properties includes crusting, deterioration of soil structure, compaction and reduction of porosity and permeability. The diagnostic characteristics include: organic matter, bulk density, permeability and infiltration capacity.

Chemical degradation refers to adverse changes in chemical properties of soil, particularly acidification brought by incorrect application of fertilizer. Biological degradation refers to decline in organic matter content of the soil. Therefore, in this study, the physical soil degradation hazard was found to be significant for evaluation. The assessment was based on soil compaction hazard by farm machinery and livestock, soil erosion hazard in terms of long term soil productivity decline due to continuous cultivation and in terms of soil sufficiency for root development as reduced by erosion . The assessment of root growth hinderance due to soil depth reduction reflects the soil management problems associated with faulty land use.

The land degradation due to soil erosion was rated through the soil productive lifespan. For this study, the soil lifespan was defined as the time in years required by the soil erosion to reduce the soil effective depth to equal the minimum marginal effective root depth of the crop in consideration. The minimum root depth for different crops were determined from literature (Sys and Riquier, 1980; Landon, 1991). The soil lifespan was determined by using equation 3.7 below:

Where: SPL = Soil productive lifespan in year

$$SPL=\frac{ESD-ERD}{A} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

ESD = Effective soil type depth (cm)

ERD = minimum marginal crop root depth (cm)

A = Mean Soil loss (cm/ year)

The minimum marginal crop root depth was used so as to compensate for the increase in effective soil depth with time due to the insitu soil formation.

The soil compaction was rated in terms of compaction observed during soil survey and bulk density in the top 50 cm and the mechanisation intensity envisaged for each land utilization type.

Table 3.16 Rating for soil degradation hazard

Land charact.or diagnostic criteria	wt	S1	S2	S3	N
soil lifespan	5	> 150	100-150	25 - 100	<25
Bulk density [1] within top 50 cm	3	> 1.2	1.2-1.4	1.5-1.8	< 1.8
Combined index		≥ 19	18 -13	12-8	< 8

[1] Source: Landon (1991).

3.6.16 Erosion hazard

Erosion hazard is caused by wind or water. Although the soil at LITI-farm is very light and susceptible to wind erosion, the area is well sheltered and there is only light wind (<1.0 m/s), therefore only water erosion hazard was found important. The water erosion hazard by sheet was assessed by using the Universal Soil Loss Equation (USLE).

A = R x K x LS x C x P........................(3.8)

where: A = mean annual soil loss m3/ha

R = Rainfall erosivity index

K = Soil erodibility index

LS =The factor of slope length (L) and slope steepness (S). LS can be found from the equation.

L = slope length in m,

S = slope gradient in percent,

C = crop management factor,

P = conservation practice factor.

$$LS=\left(\frac{L}{22.13}\right)^{m}*(0.065+0.045s+0.0065s^{2}) \quad \text{..............} (3.9)$$

where: LS= Slope factor as above

L= slope length (m)

s = slope in %

m = slope coefficient:

$m=0.5$ if $s \geq 5\%$

$m= 0.4$ if $3 \leq s < 5\%$

$m= 0.3$ if $1 \leq s < 3\%$

$m= 0.2$ if slope $< 1\%$

The rainfall erosivity factor was estimated from the study conducted by Mr. E.T.S Nyenza (Nyenza, Personal communication, 1994). Some of the crop factor and conservation factor were estimated from literature (Wischmeirer ,1974; Anorldus; 1977; Wischemeirer and Smith, 1978;) and results obtained from a soil erosion experimental plots at Tengeru (Temple, 1972).

The LS factors were determined from Tengeru farm topographic map at 1:2 500 scale. K-value was obtained from nomograph by using top soil depth data and field infiltration rate. The suitability ratings for soil erosion hazard was based upon maximum acceptable limits of soil loss corresponding to each suitability rating (Table 3.17).

Table 3.17 Ratings for erosion hazard

Suitability rating		Maximum Soil Loss Mg/ha/Year
Very suitable	S1	<11
Suitable	S2	11 - 30
Marginally suitable	S3	30 - 60
Not suitable	N	> 60

To obtain the suitability rating for each land unit and land utilization type, the following methods were followed:

(a) calculation for the soil loss on the basis of rainfall erosivity, erodibility and topographic factors, omitting the land use factors;

(b) for each land utilization type (crop type) in turn, the crop management factor (C) was multiplied by the soil loss calculated in step (a) (Table 4.5);

(c) repeating steps (a) and (b), gave estimates of soil loss for each land unit/land utilization type combination. These estimates were compared with the values set in Table 3.17 above to give suitability ratings with respect to erosion hazard;

(d) the conservation factor (P), was considered as land improvement required on lowering soil loss to acceptable level.

3.7 Land Suitability Rating

3.7.1 Stages in comparison of land use with land unit

The requirements of each land use type were compared with the qualities of each mapped land unit to give a overall land suitability class by following the stages proposed in FAO (1984). These stages include:

- initial matching of land use requirements with land qualities leading to a first approximation of land suitability classes;
- interim review and iteration;
- land improvements;
- economic and social analysis;
- review and field check; and
- land suitability classification.

3.7.2 Initial Matching of land use requirements with land qualities

This is the comparison of the requirements of crops or land utilization types with the qualities of specified land units. This comparison leads to a first approximation of land suitability classes, based on physical criteria.

The assessment stages suggested in FAO (1984) were used in this study. These included:-

(i) suitability assessments for the individual crops concerned, and for cropping systems;

(ii) suitability assessments related to management;

(iii) suitability assessments related to erosion and soil degradation hazards;

(iv) combination of steps i-iii into overall suitability classes for land utilization types.

The individual ratings were combined into an overall suitability of the site for land utilization type by using arithmetic procedures and the method of limiting conditions where there is an assessment of N, (FAO, 1984).

The correlations between overall suitability rating obtained by arithmetic procedure and observed crop yield were assessed by considering farming experience, judgement and data on crop yields from trials or experiments conducted at the station. The individual assessments, expressed numerically were combined by addition, and refined by using a weighting factor to vary the values attached to suitability assessments according to whether they were assessed as moderately important or very important. The weight of individual land quality assessment were ranked as:

S1 = 3,

S2 = 2,

S3 = 1, and

N = 0.

The weighting values allotted to significance of each land quality were ranked as:

Very important = 5,

Important = 4,

Moderately important = 3,

Slightly important = 1.

The format for assessment were as in the Table 3.15.

The sum was converted back to an overall suitability according to the index of weighted sum, rated in accordance with the scale of crop yields suggested.

Table 3.18 Rating for overall suitability classification

Suitability class	% of maximum score (138)	Range in overall score
S1	> 98 %	135 - 138
S2	92 - 98	126 - 134
S3	75 - 91	100 - 125
N1	61 - 74	81 - 99
N2	0 - 60 %	0 - 80

3.7.3 Interim Review and Iteration

This involved scrutinization to see if the initial (provisional) land suitabilities could be improved to a higher suitability rate by:

- changing the specification of the land utilization type, including improved biological,physical and chemical management such as inputs, irrigation, etc;
- altering the land unit, through land improvements.

The aim was to suggest feasible techniques which can be used to modify the limitations in land qualities with poor class, and to separate temporary limitations from permanent limitations. The permanent limitations are those which cannot easily be changed by minor land improvements.

3.7.4 Economic and social survey

Since, the institutions at Tengeru use the farm as a tool to augment technological transfer through training and research, the economic and social survey was based on the following objectives:

- analysis of the combinations of land utilization types with land units in financial and economic terms, based on costs and prices, to ensure that a specific land use will make a profit year by year. It also indicate whether capital investment on land improvement will be justified by the crop value. The kinds of use classified as suitable are financially viable (with / without improvement envisaged);
- analysis of the farming systems in the area so as to assess the potential and impact of proposed land use changes in the area;

- impact assessment of proposed land use changes in terms of the present and future research and training requirements. eg. if irrigation is not economically feasible, but necessary as a training tool.

Financial analysis was done according to Gittinger (1981). The survey for financial analysis included collection of data on crop yields, input prices, labour and machinery operation costs, pesticides, fungicides, prices of agricultural products and etc. in the area. This involved: visiting estates such as Arusha seed foundation farm, research institutions, Agricultural experts in the area eg. District Livestock Development Office (DLDO), District Agricultural Officer (DADO), Tutors and Researchers at HORTI and LITI Tengeru, visiting input suppliers in the area e.g. TFA, CARGILL and ACU, and visiting contact farmers selected by LITI and HORTI institutes.

The analysis of farming system in the area and future research and training requirements were assessed from the farming system studies in the region. The economic land suitabilities were defined according to Table 3.19.

Table 3.19 Net farm return per hectare

Suitability class	net return in Tshs/ha
highly suitable = s1	> 500 000/=
suitable = s2	250 000-500 000/=
moderately suitable = s3	100 000-250 000/=
marginally suitable = s4	25 000-100 000/=
Not suitable = N	< 25 000/=

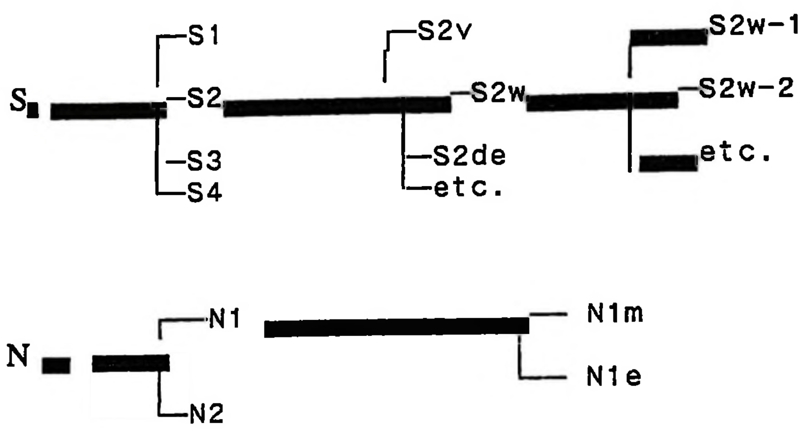
3.7.5 Review and field check

The provisional suitability classification was submitted to a field check. This was done by visiting and discussing with agricultural expert in the area, these included; LITI-Tengeru farm management committee; HORTI-Tengeru agronomists, soil scientists and other researchers; District Agriculture and Livestock Development Officer (DALDO) and extension staff; and farmers in the area.

3.8 Land Suitability Classification

The land suitability classification used is the one recommended for rainfed agriculture as given in the Framework (FAO, 1976; 1983). There are four categories: Land suitability order, class, subclass, and unit. The structure of the classification is as shown in the Figure below. The final land suitability classification was based on permanent limitations and socio - economic factors.

<u>Order</u> <u>Class</u> <u>Subclass</u> <u>Unit</u>



Phase: Sc, conditionally suitable

Fig. 3.4 FAO (1976) classification categories

4. RESULTS AND DISCUSSION

4.1 Soil Mapping Units

Based on the topography of the land, soil texture of the topsoil, effective soil depth and drainage, three soil mapping units were identified in the study area (Map. 1). Each soil mapping unit is described in the soil map by a coding system in which the above mentioned characteristics are represented. The coding system is explained in the legend of the soil Map 1.

The soils of the study area were classified according to the FAO-UNESCO (1974) system. The classification were based on the soil morphology and physical and chemical characteristics of the soils in each of the mapping units (Tables 4.1 and 4.2, and Appendix 7.1).

4.1.1 Mapping unit 34B1

4.1.1.1 Classification of soils in mapping unit 34B1

The soils of this mapping unit are classified as Mollic Andosols (FAO-UNESCO, 1974). Their extent in the study area is 200 ha. They are formed in volcanic ash material, and have a dark mollic A horizon. The bulk density is very low (< 0.9 g cm^{-3}). The pH, colour and texture of these soils, implies that, they are probably derived from andesite igneous rocks (Landon,1991).

4.1.1.2 Soil properties of mapping unit 34B1

The soil of this mapping unit are found on Mt. Meru southern foot slope. This area is characterized by the rolling topography with low rounded hills. The soils of the area are derived from volcanic ash and other pyroclastic materials from Mt. Meru. They are dominated by buried amorphous stones of andesitic origin. They are well drained and easy to till. The main limitations are their high erodibility by wind and water, limited mechanisation due to the presence of surface and buried stones. Severe sheet and gully erosion has been observed in nearby areas. Occasional manganese deficiencies have been reported in similar soils by Samki et al, (1980) and Kisanga (Personal Communication, 1994).

The soil profiles No. P5 and P7 whose description appears in Appendix 7.1 and its physical and chemical characteristics presented in Tables 4.1 and 4.2 represent the soils of this mapping unit. Where the slope is small, the soils are deep and well drained. The surface soils and subsoils are characterized by very dark greyish brown moist colour. There is little change of colour with depth due to low difference in organic matter contents of the surface horizon compared to the subsurface horizons (Table 4.1).

Table 4.1 Soil chemical properties

Chemical property	Mapping land unit					
	11C2-Vp		14C1-Je		34B1-Tm	
	0-30	30-60	0-30	30-60	0-30	30-60
PH:(1:2.5 soil:H_2O)	6.5	7.2	6.0	5.9	6.0	6.1
(1:2.5 soil:1M KCl)	6.0	6.4	5.5	5.5	5.6	5.6
Exchangeable Cation (me/100g-soil):						
Na^+	2.3	3.9	1.1	0.9	0.8	0.8
K^+	1.8	1.2	2.2	1.9	2.9	2.9
Mg^{2+}	8.9	9.5	4.4	4.6	4.7	4.9
Ca^{2+}	22.5	27.1	14.4	13.4	18.1	18.4
CEC (me/100g-soil)	50.0	54.6	34.9	34.1	47.4	46.5
Organic Carbon %	2.7	1.7	1.7	1.8	4.3	3.8
Percentage Nitrogen	0.18	0.11	0.17	0.13	0.31	0.26
Available P (ppm)	8.0	4.8	88	57	100	92
EC (mS/cm)	0.3	0.3	0.08	0.07	0.06	0.08

Table 4.2 Soil physical properties

Physical property	Mapping unit						
	11C2-Vp			14C1-Je		34B1-Tm	
Horizon (cm)	0-20	20-50	50-75	0-20	20-85	0-20	20-130
Bulk density	1.28	1.63	1.56	1.11	1.24	0.85	0.88
AWC (cm/m)	11	18	12	20	17	25	28
Particle distribution							
% Sand (S)							
% Silt (Z)	8.7	4.3	nd	12.8	11.7	18.6	16.2
% Clay (C)	26.1	17.4	nd	43.6	40.1	50.0	52.9
	65.2	78.3	nd	43.6	48.2	31.4	30.9
Textural class (USDA)	Clay	Clay	Clay	Silt Clay	Silt clay	Silt clay loam	Silt clay loam
Basic Infiltration rate (cm/hr)		0.7		6		10	

nd= not determined.

The soil structure changes from weak fine subangular in the topsoil to moderately strong subangular blocky structure due to the decrease in organic matter content and eluviation of the light fine particles from the subsoil to the topsoil when the soil is saturated. Most of the light (silt) particles in the top soil are then washed by sheet erosion due to their low density and affinity. Consequently, the bulk density increases with profile depth.

The textural class of the top soil is clay loam to silt clay loam and there is a gradual increase of silt-content with depth while, clay remains constant at 31%. The constant level of clay ,and the presence of weathered stone suggest insitu formation of clay.

The available water capacity (AWC) of 21% to 27% (vol.) in the surface and subsurface horizon, shows a remarkable high moisture storage capacity of Andosol soil (Landon, 1991). A similar range was reported by Samki et al., (1980) in vitric Andosols at Arusha Foundation Seed Farm. The high AWC is also reported by Kisanga, (Persn. communication, 1994). According to him, maize under these soils show no stress even under 20 days of dry spell.

The organic carbon content of the soils in this mapping unit are generally at medium level ranging from 4 to 6.5% at the topsoil (Landon, 1991) and low (between 3% - 5.1%) at the subsoil. The higher organic carbon in the topsoil is due to incorporation of plant residues (Brady, 1984).

Available phosphorus determined by Olsen's method are very high (Landon, 1991). Therefore, phosphorus fertilizer produces no response if applied (Kisanga

Personal Communication, 1993). The high level of phosphorus in the sub-soil horizon indicates that, the parent material is rich in phosphorus.

Total nitrogen content shows a decrease with depth, ranging from 0.22% to 0.49%. This range is interpreted as medium level (Landon, 1991). According to Kisanga (Personal communication ,1994) experiments conducted in the farm under these soils shows significant response of crops to Nitrogen fertilizer .

The soil pH increases gradually with depth from 6.0 (1:25 soil:H_2O) at the topsoil to 6.1 at the subsoil horizon. Therefore the soils are slightly acidic, signifying that they are delivered from andesite igneous rocks. This range does not limit availability of common elements in soils (Landon, 1991).

The cation exchange capacity (CEC) for the whole profile range from 37 to 54 me/100g of soil. This amount is very high and reflects good agricultural soils. Therefore, no mineral fertilizer is required (Landon, 1991).

The base saturation percentage ranges from 51% to 66%. According to Landon (1991), the level of base saturation reflects that this soil is generally fertile. The level of exchangeable cations is termed as high for Mg^{2+}, Ca^{2+}, $K+$ (Landon 1991) and low for $Na+$. The exchangeable sodium percentage is around 3%. Therefore the sodium level does not pose any alkalinity toxicity problem. However , ESP above 2% has been found to show toxicity symptom to extremely sensitive crops such as Deciduous fruits, corn, nuts, avocado, cassava and citrus (Landon, 1991). Hence, further investigation is required to check if there is any effect associated with sodium level for above crops.

Based on the organic matter level, CEC soil pH, Base saturation percentage, exchangeable cation, available water capacity and rooting depth, this mapping unit is of high soil fertility status. Nitrogen fertilization is necessary in ensuring high productivity. The erodibility of these soils is extremely high (Temple, 1972).

4.1.2 Mapping unit 11C2

4.1.2.1 Classification of soils

The typical features of these soils include black, heavy texture clay showing large deep dry season cracks. They occupy poorly drained depression of the flat land. Due to these characteristics these soils are classified as Pellic Vertisols according to FAO-Unesco (1974) system. Their extent in the study area is 60 ha.

4.1.2.2 The soil properties of soil mapping unit 11C2.

The soils of this mapping unit, locally known as "Ngusero" in Arusha or "Mbuga" soil in other areas, are found on the flat plains. At this farm, they are found in poorly drained depression of the flat lowlands. This lowland starts at this farm and extends to a width of about 30 km to the foot of Mbuguni mountains to form Mbuguni flood plain.

The soils of the area are delivered from Mt. Meru volcanic ash soils, mainly through sheet erosion. Their very poor drainage nature is a result of their topographic position and impermeability. Because of the high Calcium content in the parent material (upland volcanic ash materials), the drainage water originating from upland soils is rich in dissolved Calcium. When these alluvium and other sediments stagnate in depression, they result into Calcium carbonate concretions after evaporation. The calcareous nodules are found right up to the surface. These soils are dominated by 2:1 expanding montimorillonite clay. This is reflected by features such as wide deep cracks, and slikensides.

The physical and chemical characteristics of these soils are presented in Tables 4.1 and 4.2. Detailed data and soil profile description for representative profile P2 are presented in Appendix 7.1. The soils in this mapping unit are shallow with effective depth of about 75 cm. They are extremely hard when dry, very sticky and plastic when wet, and have strong aggregated course subangular blocky structure. The subangular blocks are separated by shrinking vertical cracks of up to 7.5 cm wide. Therefore the soils in this land unit have unfavourable texture for tilth, seed germination, and root development.

The soils underlying the ploughed layer (20 cm - 50 cm) have a hard pan as indicated by a high bulk density of 1.63 g cm^{-3}. According to Veihmeyer and Hendrickson (1948), root growth is hampered at bulk density values of about 1.65 gm cm-3 in clay soils. This hard pan causes water stagnation on the surface, with subsequent run - off and soil erosion.

As indicated in Appendix 7.1, these soils have very high water holding capacity up to 90% in volume at saturation point. And release as low as 20% at 15.8 bar. This property creates drainage problems, poor trafficability , and serious interferences with tillage operation. The tillage timeliness remains a continuous problem, since its difficult to attain suitable moisture for efficient tillage in the upper layer, and even if you succeed the moisture content level in the subsurface layer will not assure resistance to compaction.

Available phosphorus ranges from 0 to 12 ppm. This amount indicates a phosphorus deficiency (Landon, 1991). According to FAO (1983), phosphorus is low in low humus tropical vertisols, because it exists mainly in the inorganic form. Ca - phosphate predominates over Aluminium and Iron- phosphorus. Consequently, the Sodium bicarbonate extractable phosphorus is generally low (<5 ppm) as compared to 400-700 ppm of total phosphorus. Furthermore the ratio Ca:Mg is 2.7:1. According to Landon (1991), this ratio reflects inhibition for phosphorus uptake.

The soil pH increases with depth from 6.5 in the surface horizon to 7.5 in the subsurface horizon.The pH increase with depth can be attributed to the increase of the presence of $CaCO_3$ with depth. The $CaCO_3$ increases as the moisture regime goes towards the dry side. Since the hard pan restricts moisture movement downwards, the powdery lime which is chemically active increases rapidly from 50 cm to 75 cm depth. It forms calcareous layer below 75 cm. This powdery lime is the one associated with high pH of the soil (FAO,1983). The crystalline $CaCO_3$ nodules found above 50 cm depth are inert in the soil.

The amount of Potassium ranges from 1.8 to 1.0 me/100g. According to Landon (1991), this amount is slightly low. The ratio K:CEC is between 1:28 in the topsoil to 1:54 in the subsoil horizon. This indicate cation imbalance and reflect potassium deficiency (Landon, 1991). The level of Sodium increases with depth. The ESP ranges from 4.5 to 10.5. Therefore sodicity problem is envisaged if these soils will be irrigated without proper drainage management. The level of Sodium is high to sodium sensitive crops (Landon,1991)

Generally the soils in this unit have deficiency of Nitrogen , Organic carbon, Potassium and Phosphorus. However, the natural fertility of these soils as reflected by CEC and BS% is high (Landon , 1991). The effective soil depth, soil structure and drainage , are the major constraints in using these soils for crop production.

4.1.3 Soil mapping unit 14C1

4.1.3.1 Classification of soils

Soils of mapping unit 14C1 are classified as Eutric Fluvisols by using FAO-Unesco (1974) Legend. This mapping unit covers an area of 115 ha. These soils occupy the well drained part of flat land. These soils have base saturation percentage of more than 50% and they are derived from alluvial and colluvial materials from volcanic ash soils (Andosols) occupying the high Mt. Meru slopes. Most of the catchment contains these soils (Map.1).

4.1.3.2 Soil properties

These soils are found on the best drained part on almost flat land of 1-2% slope, and along the streams and riverine. They occupy the transition zone between the mollic Andosols and the clay soils formed in the lowlands.

These soils are represented by three profiles, P3, P4 and P8. The physical and chemical characteristics of these soils are presented in Table 4.1 and 4.2. The soils are generally deep and well drained. Like many other fluvisols, the cummulization added new materials to the surface of the soil as fast as the new materials could be assimilated into pedogenic horizon (Buol et al., 1980; Norman et al., 1984).

On riverine downstream, these soils have been recently deposited; they are shallow and a thin layer of gravels is fairly common. Although there is a general increase of clay content with depth in all representative profiles, the top soil shows less clay than the subsoil horizon and there is no definite pattern of textural change with profile depth (Table 4.2).

The colour (moist) of the surface soils of this mapping unit is black (10 YR 2/1) and is similar to that of upland soils (Andosol). This similarity could be due to the high sheet erosion affecting the upland soils, which deposit the upland volcanic soils into this area. The topsoil horizon texture is silt clay loam, with weak fine subangular structure. They have non-sticky non-plastic wet consistence. This, strongly suggests that they have been recently deposited from volcanic ash (Andosol) of the upland area.

The subsoil surface horizon in these profiles has clay texture. The reduction of silt content in both surface and subsurface horizon as compared to the upland soil horizons can be attributed to the fact that most of the silt remains in water suspension until the water velocity becomes very low to allow settling. Consequently there is silt mantle formed by silt deposition at Msitu wa Mbogo in Mbuguni. Msitu wa Mbogo flood plain is located 15 km downstream in the south part of the study area.

The slight increase of clay with depth can be attributed to the floating of light fine silt particles in saturated soils which cause removal of silt particles during deposition hence increase in clay particles in the subsoils horizon. Because these soils have developed from materials of volcanic origin they have a high reserve of weatherable minerals and 2:1 lattice clay.

The bulk density of the surface soils in the two profiles P8 and P4 is lower than that of the subsurface horizons. However, they remain low (1.1 g/cm^3) at the surface horizon and 1.2 gm/cm^3 at the subsoil horizon, reflecting the inherent characteristics of their parent materials. The bulk density of surface soils in profile P3 is higher than the subsurface horizon, because of machinery and livestock compaction . However, both profiles show high bulk density compared to their parent material due to insitu compaction by machinery and intensive livestock grazing in these areas.

The mean AWC for surface horizons is 18% and subsurface horizon is 15%. Therefore the AWC values of these soils are fairly high according to the average values published by ILACO (1985) and Landon (1991) for soils with similar texture. The high AWC of these soils indicate their high ability to store water at the end of rainy season. It also indicates the low risk for short dry spells during growing seasons, and residual moisture at the end of rainy season. These AWC values are suitable for irrigation planning (Landon, 1991).

The topsoil organic carbon ranges from 1% to 2.9%. It decreases with depth. The mean available phosphorus ranges from 88 ppm at the surface horizon to 57 ppm at the subsurface horizon. In both horizons, there is high variation between sites. However the level of phosphorus in general is high, probably due to uplands parent material natural reserve.

The total nitrogen content range from 0.17% in the surface horizon to 0.13% in the subsurface horizon. This amount is rated as low in both horizons (Landon, 1991). Experiments in these soils have shown good response to nitrogen fertilizer (Kisanga, personal communication, 1994). The soil pH in 1:25 H_2O soil suspension, shows that the soil pH in between 5.9 and 6.0 in the surface and subsurface horizons respectively. This indicates that the soils are slightly acidic. However, this range is within favourable soil medium for crop production (Landon, 1991). The CEC values for these soils are almost constant, ranging from 28 me/100g to 40 me/100g soil. The CEC level is high in all horizons showing good mineral reserves.

The mean base saturation percentage is 65% and 61% for surface and subsurface horizons, respectively. According to Landon (1991), this BSP level is rated as high, hence reflecting high soil fertility status even for acid-sensitive crops.

The level of Calcium, Magnesium and Potassium can be termed as high and balanced. The mean for Calcium stands at 14.4 me/100g of soil for surface horizon and 13.4 me/100g soil in subsoil horizons. The values exceed 10 me/100g soil, therefore, the amount of calcium is high (Landon, 1991). The Ca: Mg ratio stands at 3.2:1. This indicates that Calcium level in surface horizon is within optimum range for most crops (Landon, 1991). This ratio is 2.9:1, in the subsurface horizon, according to Landon (1991), P uptake may be inhibited if the ratio is less than 3:1. The value for exchangeable magnesium stands at 4.43 me/100g of soil in the surface. These value is above 4 me/100g, therefore the available exchangeable

Magnesium is high in these soils (Landon, 1991). The ratio K: Mg stands at 0.1:1 and 0.4:1 for surface and subsurface horizon respectively. These ranges are within the recommended level, where Magnesium uptake is not inhibited (Landon, 1991).

The exchangeable Potassium ranges between 2.2 me/100g of soil to 1.9 me/100g of soil in the surface and subsurface horizons, respectively. As these values are above 0.5 me/100g of soil, these soils have high Potassium, therefore, no Potassium is required (Landon, 1991).

The exchangeable Sodium ranges from 1.1 me/100g of soil to 0.85 me/100g soil for surface and subsurface horizons respectively. Hence, the level of sodium in these soils poses no potential danger to crop production. However, if the area will be irrigated management precautions should be taken to avoid sodium accumulation. The ESP of these soils ranges from 3% in the surface horizon to 2.5% in the subsurface horizon. Though, the ESP is low as compared to 15% required to qualify the soils into sodic-soils (Landon, 1991), its use to Sodium very sensitive crops should be well investigated.

Therefore, the natural fertility, soil structure and moisture holding properties of these soils are favourable for crop production. However, low rainfall can hinder plant growth, especially on shallow soils. The erodibility of these soils is also high, especially during very intense rains. Crusting occurs on the surface of these soils. In wet condition, these soils are vulnerable to machinery and livestock compaction.

4.2 Land use (crop) requirements

The crop requirements for the 19 Land Utilization Types are presented in Table 4.3. The crop requirements data were deduced from different literature. Crop requirements for field crops, vegetables, coffee and citrus were mostly found in Landon (1991), Dent and Young (1981). Crop requirements for grass and legume pastures were deduced from Bogdan (1977), Whiteman (1980), Skerman et al,. (1988), and Skerman and Riveros (1990).

However, specific crop requirements data for land evaluation purposes are still difficult to find. In addition, most statements in books about crop requirements are still in qualitative form as a result, qualitative statements which can be used to infer quantitative data for assessment have been included in table 4.3.

Table 4.3 Crop requirements

a: Land use requirements- field crops

Land quality/characteristics	Maize	Beans	Sunflow.
			Crop
1. Radiation regime a. flowering Day length	day neutral /short day	day neutral /short day	day neut. /short day
2. Temperature regime:			
a. Optimum temperature	24 - 30	15 - 20	18 - 25
b. Absolute temperature	15 - 35	10 - 27	15 - 30
3. Moisture availability			
a. growing length (days)	90 - 140	90 - 120	90 - 130
b. drought resistance(Ky)	low (1.25)	med.(1.15)	high(0.95)
c. rainfall (growing)	500 - 800	300 - 500	600 - 1000
4. Oxygen availability:			
a. water table (cm)	75	30-50	75
b. water logging toler.	low	low/med.	medium
5. Nutrients requirement:			
a. nutrient need	high	medium	medium
b. N:P:K (min. kg N/ha)	100:50:60	20:40:50	50:20:60
c. pH opt. range	5.5-7.0	6.0-7.0	6.0-7.0
pH abs. range	5.5-8.0	5.5-7.5	5.5-7.5
d. N% high	>0.5	> 0.5	> 0.5
medium.	0.2-0.05	0.5-0.2	0.5-0.2
low)	< 0.05	< 0.2	< 0.2
e. P (ppm) high	> 8	> 8	> 8
medium	5-7	5-7	5-7
low	< 4	< 4	< 4
6. Rooting condition:			
a. Depth (cm)	200	100-150	200-300
b. Main nutrient uptake	80-100	50-70	80-150
c. soil consistence	medium	medium	medium
d. rooting pattern	80% in top 100cm	concentr.in top 30cm	moderately dense
7.Cond. for ripening RH%	low	low	low
8. Condition for seed germination a. texture	light/med.	light/med.	light/med.
b. soil consistence	friable	friable	friable
9.excess of salts:			
a.sodicity ESP% s1=v.low.	<2.	<6.	<10
s2=low.	2-10	6-10	11-15
s3=high)	10-15	11-20	15-20
b.Salinity ms/cm - s1	< 2.5	< 1.5	<6.2
s2	2.5-3.8	1.5-2.3	6.2-7.6
s3).	3.8-10.	2.3-6.5	7.6-9.9
11. Pest and diseases	aphids (in tussling (jun-july)	Nematodes Aphids diseases	Moles
12. Soil erosion:			
a. crop factor (C)	0.7	0.4	0.6
b. erosion hazard	high	medium	medium

Table 4.3 Continued ..
b: Crop requirements - Vegetables

Land quality/characteristics	Crop		
	Onion	Cabbage	Tomato
1. Radiation regime			
a. Day length for flowering	day neutral	day neutral	day neutral
2. Temperature regime:			
b. Optimum temperature	14 - 20	15 - 20	18 - 25
c. Absolute temperature	10 - 25	10 - 25	15 - 28
3.Moisture availability			
a. growing length (days)	100 - 140	100- 150+	90 - 120
b. drought resistance(Ky)	med (1.1)	high(0.95)	med.(1.05)
c. rainfall (growing period)	350 - 550	380 - 500	400 - 600
4. Oxygen availability:			
a.water table (cm)	50	50	50
b.tolerance to water logging	low	low	low
5. Nutrients requirement:			
a. nutrient need	high	high	high
b. N:P:K(min.kg N/ha)	60:25:45	100:50:100	100:65:160
c. pH opt. range	6.0-7.0	6.0-6.5	5.0-7.0
pH abs. range	5.5-7.5	6.0-7.5	4.5-7.5
d. N% high	>0.5	>0.5	>0.5
medium	0.2-0.05	0.5-0.2	0.5-0.2
low)	< 0.05	< 0.2	<0.2
e. P (ppm) high	>8	> 8	> 8
med.	5-7	5-7	5-7
low	2-4	< 4	< 4
6. Rooting condition:			
a. Depth (cm)	50	60	150
b. Main nutrient uptake	30-50	40-50	70-150
c. soil texture	medium	medium	medium
d. rooting pattern	80% Water uptake in top 30cm	extensive shallow system	deep rooting >80%in top 50-70 cm
7.Condition for seed germination: a. soil texture	light/med	light/med.	light/med.
b. consistence	friable.	friable	friable
9.excess of salts:			
a. sodicity ESP% s1=v.low	<10	<10	<10
s2=low	11-15	11-15	10-20
s3=high	16-35	16-25	21-60
b.Salinity mS/cm=s1	< 1.8	< 2.8	< 3.9
s2	1.8-2.8	2.8-4.4	3.9-5.5
s3)	2.8-10	4.4-7.0	5.5-8.2
10. Pest and diseases:	mites	fungi (Mildew) Nematodes weevils	Nematodes Aphids fungi disease)
12. Soil erosion:			
a.crop factor	0.3	0.3	0.2
b.erosion hazard	medium	medium	low

Table 4.3 Continued..

c: Crop requirements Citrus and Pasture grasses

Land quality/characteristics	Citrus	Chloris gayana	Cenchrus ciliaris
1. Radiation regime			
a. Day length for flowering	day neutral	short day	day neutral
2. Temperature regime:			
a. Optimum temperature	23 - 30	26 - 40	25 - 40
b. Absolute temperature	13 - 35	8 - 50	8 - 50
3.Moisture availability			
a. growing length (days)	240- 365	60- 365	60 - 365
b. drought resistance (Ky)	med(1.1)	high(0.70)	high(0.7)
c.rainfall (growing period)	900 - 1200	650 -1600	350-1600
4. Oxygen availability:			
a.water table (cm)	100	30	30
b.tolerance to water logging	low	med/high	med/high
5. Nutrients: a.nutrient need	low/high	low/high	med./high
b. N:P:K (min. kg/ha)	100:35:50	100:35:25	100:35:25
c. pH opt. range	6.5-7.5	5.0-7.0	5.0-7.0
pH abs. range	5.0-8.0	4.5-7.5	4.5-8.0
d. N% high	>0.5	>0.5	>0.5
medium	0.5-0.2	0.5-0.2	0.5-0.2 <
low)	< 0.2	<0.2	0.2
e. P (ppm) high	> 8	>8	> 8
med.	5-7	5-7	5-7
low.)	< 4	<4	< 4
6. Rooting :a. Depth (cm)	100-200	240	250
b.Main water uptake roots(cm)	120-160	30-450	30-450
c. soil texture	medium	med./loose	light/med.
d. soil consistence	shallow	deep	deep
e. rooting pattern	60% in <50 cm 30% in 50-100 cm	extensive capable of deep water extraction	extensive deep water extraction
7.Condition for seed germination: a. soil texture	med/course	loam	loam
b. soil consistence			
8.excess of salts:			
a.sodicity ESP% s1=v.low	<2	<10	<10
s2=low.	2-10	10-25	10-15
s3=high)	10-15	25-60	15-35
b.Salinity ms/cm=s1	< 1.8	< 8.5	<8.0
s2	1.8-3.0	8.5-11	8.0-10
s3	3.0-4.8	11-15	10-16
9. Pest and diseases:	Aphids	Aphids	
11.Soil erosion:			
a.crop factor	0.3	0.01	0.01
b.erosion hazard	medium	high	high

Table 4.3 Continued...
d: Crop requirements : Coffee, Banana, Sorghum

Land quality/characteristics	Crop type		
	Coffee (arabica)	Banana	Sorghum
1. Radiation regime a. Day length for flowering	short day	day neutral	neutral/ short day
2. Temperature regime:			
a. Optimum temperature	15 - 25	23 - 30	24 - 30
b. Absolute temperature	10 - 30	15 - 35	15- 40
3.Moisture availability			
a. growing length (days)	365	240- 365	100-140+
b. drought resistance (Ky)	med.(1.1)	low(1.2)	high(0.9)
c. rainfall (growing period)	750 - 2500	1200- 2200	450 -650
4. Oxygen availability:			
a. water table (cm)	100	100	50
b. tolerance to water logging	low	low	med/high
5. Nutrients requirement:			
a. nutrient need	med./high	low/high	medium
b. N:P:K(min.kg/ha)	135:35:145	200:45:240	100:20:35
c. pH opt. range	5.0-6.0	5.5-7.0	5.5-7.0
pH abs. range	4.5-7.0	5.0-7.5	5.0-8.5
d. N% high	>0.5	>0.5	>0.5
medium	0.2-0.05,	0.5-0.2	0.5-0.2
low)	< 0.05	<0.2	<0.2
e. P (ppm) high	>8	>8	>8
medium	5-7	5-7	5-7
low	2-4	<4	<4
6. Rooting: a. Depth (cm)	200	< 90	100-200
b. Main nutrient-water uptake	75-120	50-75	70-200
c. soil texture	medium	med/course	versatile
e. rooting pattern	80% in top 110cm	60% of water uptake in top 30 cm	60-90% of water uptake in top 100 cm
7.Condition for ripening: RH%			
8.Condition forseed germination a. soil texture	med./course	med/course	loam / light clay
9. excess of salts:			
a. sodicity ESP% s1=v.low,	<2	<2	<10
s2=low	2-6	2-6	11-15
s3=high	6-15	6-15	15-25
b. Salinity mS/cm s1	<1.1,	< 1.0,	<7.4
s2	1.1-1.3,	1.0-1.5	7.4-8.4
s3	1.3-3.0	1.5-3.0	8.4-11
10. Pest and diseases	fungi, aphids	Nematodes, weevil, panama wilt	fungi for late crops
12. Soil erosion: a.crop factor	0.8	0.3	0.7
b. erosion hazard	medium	medium	high

Table 4.3 Continued...
e. Crop requirements: Legume pasture

Land quality	Greenleaf Desmodium	Glycine wightii	Siratro
1. Radiation regime			
a.Day length-flowering	short day	short day	short day
2. Temperature regime:			
a. Optimum temperature	25 - 30	22 - 27	26 - 30
b. Absolute temperature	13 - 35	13- 35	14- 40
3.Moisture availability			
a. growing length (days)	240- 365	60- 365	60 - 365
b.drought resistance (Ky)	med.(1.1)	high(0.85)	high(0.85)
c. rainfall (growing)	875 - 3500	750 -1500	610-1600
4. Oxygen availability:			
a.water table (cm)	50	50	50
b.toler.to water logging	med./high	low	low
5. Nutrients requirement:			
a. nutrient need	low/high	high	low/balance
b. N:P:K(min. kg/ha)	20:40:80	100:35:25	50:35:25
c. pH opt. range	6.5-7.5	5.0-7.0	5.0-7.0
pH abs. range	5.0-8.0	4.5-7.5	4.5-8.0
d. N% high	>0.5	>0.5	>0.5
med.	0.5-0.2	0.5-0.2	0.5-0.2
low	<0.2	<0.2	<0.2
e. P (ppm) high.	>8	>8	>8
medium	5-7	5-7	5-7
low	<4	<4	<4
6. Rooting:a. Depth (cm)	100-150	100-200	150-250.
a. Main nutrient uptake	60-100	50-100	50-450
b. soil texture	med./ light	light/med.	versatile
c. rooting pattern	roots concentrated in top 30 cm	deep extensive deep water extraction	deep extensive deep water extraction
8.Condition for germination:			
a. soil texture	versatile	loam	loam
9.excess of salts:			
a.sodicity ESP: s1=v.low.	<10	<10	<10
s2=low	10-15	10-25	10-15
s3=high	15-30.	25-60	15-35
b.Salinity mS/cm s1	<1.5.	<8.5	<8.0
s2	1.5-2.5.	8.5-11	8.0-10
s3	2.5-6.8.	11-15	10-16
10. Pest and diseases:	Weevil. moles Nematodes (very resistance)	Weevil. nematodes. aphids	Nematodes rhizoctania solani(root rot) under v.wet cond.
12. Soil erosion:			
a. crop factor	0.1	0.3	0.3
b. erosion hazard	low	high	high

Table 4.3 Continued...
f: crop requirements: Fodder grasses

Land quality/Characteristics	Pennisetum purpureum	Tripsacum laxum	Setaria splendida
1. Radiation regime a. Day length for flowering	Short day	short day	short day
2. Temperature regime:			
b. Optimum temperature	20 - 30	22 - 30	24 - 30
c. Absolute temperature	10 - 40	15 - 40	18- 40
3.Moisture availability			
a. growing length (days)	120-365	120- 365	56- 105
b. drought resistance (Ky)	low.(1.2)	low(1.1)	high(0.81
c. rainfall (growing period)	850 - 2500	850 - 1650	650 -1250
4. Oxygen availability:a.water table (cm)	1.2	1.5	50
b.tolerance to water logging	moderate	v. low	low
5. Nutrients requirement:a. nutrient need	med./high	low/high	high
b. N:P:K (kg/ha)	100:20:125	200:80:40	55:35:25
c. pH opt. range	6.5-7.5	6.5-7.5	5.0-7.0
pH abs. range	6.0-8.0	5.0-8.0	4.5-7.5
d. N% : high	>0.5	>0.5	>0.5
medium.	0.2-0.05	0.5-0.2.	0.5-0.2.
low)	< 0.05	<0.2	< 0.2
e. P (ppm) high	> 8	>8	>8
medium	5-7	5-7	5-7
low	2-4	<4	<4
6. Rooting condition:a. Depth (cm)	>100	100-150	60-120
b. Main nutrient uptake roots(cm)	85-200	80-100	50-100
c. soil texture	medium	medium	light/med
d. rooting pattern	deep extensive deep water extraction	roots concentr. in top 50 cm	extensive extra-ction
7.Condition for ripening: RH%	cool 10 -20°C	Dry. sun	dry weather
8.Condition for seed germination a. soil texture	fine/medium	deep friable	sand loam clay loam
9.excess of salts:			
a. sodicity ESP% s1=v.low	<9	<9	<10
s2=low	10-15	10-15	10-25
s3=high	15-25	15-25.	25-60
b.Salinity ms/cm s1	<2.0	<3.4	< 5.5
s2	2.0-5.0	3.4-4.9	5.5-11
s3	5.4-12	5.0-12	11-15
10. Pest and diseases: a. pests b. diseases	Nematodes. moles. fungi	moles nematodes	head blast birds moles
12. Soil erosion: a.crop factor	0.1	0.1	0.6
b.erosion hazard	low	low	high

4.3 Results for land qualities and land characteristics

The land qualities and characteristics required in conversion tables in section 3.6 for land suitability assessment were determined from land resource survey data. The results are presented in Table 4.3. The procedures and sample calculations used to find these results are presented in Appendix 7.2.

As can be gathered from the agro-climatic data relevant presented in Tables 3.1a and 3.1b, the decad rainfall coefficient of variation (Cv) in the area ranges from 48 % in May to 230% in September. This variation indicates that the rainfall in the area is not normally distributed. The higher seasonal variability of rainfall (Fig 4.1) in space and time in the area is largely due to local variation of onset and end of rain season rather than the lack of long term rainfall data (FAO, 1983; Kassase, 1992; Kingamkono, 1993). Consequently, the assessment of moisture availability should base on individual season in order to avoid the time variability error for the start and end of rain season.

The moisture availability (Fig. 4.2) determined by soil water balance method indicates that the Mollic Andosols soil can support crops after the end of rain season by more days than the Eutric Fluvisol soil, and Pellic Vertisols. The length of rainfall seasons is less than the soils moisture availability growing period in all soils.

As can be gathered from Table 4.4, the moisture availability growing seasons for season A exceed the annual crops growing cycle in all soil types. This indicates that moisture availability is not a limiting factor for annual crops in the area. However, the actual crop root depth and crop coefficient should be used in the water balance model, to ascertain this argument.

The soil degradation hazard based on soil productive lifespan in years in Table 4.6 and the soil erosion hazard in Table 4.5, gives different interpretations of the results, although all results were estimated by using the same USLE parameters. The results in Table 4.5 show that soil erosion is minimum in land unit 11C2 (Pellic Vertisols), however, when its shallow soil depth is considered its erosion hazard becomes highest (Table 4.6).

Table 4.7 show that the risk for pest and diseases especially ground moles and nematodes is high in fine friable and well aerated soils in land units 34B1 and 14C1 than in heavy clay in land unit 11C2. However, the effect of pests and diseases were found to be not of economic significant for all crops.

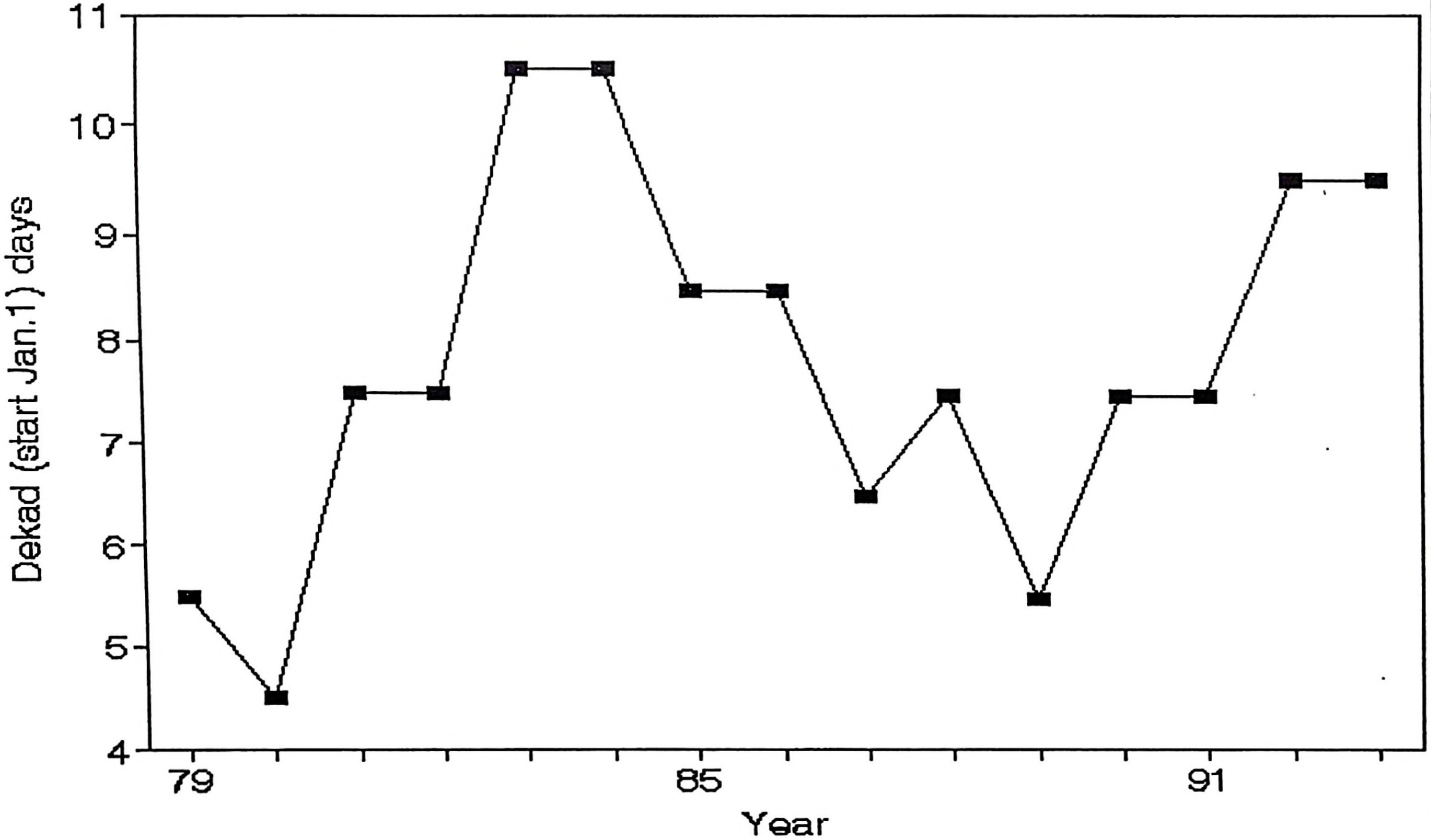


Fig. 4.2: Start of main season

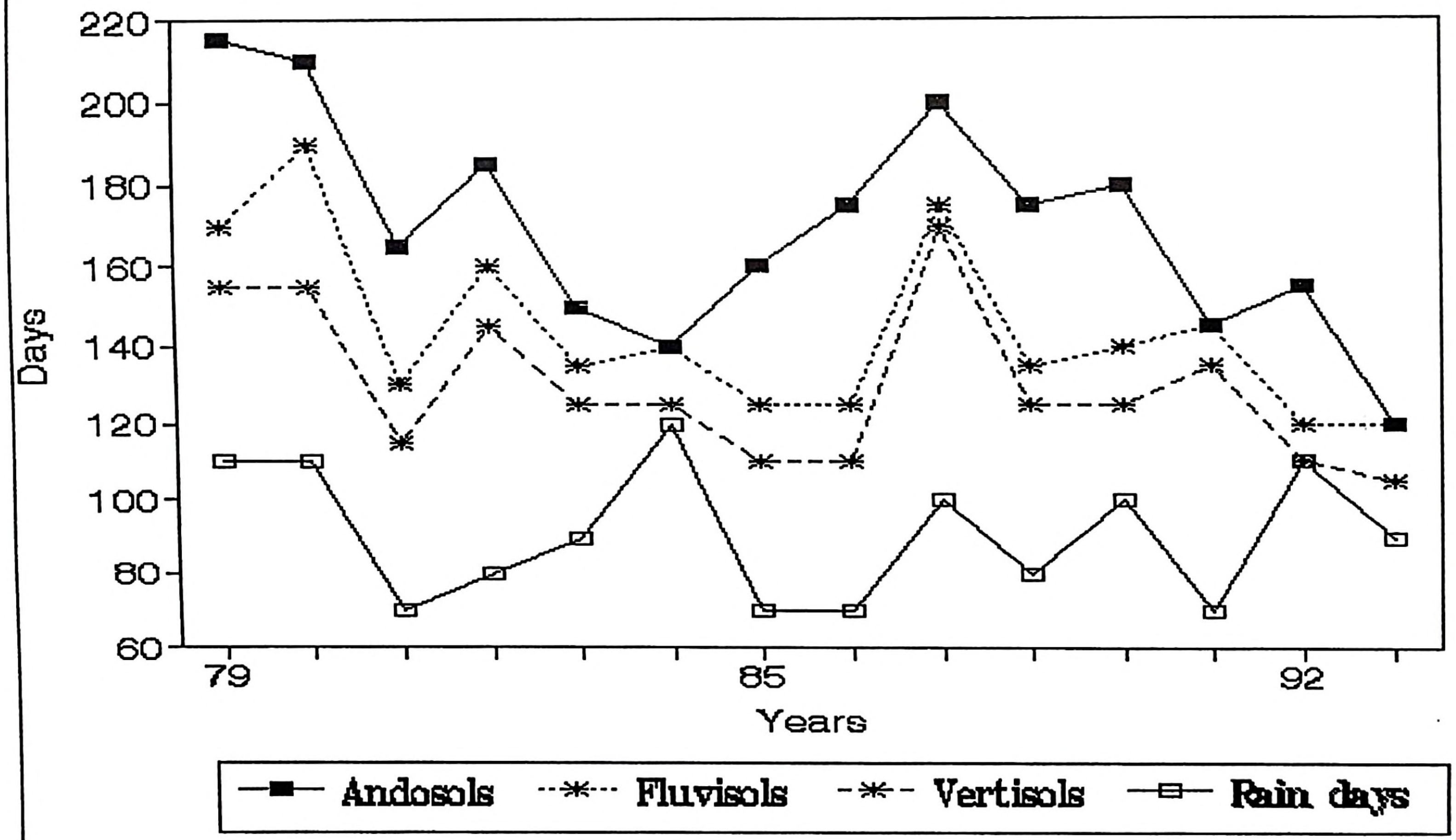


Fig. 4.3: Main season growing length

4.3 Results for land qualities and land characteristics

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The soil degradation hazard based on soil productive lifespan in years in Table 4.6 and the soil erosion hazard in Table 4.5, gives different interpretations of the results, although all results were estimated by using the same USLE parameters. The results in Table 4.5 show that soil erosion is minimum in land unit 11C2 (Pellic Vertisols), however, when its shallow soil depth is considered its erosion hazard becomes highest (Table 4.6).

Table 4.7 show that the risk for pest and diseases especially ground moles and nematodes is high in fine friable and well aerated soils in land units 34B1 and 14C1 than in heavy clay in land unit 11C2. However, the effect of pests and diseases were found to be not of economic significant for all crops.

Table 4.4 Crop moisture availability

Land utilization type (LUT) or crop	Crop growing cycle (medium variety)	Fa= Probability of exceedence for different land unit %		
		34B1 (Tm)	14C1 (Je)	11C2 (Vp)
LUT A: Maize#	120	96	93	65
LUT B: Beans#	100	100	100	82
LUT C: Sunflower#	110	100	100	82
LUT D: Sorghum#	120	96	93	65
LUT E: Onion#	120	96	96	65
LUT F: Cabbage#	120	96	96	65
LUT G: Tomato#	110	100	100	82
LUT H: Banana*	250+	42	25	11
LUT I: Arabica coffee*	230+	65	31	19
LUT J: Citrus*	230+	65	31	19
LUT K: C. gayana (Rhodes)*	150+	100	100	100
LUT L: C. ciliaris (Buffel)*	150+	100	100	100
LUT M: M. Sativa (lucerne)*	180+	100	80	73
LUT N: Desmodium intortum*	210+	89	65	35
LUT O: N. wightii (Glycine)*	180+	100	80	73
LUT P: M. atropurpureum* (Siratro)	180+	100	80	73
LUT Q: P.purpureum*	250+	42	25	11
LUT R: T. laxum*	210+	89	65	35
LUT S: Setaria splendida#	100	100	100	96

NB: # Main rain season (A) moisture was used for annual crops.
* Total annual moisture was used for perennial crops

Table 4.5 Soil erosion hazard

LUT or Crop type	Crop (C) conse-rvation coefficient (USLE)*	Soil loss A=RKLS*C (t/ha/year)		
		34B1 (Tm) RKLS= 272	14C1 (Je) RKLS=64	11C2 (Vp) RKLS=40.7
LUT A	0.7	190.4	45	28.5
LUT B	0.4	108.8	25.6	16.3
LUT C	0.6	163.2	38.4	24.4
LUT D	0.7	190.4	45	28.5
LUT E	0.3	81.6	19.2	12.21
LUT F	0.3	81.6	19.2	12.21
LUT G	0.2	54.4	12.8	8.1
LUT H	0.3	81.6	19.2	12.2
LUT I	0.8	217.6	51.2	32.6
LUT J	0.3	81.6	19.2	12.2
LUT K	0.01	2.72	0.6	0.4
LUT L	0.01	2.72	0.6	0.4
LUT M	0.1	27.2	6.4	4.1
LUT N	0.1	27.2	6.4	4.1
LUT O	0.3	81.6	19.2	12.2
LUT P	0.3	81.6	19.2	12.2
LUT Q	0.1	27.2	6.4	4.1
LUT R	0.1	27.2	6.4	4.1
LUT S	0.6	190.4	38.4	24.4

* Source: Roose (1977)

Table 4.6 Soil productive lifespan for different land uses

LUT or Crop type	Crop coeff. (C)[1]	Marginal root depth= ERD (cm)	Soil lifespan= (SRD-ERD)/RKLSC (years) Land unit (soil type) 34B1 (Tm) RKLS=3.13 cm/yr SRD = 130 cm	14C1(Je) RKLS=0.53 cm/yr SRD=145 cm	11C2 (Vp) RKLS=0.32 cm/yr SRD=75 cm
A	0.7	50	36	215	111
B	0.4	50	51	448	208
C	0.6	70	31	236	28
D	0.7	50	36	215	111
E	0.3	30	105	723	500
F	0.3	40	95	660	389
G	0.2	60	110	802	250
H	0.3	50	69	597	278
I	0.8	70	24	177	21
J	0.3	70	63	472	56
K	0.01	30	3164	21694	15000
L	0.01	30	3164	21694	15000
M	0.1	70	190	1415	167
N	0.1	70	190	1415	167
O	0.3	60	74	534	167
P	0.3	65	69	503	111
Q	0.1	70	190	1415	167
R	0.1	50	206	1792	833
S	0.6	50	34	298	140

[1] Source: Roose (1977); Skerman (1990);Landon (1991).

Table 4.7 Mapping unit land qualities

Land quality/characteristics	unit	Soil/land unit factor rating: mollic Andosols	eutric Fluvisols	pellic Vertisols
1. Radiation regime:	photoperiod	short day	short day	short day
a. Day length (flowering)				
2. Temperature regime:a:growing season	season	A B	A B	A B
A&B	centigrade	19.0 21.3	19.0 21.3	19.0 21.3
b. mean growing season temp.	centigrade	17.7 21.1	17.7 21.1	17.7 21.1
c. min. growing season temp.	hrs/day	4 7.0	4 7.0	4 7.0
d. sunshine hours flowering period				
3. Moisture availability		T A B	T A B	T A B
a. 75% dependable growing length	days	215 150	190 125	180 115
b. drought hazard	drought			
c. effective mean rainfall	index			
	mm/season			
4. Oxygen availability:a. water table	min.in cm	300	200	150
b. Drainage class		well	moderate	poor
c. infiltration rate	cm/hr	9.0	5.6	< 1 cm/hr
5. Nutrients requirement:a. nutrient status		high	high	high/balance
b. CEC	me/100g soil	47	34.5	d
c. Soil reaction or mean pH	pH 1:2.5	6.1	6.0	52
d. total Nitrogen	H_2O	0.3	0.17	7.0
e. available phosphorus	%	97	88	0.18
f. Cation ratio i. K:CEC	ppm (Olsen)	1:16	1:17	8.0
ii. Ca:Mg		3.8:1	3.1:1	1:34
iii. Mg:K		1.6:1	2.2:1	2.7:1
g. Organic Carbon		4.3	1.9	6:1
h. Sum of Cation	%	26.5	22.0	2.7
i. Base saturation	me/100g soil	57	62	35.5
	%			75
6. Nutrient retention capacity:				
a. total exchangeable bases (TEB)	me/100g soil	26.8	21.4	39
b. Weatherable minerals	%			
7. Rooting condition:a. bulk density	g cm^{-3}	0.86	1.2	1.5
b. Effective soil depth	cm	130+	145	75
c. Moist soil consistence	-	v. friable	friable	Ext.firm
d. gravels or and stones in root zone	%	few	frequent below 85 cm	Very few
8. Condition for ripening:Season		A B	A B	A B
a: Relative Humidity (RH%)	%	72 65	72 65	72 65
b: Rainfall (mean) at maturity stage	mm/decade	6.5 5.5	6.5 5.5	6.5 5.5

Table 4.7 Continued...

9.Condition for germination & establishment: a. soil texture 0-20 cm b. soil consistence 0-20 cm		silt clay loam. v.friable and fine.	silt clay. friable and moderate fine.	clay v.firm, strong aggregate
10. Excess of salts: a.sodicity in exchangeable sodium % b.Salinity (EC-saturation soil extract)	% mS/cm	1.7 0.08	2.75 0.08	6 0.3
11. Pest and diseases: a. pests b. diseases		nematodes moles, Aphids fungi	nematodes moles, aphids, fungi	Aphids and fungi.
12. Soil workability: a. Stone b. rock outcrop c. soil texture/ consistence	% %	<15 <10 light, loose to very friable	<5 < 2 medium firm to friable	< 5 < 2 medium to heavy, and very firm
13. Potential for mechanisation: a. slope b. Stone (top 30 cm) c. Clay content	% % %	9 15 31	4 < 5 48	2.7 < 5 70
14. Degradation hazard a: Soil lifespan index b: hazard to compaction		medium	high	v. high
15. Soil toxicities a:presence of calcarious horizon (depth)	cm	none	145	75
16. Soil erosion: a.USLE soil loss A=KLSCP Where C & P =1 b.erosion hazard by field observation	t/ha/annual	272 very high	64 high	41 low

4.4 Results for land suitability classification

4.4.1 General results

Results for the preliminary matching of the land use requirements with the land qualities are presented in Tables 4.8a - 4.8f. and Map 2.

The common limitations in all land units are: inadequate moisture availability for perennial crops; low level of total Nitrogen; pests and diseases and soil erosion hazard. The moisture stress is more serious to perennial crops with shallow effective rooting depth. The effect of moisture stress for deep rooted perennial crops is mainly poor yields rather than crop failure. Consequently, all perennial crops need supplementary irrigation for optimum production.

Pests and diseases are another limitation to some of the crops such as tomato, coffee, beans, banana, and lucerne especially during humid and wet season. Common pests in the area include ground moles, mites, and nematodes. Common diseases include fungal and virus diseases transmitted by aphids. However, damages and yield losses caused by pests and diseases are not of economic significance as the control methods used are very effective and cheap economically. However Tomato grown during the main wet season is highly vulnerable to pests and diseases such that only farmers who can afford high management and frequent chemical application take the risk.

Except for the head sterility caused by cool temperature to sorghum and rice paddy tussling during late June and July, temperature is not a serious limiting factor for crop production in the area. The mean minimum and maximum temperature were found to agree with the field crop performance in assessment of temperature regime than the mean temperature proposed in the FAO (1984) guidelines. This is probably due to the use of crops (varieties) adapted to the area.

4.4.2 Land suitability classification for land unit 34B1

The land characteristics for this mapping unit are described in section 4.1.1. The land suitability classification for the 19 LUTs is presented in Table 4.8a.

This mapping unit is classified as marginally suitable (S3) for rainfed maize, beans, sorghum, sunflower, vegetables, and banana due to soil erosion hazard and buried stones which may hinder tractor tillage operations. It is classified as marginally suitable to coffee, banana and elephant grass production due to inadequate moisture availability and soil erosion hazard. It is moderately suitable for pasture grasses due to erosion hazard. It is moderately suitable to some legumes such as Glycine wightii, Desmodium intortum, Siratro, and fodder grasses such as Guatemala grass (Tripsacum laxum), and giant setaria due to moisture availability.

The use of low velocity farming implements such as ox-drawn implements is recommended for tillage in this mapping unit. Biological and physical soil conservation methods (Morgan, 1986) can be integrated in crop production to control soil erosion hazard. Soil water conservation techniques (FAO, 1987; Flug, 1981) and supplementary irrigation may be applied to correct soil moisture deficit for perennial crops. Therefore if the above land improvement can be effected, the climate and soil of this land unit are highly suitable for agriculture production as shown in Map 2.

4.4.3 Land suitability classification for land unit 11C2

The land characteristics of this mapping unit are described in section 4.1.3. Its results for land suitability classification are presented in Table 4.8c and suitability Map 2. This mapping unit is marginally suitable for almost all crops for rainfed agriculture production. It is not suitable for banana, coffee , citrus. It is currently not suitable for maize, sunflower, cabbage, and tomato production.

The common specific limitations for this land unit include: insufficient root depth; the presence of toxic layer ($CaCO_3$) below 75 cm depth , presence of hard pan below 20 cm; the poor soil texture and structure for root development and crop germination; difficulty in soil workability and mechanisation; high vulnerability to soil compaction and erosion hazards; poor oxygen availability due to poor drainage. Furthermore, this land unit has moderately high exchangeable sodium level for sodium sensitive crops. There is also fertility problem due to deficiency in available phosphorus, potassium and total nitrogen. However the effect of ground moles and nematodes on crops in this unit is low compared to other land units.

The results for land suitability classification after minor land improvements are presented Map 2. The soil structure and texture can be improved by subsoil deep tillage and ripping integrated with manuring and mulching (FAO,1983). Proper drainage system and management is necessary if irrigation is to be used in order to avoid salinity problem. For irrigation , a fallow is recommended as a standard practice, as cracks developed due to fallowing are very effective in initial wetting of the soil. Crops with shallow root depth and tolerant to water logging such as Sorghum, rice paddy, and some grass and legume pastures are recommended for this land unit. NPK fertilizer is recommended for optimum crop performance.

4.4.4 Land suitability classification for land unit 14C1.

The land characteristics of this mapping unit are described in section 4.1.2. The results for land suitability classification for this land unit are presented in Table 4.8b and suitability Map 2.

This mapping unit is highly suitable for onion production. It is marginally suitable for coffee and banana production due to moisture limitations. It is moderately suitable to the rest of the 19 crops considered. Major limitations include soil erosion, soil compaction hazard and pests and diseases. However most of these limitations can be corrected at reasonable costs. The results in Table 4.8b show that this land unit is highly suitable for crop production after minor land improvements.

Table 4.8 Suitability classifications

Table 4.8a. Suitability classification for land unit 34B1

Land Quality	Land utilization types (Crops)									Wt
	A	B	C	D	E	F	G	H	I	
LQ1: Radiation regime	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ2: Temperature regime	s1	s1	s1	s2	s1	s1	s1	s1	s1	1
LQ3: Moisture availability	s1	s1	s1	s1	s1	s1	s1	s3m	s3m	5
LQ4: Oxygen availability	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
LQ5: Nutrient requirements	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ6: Rooting condition	s1	s1	s1	s1	s1	s1	s1	s1	s1	4
LQ7: Condition for ripening	s2i	s2i	s2i	s2i	s1	s1	s3i	s1	s1	2
LQ8: Soil workability	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ9: Excess of salts	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
LQ10: Pests and diseases	s1	s2v	s1	s1	s1	s2v	s3v	s2v	s2v	2
LQ11: Soil erosion hazard	s3	s3	s3	s3	s3	s3	s3	s3	s3	3
LQ12: Nutrient retention	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ13: Condition for germination	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ14: Potential for mechanisation	s2s	s2s	s2s	s2s	s2s	s2s	s2s	s1	s2	2
LQ15: Land degradation	s2e	s2e	s2e	s2e	s2e	s2e	s2e	s2e	s3e	4
LQ16: Soil toxicity	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
Total Score:	124	122	124	124	126	124	118	116	110	
Overall class	s3es	S3es	S3es	S3es	S2es	S3es	S3ev	S3me	S3me	46

Table 4.8a Suitability for land unit 34B1 (continued...)

Land Quality	Land utilization types (Crops)										
	J	K	L	M	N	O	P	Q	R	S	
LQ1: Radiation regime	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ2: Temperature regime	s1	s1	s1	s2	s1	s1	s1	s2	s1	s2	1
LQ3: Moisture availability	s2	s2	s2	s2	s2	s2	s2	s3m	s2	s1	5
LQ4: Oxygen availability	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
LQ5: Nutrient requirements	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ6: Rooting condition	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	4
LQ7: Condition for ripening	s1	s1	s1	s1	s1	s1	s2i	s1	s1	s1	2
LQ8: Soil workability	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ9: Excess of salts	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
LQ10: Pests and diseases	s2	s2	s1	s2	s1	s2	s3	s2	s1	s3	3
LQ11: Soil erosion hazard	s3e	s1	s3	s3	s2	s1	s1	s2	s2	s3	2
LQ12: Nutrient retention	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ13: Condition for germination	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ14: Potential for mechanisation	s1	s1	s1	s1	s1	s1	s1	s2	s2	s2	2
LQ15: Land degradation	s2	s1	s1	s1	s1	s1	s1	s1	s1	s1	4
LQ16: Soil toxicity	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
Total Score:	123	133	133	124	130	131	125	121	128	129	7
Overall class	S3em	S2m	S2m	S3em	S2em	S2me	S3mi	S3me	S2m	S2e	46

Table 4.8b Suitability classification for land unit 14C1

Land Quality	Land utilization types (Crops)									Wt
	A	B	C	D	E	F	G	H	I	
LQ1: Radiation regime	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ2: Temperature regime	s1	s1	s1	s2	s1	s1	s1	s1	s1	1
LQ3: Moisture availability	s1	s1	s1	s1	s1	s1	s1	s3m	s3m	5
LQ4: Oxygen availability	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
LQ5: Nutrient requirements	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ6: Rooting condition	s1	s1	s1	s1	s1	s1	s1	s1	s1	4
LQ7: Condition for ripening	s2i	s2i	s2i	s2i	s1	s1	s3i	s1	s1	2
LQ8: Soil workability	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ9: Excess of salts	s1	s1	s1	s1	s1	s1	s1	s2n	s2n	5
LQ10: Pests and diseases	s1	s2	s1	s1	s1	s2	s3	s2	s2	2
LQ11: Soil erosion hazard	s3	s2	s3	s3	s2	s2	s1	s2	s3	3
LQ12: Nutrient retention	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ13: Condition for germination	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ14: Potential for mechanisation	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ15: Land degradation	s1	s1	s1	s1	s1	s1	s1	s1	s1	4
LQ16: Soil toxicity	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
Total Score:	130	131	134	132	135	133	130	120	115	7
Overall class	S2e	S2ev	S2e	S2e	S1	S2ev	S2ei	S3em	S3em	46

Table 4.8b Suitability for land unit 14C1 (Continued....)

Land Quality	Land utilization types (Crops)										
	J	K	L	M	N	O	P	Q	R	S	
LQ1: Radiation regime	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ2: Temperature regime	s1	s1	s1	s1	s2	s1	s1	s2	s1	s2	1
LQ3: Moisture availability	s3m	s2m	s2m	s2g	s2g	s2	s1	s3m	s2m	s1	5
LQ4: Oxygen availability	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
LQ5: Nutrient requirements	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ6: Rooting condition	s1	s1	s1	s2	s1	s1	s1	s1	s1	s1	4
LQ7: Condition for ripening	s1	s1	s1	s1	s1	s1	s2i	s1	s1	s1	2
LQ8: Soil workability	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ9: Excess of salts	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
LQ10: Soil erosion hazard	s1	s1	s1	s1	s1	s2e	s2e	s1	s1	s3e	3
LQ11: Nutrient retention	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ12: Pests and diseases	s2v	s1	s1	s2v	s1	s2	s2	s2	s1	s1	2
LQ13: Condition for germination	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ14: Potential for mechanisation	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ15: Land degradation	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	4
LQ16: Soil toxicity	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
Total Score:	126	133	133	130	133	128	126	125	133	131	7
Overall class	s2m	S2m	S2m	S2m	S2m	S2me	S2me	S3m	S2m	S2e	46

Table 4.8c Suitability classification for land unit 11C2

Land Quality	Land utilization types (Crops)									Wt
	A	B	C	D	E	F	G	H	I	
LQ1: Radiation regime	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ2: Temperature regime	s1	s1	s1	s2	s1	s1	s1	s1	s1	1
LQ3: Moisture availability	s1	s1	s1	s1	s1	s1	s1	N1	s3m	5
LQ4: Oxygen availability	s3d	s3	s3	s2	s3	s3	s3	sw	s2	5
LQ5: Nutrient requirements	s2	s1	s1	s1	s2	s2	s2	s2	s2	2
LQ6: Rooting condition	s3r	s3	s3	s3	s3	s3	s3	s3	s3	4
LQ7: Condition for ripening	s2	s2i	s2i	s2i	s1	s1	s3i	s1	s1	2
LQ8: Soil workability	s3t	s3	s3	s3	s3	s3	s3	s3	s3	2
LQ9: Excess of salts	s2z	s1	s1	s1	s1	s1	s1	s2z	s2z	5
LQ10: Soil erosion hazard	s2	s2	s2	s2	s2	s2	s1	s1	s3	2
LQ11: Nutrient retention	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ12: Pests and diseases	s1	s2	s1	s2	s1	s2	s1	s1	s1	3
LQ13: Condition for germination	s3t	s3	s3	s2	s3	s3	s3	s1	s1	1
LQ14: Potential for mechanisation	s2	s2	s2	s2	s2	s2	s2	s2	s2	2
LQ15: Land degradation	s3e	s1	s3	s3	s1	s1	s1	s1	s3e	4
LQ16: Soil toxicity	s2	s1	s2	s1	s1	s1	s2	s3	n1	5
Total Score:	85	105	94	103	104	105	99	75	68	
Overall class	N1	S3	N1	S3	S3	S3	N1	N2	N2	

Table 4.8c Suitability for land unit 11C2 (Continued...)

Land Quality	Land utilization types (Crops)										wt
	J	K	L	M	N	O	P	Q	R	S	
LQ1: Radiation regime	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ2: Temperature regime	s1	s1	s1	s2	s1	s1	s1	s2	s1	s2	1
LQ3: Moisture availability	N1m	s1	s1	s2	s3	s2	s2	N1m	s3	s1	5
LQ4: Oxygen availability	s3w	s2	s2	s3	s2	s3	s3	s3	s3	s3	5
LQ5: Nutrient requirements	s1	s1	s1	s2	s1	s1	s1	s2	s2	s1	2
LQ6: Rooting condition	s3r	s2	s2	s3	s3	s3	s3	s3	s3	s2	4
LQ7: Condition for ripening	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	2
LQ8: Soil workability	s3t	s2	s2	s2	s2	s2	s2	s3	s3	s3	2
LQ9: Excess of salts	s2z	s1	s1	s1	s1	s1	s1	s1	s1	s1	5
LQ10: Soil erosion hazard	s1	s1	s1	s1	s1	s1	s1	s1	s1	s2	2
LQ11: Nutrient retention	s1	s1	s1	s1	s1	s1	s1	s1	s1	s1	1
LQ12: Pests and diseases	s2	s1	s1	s2	s1	s1	s1	s1	s1	s1	3
LQ13: Condition for germination	s1	s2	s2	s2	s2	s2	s2	s1	s1	s2	1
LQ14: Potential for mechanisation	s2s	s1	s1	s1	s1	s1	s1	s1	s1	s2	2
LQ15: Land degradation	s3e	s1	s1	s1	s1	s1	s2	s1	s1	s2	4
LQ16: Soil toxicity	s3x	s1	s1	s1	s1	s1	s3	s1	s1	s1	5
Total Score:	63	126	126	119	112	112	96	98	104	108	7
Overall class	N2	S2td	S2	S3	S3	S3	N1tx	N1m	S3dr	S3dt	

4.5 Results for social and economic analysis

The gross margin analysis in Table 4.9 show that seed production for legume pastures gives the highest net income per hectare. The market potential for pasture seeds is high in the country and abroad. However, management skills and technology in pasture seed production is lacking among farmers in the area. Consequently, pasture seeds production by LITI Tengeru is highly suitable for technological transfer in the area and economical gain.

Vegetables production ranks second in net farm income generation. Vegetable products are highly marketable in fresh and packed form. However due to lack of vegetables processing factories and conservation techniques in the area , the price fluctuation for fresh product is very high.In addition there is a need to improve local farmers vegetable production management and technology in controlling diseases and pests in order to achieve optimum production. Therefore, vegetables production is vital for HORTI Tengeru technological transfers activities and for maximum economic gain.

Third on the net farm income list is perennial crops such as banana, citrus and coffee. Banana is a staple food crop in the urban and highland zone. It is common in the highland farming system. As a result it is well adapted to the area. The production technology is common among farmers in the area. Consequently, socially its production promotion is moderately suitable for LITI and HORTI activities. Citrus production is not very common in the area .

Table 4.9 **Net farm income for different land uses**

Crop type		Production cost Tshs/ha	Gross income Tshs/ha	Net farm income Tshs/ha
LUT A: Maize		161 000	210 000	49 000
LUT B: Beans		136 000	225 000	88 150
LUT A/B: Maize/Bean intercropping		169 855	300 000	130 145
C: Sunflower		127 027	180 000	52 925
D: Sorghum		115 000	180 000	65 000
E: Tomato		242 400	1 000 000	757 000
F: Cabbage		218 400	1 500 000	1 281 600
G: Onion		231 000	1 500 000	1 269 000
H: Arabica coffee		282 000	900 000	618 000
I: Banana		217 000	1 250 000	1 032 000
J: Citrus		210 000	1 200 000	990 000
K: Chloris gayana	Greem Matter (GM)	144 000	600 000	456 000
	Seed	159 600	900 000	740 000
L: Cenchrus ciliasis	(GM)	144 000	600 000	453 000
	Seed	159 600	900 000	740 000
M:Lucerne (Medicago sativa)	GM	171 750	500 000	328 000
	Seed	187 350	2 000 000	1 812 650
N: Desmodium Intortum	GM	127 950	350 000	222 050
	Seed	142 350	1 500 000	1 357 050
O: Glycine wightii	GM	124 450	500 000	373 550
	Seed	140 850	1 500 000	1 359 150
P: Siratro	GM	124 450	300 000	373 550
	Seed	160 050	3 000 000	2 839 950
Q: P. Purpurium	GM	225 600	400 000	174 400
R: T. laxum	GM	225 600	400 000	174 400
S: Setaria splendida	GM	120 600	400 000	279 400
	Seed	156 000	1 600 000	1 444 000

Research trials at HORTI Tengeru show that, under good management, citrus thrives well in the area. Citrus fruits are highly marketable. Therefore, production and processing technologies are necessary in promoting Citrus expansion in the area. Hence, socio-economically, citrus production is highly suitable in HORTI Tengeru activities and in the area.

Coffee is a traditional cash crop in the area. It has a well organised production and marketing system. Since, Lyamungu Agricultural Research Institute is the one involved in Coffee research and development in the area, then Coffee is moderately suitable in HORTI and LITI activities.

Pasture production for fodder and forage is one of the new and lucrative business in the area. It is highly profitable (Table 4.9). Grass and legume fodder are highly marketable in green hay and in processed form (silage). The high demand for pasture fodder is due to the current promotion and expansion of dairy cattle farming under zero grazing in the area. The promotion of dairy cattle farming was introduced in the area by soil conservation projects for conservation and destocking purposes. Other factors contributing to fodder demands include: the high demand of milk and milk products in Arusha town; the reduction of grazing area due to expansion of cultivated area , and overgrazing of those areas left (ICRA-SARI, 1993).
Pasture improvement and research are important in promoting dairy farming, soil conservation and economic activities in the area. Therefore, fodder production was rated as highly suitable economically and socially in LITI activities.

Maize, beans , sorghum and sunflower have the lowest net farm income (Table 4.9). These crops are classified as moderately suitable economically. Maize and beans are the staple food and major crops cultivated in the intermediate and lowland zone (ICRA - SARI, 1993). In all farming systems in the area, protein is provided by beans, milk and occasionally by meat. Milled Maize and Sorghum (Ugali) are the staple food in the semi-arid lowland area. Therefore increased agricultural production of these crops is important for food sufficiency in the area. However, these crops are well adapted in the area, in addition other institutions such as SARI are involved in their development. Therefore, socio-economically the production of maize, beans, sorghum and sunflower are marginally suitable on HORTI and LITI land.

The common limiting factors in the farming system for agricultural development in the area are the low level of farming technology and management skills, low capital for subsistence and intermediate farmers, and land scarcity. There is no hired labour problem for farm work (Laurent and Centres,1988; Nkonya et al., 1991).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 FAO Framework applicability and difficulties

(a) The study has demonstrated that land evaluation using the FAO (1976) Framework is efficient and adaptable to our local environment. However, the system works well if the relevant data are well identified and is collected by using special purpose land resource survey methods.

(b) Some of the procedures proposed in the FAO (1984) guidelines need refinements to match with the actual local environments. The following procedures are recomended in this regard:

(1) The soil water balance method based on individual season and years, as used in this study, be adopted for moisture availability assessment. This method takes into account the high rainfall variability common in the tropics, and it is therefore more suitable than the methods based on the use of agroclimatic data only. In addition, the approach takes into account the assessment of total moisture, drought hazard, and moisture stress during critical periods , hence reducing the difficulties of assessing these aspects separately.

(2) The minimum and maximum temperature be assessed when evaluating land in the tropical areas.

(3) The arithmetic procedure should be applied rigorously in converting land characteristics and land qualities into overall land unit suitability classes for practical land suitability classification.

5.2 Results from LITI farm land evaluation

(a) As most of the soils are deficient in Nitrogen, use of Nitrogen fertilizer is recommended for land unit 34B1 and 14C1. Use of NPK fertilizer is recommended for land unit 11C2. However, the rate and frequency of application should be determined for each crop.

(b) Drainage is recommended for soil unit 11C2. Mulching and organic fertilizers are required to improve soil structure. In addition chiselling to breakdown the fragipan, coupled with thorough mixing with organic matter is suggested for better crop performance.

(c) Since soil erosion is a major limitation in using land unit 34B1, use of biological control is strongly encouraged. In addition, mechanical control should be considered where biological control is inadequate.

(d) Vegetables, pastures and citrus production are economically and socially highly suitable for this farm and whenever possible irrigation should be considered for optimal production.

5.3 Suggestion for future works

a. The field of land evaluation by using FAO (1976) Framework has not been applied in detail and extensively in Tanzania. The following would help towards the achievement of such an aim:

- Experimental sites for testing specific crop requirements and reliable assessments should be set up in major agro-ecological zones.

- Soil erosion is a menace in many areas of this country. Further studies should be conducted to increase the reliability and accuracy of data on soil erosion estimation parameters and control measures.

-Detailed investigations and long term monitoring are required in standardizing and computerizing land quality ratings and conversion tables. This is important to avoid subjective judgements of the land evaluator and variability of some land qualities in time, from one crop to another and from one agro-ecological zone to another.

b. The effect and factors associated with occurrence of clay allophane in the Andosol soils need further investigation.

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7. APPENDICES

Appendix 7.1 Soil survey data

Table 7.1a Soil profile description mapping unit 34B1 Tm-s

Profile no: P7	
Soil classification	FAO: Mollic Andosols
1. SITE	CHARACTERISTICS
Location/date/author	South east of LITI-Tengeru; 50 metres HORTI Tengeru centre; Soil map sheet 1; Dec, 2, 1993; by Mr. Muya M.N.C., D.R. Kissanga, and S.A. Mtali.
Altitude	1245 metres
Landform / physiography	rolling
Drainage	well drained;highly permeable
Parent material	Diluvium derived from volcanic debris, probably reworked Andesite rocks.
Vegetation/Land use	Citrus fruits research plot (HORTI)
Climate	Warm / moderately cool subtropics with summer rainfall Temperature range (mean) 22.2 in march to 17 ^{0}C in july; mean rainfall 1070 mm per annual.

2. PROFILE CHARACTERISTICS

Horizon	Depth (cm)	profile description
Ap	0 - 20	Very dark greyish brown (10 YR 3/2 dry), black (10 YR 2/1 moist) clay loam hozion; soft consistence when dry, very friable when moist and non-plastic non-sticky when wet; weak fine granular structure ; few angular weathered andesite gravels; very good rooting; common moles activities, clear smooth boundary.
Ah	20 - 130	Very dark greyish brown (10YR 3/2 dry), black (10YR 2/1 moist) silt clay loam horizon; slightly hard consistence when dry, very friable when moist and non-plastic non-sticky when wet; many course pores; much moles activities ; good rooting; few weathered buried angular andesite gravels; diffuse irregular boundary.
C	130+	horizon with high concentration of buried weathering volcanic stones. probably andesite; very few fine roots; plenty course pores.

3. SOIL ANALYTICAL DATA PROFILE P7

Depth	Texture	Soil particles %			pH 1:2.5		EC 1:2.5	OC (%)	N (%)
cm	(Lab)	S	Z	C	H_2O	KCl	mS/cm		
0 - 20	ZCL	12	57.3	30.7	6.3	5.7	0.08	3.73	0.3
20 -130	ZCL	16	53	31.0	6.4	5.7	0.06	3.02	0.2

	me/100g of soil)				CEC	BSP	ESP	Avail P
	Na	K	Mg	Ca	me/100g	%	%	ppm
0-20	0.98	3.13	4.5	17.5	49.02	53	2.0	102
20-130	1.33	2.87	6.3	22.0	49.02	66	2.7	71

4. Soil physical properties

Depth (cm)	Bulk density	Lab. Water holding capacity volume moist (v/v %) at:					AWC (%v/v)
	$g\ cm^{-3}$	pF 0	pF 2	pF 2.4	pF 2.7	pF 4.2	pF2.4-pF4.2
0 - 20	0.87	61.13	60.01	58.31	37.76	31.20	27.11
20-130	0.88	58.70	58.57	56.59	35.84	28.69	29.90
85-130+	1.27	49.93	48.98	47.01	37.50	30.84	16.17

Table 7.1c Soil profile description mapping unit 34B1 Tm-s

Profile no: P5	
Soil classification	FAO Mollic Andosols
1. SITE	CHARACTERISTICS
Location/date/author	West of LITI-Tengeru, 250 metres from CAMARTEC - Tengeru road. Soil map sheet 1; Dec 4, 1993; Mr. Muya M.N.C., D.R. Kissanga, and S.A. Mtali.
Altitude	1275 metres
Landform / physiography	minor escarpment/ steep slope.
Drainage	well drained; very permeable
Parent material	Diluvium derived from volcanic debris, probably reworked Andesite rocks.
Vegetation/Land use	Eucalyptus spp. forest and improved pasture, but fortunately eucalyptus spp. secretes poisonous enzymes which drop and kill all vegetations below it, there fore causing severe waterwash erosion in the process.
Climate	Warm / moderately cool subtropics with summer rainfall Temperature range (mean) 22.2 in march to 17 ^{0}C in july; mean rainfall 1070 mm per annual.

2. SITE CHARACTERISTICS

Horizon	Depth (cm)	profile description
Ah	0 - 15	Very dark greyish brown (10 YR 3/2 dry), black (10 YR 2/1 moist) clay loam horizon; highly affected with rill erosion; very soft (dry), very friable (moist) non-plastic non-sticky (wet) consistence; weak single grain to medium subangular blocky structure; frequent fresh angular andesite stones; frequent small soft spherical clay allophane concretions; abundant fine pores and course roots; much moles activities; gradual wavy boundary.
AC	15 - 50	Very dark greyish brown (10YR 3/2 dry), black (10YR 2/1 moist) andesites boulders mixed with clay loam horizon; very soft (dry) very friable (moist) non-sticky non-plastic wet consistence; Weak fine sub-angular structure; very frequent weathered angular andesite boulders; very frequent medium roots; clear irregular boundary; common moderately thick clay films on peds and pore surfaces (clay allophanes).
CA	50 - 80	Very frequent strongly weathered angular volcanic (andesite) buried boulders and other rock fragments; abundant burried stones.

3. SOIL ANALYTICAL DATA PROFILE P5

Depth	Texture	Soil particles %			pH 1:2.5		EC 1:2.5	OC (%)	N (%)
cm	(Lab)	S	Z	C	H_2O	KCl	mS/cm		
0 - 15	CL	25.3	42	32.7	6.1	5.8	0.05	3.4	0.3

Depth cm	Exchangeable Cation (mg/100g soil)				CEC	BSP	ESP	Avail P
	Na	K	Mg	Ca	me/100 g	%	%	ppm
0-15	0.63	2.6	4.5	17.2	48.7	51	1.2	8.0

4. Soil physical properties

Depth (cm)	Bulk density	Lab. Water holding capacity volume moist (v/v %) at:					AWC (%v/v)
	g cm^{-3}	pF 0	pF 2	pF 2.4	pF 2.7	pF 4.2	pF2.4-pF4.2
0 - 15	0.83	64.95	62.42	60.61	43.29	38.73	21.9

Table 7.2a Soil profile description mapping unit 11C2 Vp-a

Profile no: P2

Soil classification FAO Pellic Vertisols

1. SITE CHARACTERISTICS

Location/date/author	South east of LITI-Tengeru; 50 metres from old Moshi - Arusha main road Soil map sheet 1, November 26, 1993; By Muya M.N.C., D.R Kissanga, and Mr. S.A. Mtali.
Altitude	1200 m a.s.l
Landform / physiography	flat plain
Drainage	water ponding during main rain season
Parent material	Alluvial -Vertisols of topographic depression
Vegetation/Land use	improved pasture
Climate	Warm / moderately cool subtropics with summer rainfall temperature range (mean) 22.2_0 C in March to the minimum to 17 ^{0}C in July.

2. PROFILE CHARACTERISTICS

Horizon	Depth (cm)	profile description
Ap	0 - 20	Very dark grey (2.5Y 3/0 dry) black (2.5 Y 2/0 moist) clayey horizon. Few fine brown mottles; extremely hard dry consistency, very firm when moist, sticky and plastic when wet; strong aggregated course sub angular block structure; wide (7.5 cm) vertical cracks partly filled with surface mulch when dry; very few weathered rounded limestone (carbonate) gravels; sign of compaction through human activities and overgrazing; soil show surface crusting.

A1	20 - 50	Very dark grey (2.5Y 3/0 dry) black (2.5Y 2/0 moist) heavy compacted clayey horizon; soil mass takes up water very slowly, swelling in the process; consists of strong aggregated huge sub angular blocks up to 32 cm across separated by vertical cracks up to 7.5 wide; intersecting slikensides prominent; few large hard irregular carbonate concretion with strong effervescence reaction with HCL acid: continuous thick clay mineral and organic matter cutans; some isolated feldspar and agate pebbles; numerous very fine roots; gradual smooth boundary.
AC	50 - 75	Very dark grey (2.5 Y 3/0 dry) black (2.5 Y 2/0 moist) heavy clay horizon; pronounced intersecting slikensides; vertical cracks narrowing with depth; extremely hard consistence, extremely firm moist consistence, very sticky and very plastic when wet; patchy clay mineral cutans; abundant large hard and irregular carbonate concretions, reacting with strong effervescence to HCL acid; soft carbonate powdery increasing with depth,; fairly numerous fine roots; clear smooth boundary.
Cck	75 - 110 +	Grey brown (10YR 5/2 dry) greyish brown (10 YR 4/2 moist) calcareous horizon; slightly hard dry consistence , friable moist consistence and slightly sticky wet consistence; few large hard irregular carbonate concretions in addition to soft powdery free carbonate; several tongues and thin stringers of black clay occurring mainly in the first 10 cm of this horizon; very few fine roots; common fine distinct clear dark brown mottles.

3. SOIL ANALYTICAL DATA

Depth	Texture	Soil particles %			pH 1:2.5		EC 1:2.5	OC (%)	N (%)
cm	(Lab)	S	Z	C	H_2O	KCl	mS/cm		
0 - 20	C	8.7	26.1	65.2	6.5	6.0	0.30	2.74	0.2
20 - 50	C	4.3	17.4	78.3	7.2	6.5	0.32	1.47	0.1
50 - 75	C	nd	nd	nd	7.4	6.8	0.31	1.23	0.1

nd: Not done

Depth cm	Exchangeable Cation (me/100g of soil)				CEC	BSP	ESP	Avail P
	Na	K	Mg	Ca	me/100g	%	%	ppm
0-20	2.3	1.83	9.1	24.7	51.03	73	4.5	8.0
20-50	4.52	1.04	9.5	27.9	56.70	76	8.0	4.8
50-75	5.85	1.04	9.5	25.8	55.69	76	10.5	0.0

4. Soil physical properties

Depth (cm)	Bulk density	Lab. Water holding capacity volume moist (v/v %) at:					AWC (%v/v)
	g cm^{-3}	pF 0	pF 2	pF 2.4	pF 2.7	pF 4.2	pF2.4-pF4.2
0 - 20	1.28	88.76	84.76	83.22	79.49	72.32	10.1
20- 50	1.63	89.35	88.85	86.27	81.79	69.52	16.75
50-75	1.56	88.74	88.02	85.02	84.14	73.08	19.94
75-110	1.27	81.33	78.92	76.99	76.32	62.05	14.94

Table 7.3 Soil profile description mapping unit 14C1 Je

Profile no: P3

Soil classification FAO: Eutric Fluvisols

1. SITE CHARACTERISTICS

Location/date/author	South east of LITI-Tengeru; 250 metres from old Moshi - Arusha Main road; Soil map sheet 1; Nov. 30, 1993; Mr. Muya M.N.C., D.R. Kissanga, and S.A. Mtali.
Altitude	1215 m a.s.l.
Landform / physiography	slightly flat to undulating
Drainage	well drained; moderately permeable
Parent material	Alluvial/ colluvial volcanic materials
Vegetation/Land use	improved pasture
Climate	Warm / moderately cool subtropics with summer rainfall Temperature range (mean) 22.2^0 in March to 17 ^{0}C in July; mean rainfall 1070 mm per annual.

2. SITE CHARACTERISTICS

Horizon	Depth (cm)	profile description
Ap	0 - 20	Dark brown(10 YR 3/3 dry), very dark greyish brown (10 YR 3/2 moist) silt clay hozion; small amount of weathered feldspar and carbonate minerals ; moderate course sub angular structure; hard consistence when dry, firm and sticky plastic when wet; slightly compact insitu; very few small hard spherical clay nodules; many medium pores, very good rooting; gradual irregular transition to the next horizon; soil show surface crusting.

Bt	20 - 60	Very dark greyish brown (10YR 3/2 dry), very dark brown (10YR 2/2 moist) clay horizon; very few round gravels of weathered feldspar and carbonate in nature ; strong course sub-angular block structure ;less compact than the previous horizon; pronounced course porosity; very hard when dry and very firm sticky plastic when moist;gradual smooth boundary.
BC	60 - 110	Dark brown (10YR 3/3 dry), very dark brown (10 YR 2/2 moist) clay horizon; very hard (dry) , very firm (moist) ,sticky plastic (wet) consistence; moderate course sub angular structure ; common course pores; frequent weathered round irone stone and carbonate gravels;many very thin clay films on ped faces; frequent small hard spherical clay nodules; good rootings; gradual smooth boundary.
Cc	110+	Grey brown (10YR 5/2 dry) greyish brown (10 YR 4/2 moist) course sand loam horizon;very rich in carbonates and ironestone concretions; very few fine roots; plenty course pores.

3. SOIL ANALYTICAL DATA PROFILE P3

Depth	Texture	Soil particles %			pH 1:2.5		EC 1:2.5	OC (%)	N (%)
cm	(Lab)	S	Z	C	H_2O	KCl	mS/cm		
0 - 20	ZC	13	43.6	43.6	5.8	5.6	0.05	2.32	0.2
20 -60	ZC	13	40.7	46.3	5.8	5.6	0.09	1.93	0.1
60 -110	C	-	-	-	5.9	5.6	0.03	1.09	0.1

Depth cm	Exchangeable Cation (mg/100g soil)				CEC	BSP	ESP	Avail P
	Na	K	Mg	Ca	me/100g	%	%	ppm
0-20	0.8	1.56	3.6	12.1	30.68	59	2.6	59
20-60	0.44	1.56	3.6	14.8	29.01	70	1.5	29
60-110	1.24	0.78	4.1	15.4	27.72	77	4.5	22

4. Soil physical properties

Depth (cm)	Bulk density	Lab. Water holding capacity volume moist (v/v %) at:					AWC (%v/v)
	g cm^{-3}	pF 0	pF 2	pF 2.4	pF 2.7	pF 4.2	pF2.4-pF4.2
0 - 20	1.34	48.37	47.51	46.11	40.89	35.08	11.03
20- 60	1.27	50.31	49.75	48.18	41.24	33.35	14.83
60-110	1.33	47.47	46.52	43.26	38.07	33.18	10.08
110 +	1.36	45.23	44.64	43.92	36.97	30.33	13.63

Table 7.3b Soil profile description mapping unit 14C1 Je

Profile no: P4

Soil classification FAO Eutric Fluvisols

1. SITE	CHARACTERISTICS
Location/date/author	South east of LITI-Tengeru; 250 metres from old Moshi - Arusha; Main road soil map sheet 1; December 3, 1993; Mr. Muya M.N.C., D.R. Kissanga, and S.A. Mtali.
Altitude	1267 metres a.s.l
Landform / physiography	undulating to steep on the foot slopes of mountains surrounding lake Duluti.
Drainage	well drained; moderately permeable
Parent material	Alluvial/ colluvial volcanic materials
Vegetation/Land use	improved pasture, Chloris guyana on terraces
Climate	Warm / moderately cool subtropics with summer rainfall temperature range (mean) 22.2^{0} C in March to 17 ^{0}C in July; mean rainfall 1070 mm per annual.

2. PROFILE CHARACTERISTICS

Horizon	Depth (cm)	profile description
Ap	0 - 25	Very dark greyish brown (10 YR 3/2 dry), black (10 YR 2/1 moist) silt clay horizon; slightly hard (dry) , friable (moist) non plastic non- sticky (wet) consistence ; weak fine sub angular structure; very few angular weathered andesite gravels; slightly compact insitu; very few small hard spherical clay nodules; many medium pores, very good rooting: soil show surface crusting; gradual irregular transition to the next horizon.
B	25 - 85	Very dark brown (10YR 2/2 moist)silt clay horizon; slightly hard (dry); hard consistence when dry, friable when moist and slightly sticky and plastic when wet; moderate medium subangular block structure; many medium pores: very few weathered angular gravels; frequent small hard spherical ironstone concretions; very frequent medium roots; very high termite activities; clear smooth boundary.
BC	85-130	Dark brown (10YR 3/3 dry), very dark greyish brown (10 YR 3/2 moist) clay loam horizon; very hard (dry) , slightly friable (moist), ,sticky plastic (wet) consistence; moderate medium sub angular structure ; common fine pores; very few weathered angular ironestone gravels; frequent small hard spherical ironestone cooncretions; frequent fine roots; high termite activities.

3. SOIL ANALYTICAL DATA PROFILE P4

Depth cm	Texture (Lab)	Soil particles % S	Z	C	pH 1:2.5 H_2O	KCl	EC 1:2.5 mS/cm	OC (%)	N (%)
0 - 25	ZC	13	43.5	43.5	6.0	5.3	0.03	1.83	0.1
25 -85	ZC	12	40.6	47.4	5.6	5.2	0.03	1.05	0.1

Depth cm	Exchangeable Cation (mg/100g soil) Na	K	Mg	Ca	CEC me/100g	BSP %	ESP %	Avail P ppm
0-25	1.24	1.56	4.5	13.7	39.69	53	3.1	142
25-85	0.53	1.56	5.0	11.0	37.35	48	1.4	90

4. Soil physical properties

Depth (cm)	Bulk density g cm^{-3}	Lab. Water holding capacity volume moist (v/v %) at: pF 0	pF 2	pF 2.4	pF 2.7	pF 4.2	AWC (%v/v) pF2.4-pF4.2
0 - 25	1.10	51.07	50.02	48.98	36.85	29.31	19.65
25- 85	1.27	48.74	47.97	47.46	39.99	31.09	16.36
85-130+	1.27	49.93	48.98	47.01	37.50	30.84	16.17

Table 7.3c Soil profile description mapping unit 14C1

Profile no: P8	
Soil classification .	FAO Eutric Fluvisols
1. SITE	CHARACTERISTICS
Location/date/author	South east of HORTI-Tengeru; between HORTI vegetable experimental plots and Polish cemetary; Soil map sheet 1; Dec. 2. 1993: Mr. Muya M.N.C., D.R. Kissanga, and S.A. Mtali.
Altitude	1224 metres
Landform / physiography	slightly flat to undulating
Drainage	well drained: moderately permeable
Parent material	Alluvial/ colluvial volcanic materials
Vegetation/Land use	along the old canal bank near the vegetable research plots (HORTI).
Climate	Warm / moderately cool subtropics with summer rainfall Temperature range (mean) 22.2 in march to 17 °C in july; mean rainfall 1070 mm per annual.

2. PROFILE CHARACTERISTICS

Horizon	Depth (cm)	profile description
Ap	0 - 15	Very dark greyish brown(10 YR 3/2 dry), black (10 YR 2/1 moist) silt clay hozion; soft consistence when dry, friable when moist and non-sticky non-plastic when wet; weak fine sub angular structure; many course pores; very few weathered round feldspar gravels ;very frequent course roots; gradual smooth boundary. show surface crusting.
A	15 - 85	Dark brown (10YR 3/3 dry), very dark greyish brown (10YR 3/2 moist) silt clay horizon; soft dry consistence, slightly sticky and plastic wet consistence: moderately strong medium subangular structure ; many medium pores; very few weathered round feldspar gravels; frequent medium roots; gradual smooth boundary.
B	85 - 145	Greyish brown (10YR 4/2 dry), very dark brown (10 YR 2/2 moist) clay horizon; slightly hard (dry) , friable when moist , slightly sticky and plastic when wet; moderately strong sub angular structure ; many medium pores; frequent weathered angular feldspar gravels: very few small hard angular black nodules; frequent fine roots; gradual smooth boundary.
C	145+	Gravel texture : very frequent weathered angular feldspar and other rock fragments.

3. SOIL ANALYTICAL DATA PROFILE P8

Depth cm	Texture (Lab)	Soil particles % S	Z	C	pH 1:2.5 H_2O	KCl	EC 1:2.5 mS/cm	OC (%)	N (%)
0 - 15	ZC	12	44	44	6.5	5.6	0.04	1.65	0.1
15 -85	ZC	10	40	50	6.4	5.6	0.04	1.16	0.1

Depth cm	Exchangeable Cation (me/100g soil) Na	K	Mg	Ca	CEC me/100g	BSP %	ESP %	Avail P ppm
0-15	1.06	2.81	4.1	13.7	35.02	53	3.0	43.0
15-85	1.24	2.09	4.5	12.1	37.35	48	3.5	14.2

4. Soil physical properties

Depth (cm)	Bulk density g cm^{-3}	Lab. Water holding capacity volume moist (v/v %) at: pF 0	pF 2	pF 2.4	pF 2.7	pF 4.2	AWC (%v/v) pF2.4-pF4.2
0 - 15	1.12	52.54	51.80	50.71	38.63	30.45	20.26
15- 85	1.19	57.33	56.87	55.43	36.98	32.09	23.34
85-145+	1.20	52.86	47.76	48.82	38.77	33.13	15.68

Table 7.4 Soil composite samples analytical data

1. SOIL PHYSICAL DATA

Land unit	Sample Code	Depth cm	Texture (Lab)	Soil particles % S	Z	C	pH 1:2.5 H_2O	pH 1:2.5 KCl	EC 1:2.5 mS/cm	OC %	N (%
11C2 Vp	FR10	0 - 30	Clay	8.7	26.1	65.2	6.5	6.0	0.32	2.67	0.1
		30-60					7.4	6.4	0.29	1.89	0.1
14C1Je	AR1	0-30					6.3	5.7	0.20	2.87	0.2
		30-60					6.2	5.6	0.12	2.35	0.1
14C1 Je	AR6	0-30	Silt clay	12.8	43.6	43.6	5.6	5.3	0.08	2.39	0.1
		30-60					5.6	5.3	0.06	1.83	0.1
34B1 Tm	A5	0-30					6.2	5.6	0.07	4.05	0.2
		30-60					6.3	5.6	0.12	4.29	0.2
34B1 Tm	R3	0-30					5.9	5.6	0.08	6.56	0.4
		30-60					6.0	5.7	0.10	5.12	0.3
34B1 Tm	R2	0-30	Silt clay loam	11.8	57.3	30.9	5.7	5.5	0.10	3.68	0.3
		30-60					5.8	5.5	0.05	2.63	0.2

Table 7.4 Continue

Land unit	composite code	Depth cm	Exchangeable Cation (me/100g of soil) Na	K	Mg	Ca	CEC me/100g	BSP %	ESP %	Avail PF
11C2 Vp	FR10	0-30	2.31	1.83	8.59	20.31	48.02	69	4.8	
		30-60	3.10	1.56	9.50	27.45	51.36	81	6.0	12
14C1 Je	AR6	0-30	0.89	2.09	4.07	11.53	31.35	59	2.5	8
		30-60	0.80	1.56	4.07	11.53	30.68	58	2.6	96
14C1 Je	AR1	0-30	1.33	3.13	5.88	20.86	37.68	83	3.5	87
		30-60	1.24	2.61	5.88	17.56	37.68	72	3.3	1
34B1 Tm	A5	0-30	1.06	2.61	4.52	18.11	47.02	56	2.2	
		30-60	0.62	3.13	4.07	18.17	46.36	56	1.3	1
34B1 Tm	R3	0-30	0.71	3.13	5.88	20.86	54.69	56	1.2	1
		30-60	0.80	3.65	5.43	19.21	50.36	58	1.6	
34B1 Tm	R2	0-30	0.62	2.87	4.07	17.02	37.35	66	1.6	1
		30-60	0.44	2.09	3.62	14.27	40.35	51	1.1	

NATIONAL SOIL SERVICE, TANZANIA

SOIL OBSERVATION DESCRIPTION FORM

Observation no.

Survey area :
Map sheet no. : Photo no:
Location :

Author(s) :
Date :

Soil name :
Classification :

Phase :
Mapping unit :

Parent material :
Landform :
Macrorelief : *flat alm. flat gently undul. undulating rolling hilly mountainous*
Elevation.......
Slope gradient :.........%
Microrelief :
Slope form :
Slope length :
Position on slope :

Nat. drainage class : *very poor poor imperfec. mod. well well somewh. exc. excessive*
Groundwater level : actual..........cm range from.................to................cm.
Flooding / Ponding : *never very rare rare infrequent frequent very frequent regular*
Erosion : *splash & rillwash sheet rill gully* Degree :
Overblow :
Deposition : Overwash :

Rock outcrops : *none little fairly r. rocky very rocky extr. rocky rockland*
Surface stoniness : *none very few fairly st. stony very stony extr. stony rubble*
Alkalinity / Salinity : *none slight moderate strong*
Cracking :
Sealing / Crusting :

Landuse :

Vegetation/Crops :

HORIZON			COLOUR	MOISTURE CONDITION	MOTTLING		TEXTURE & COARSE FRAGMENTS	CONSISTENCE			STRUCTURE			NODULES			REACTION HCl	pH	OTH FEAT
designation	profile sketch	depth (cm)	dry / moist		abundance	colour		dry	moist	wet	grade	size	form	quantity	size	type		Ec / 1:2.5	

Remarks :
Soil depth cm

NATIONAL SOIL SERVICE, TANZANIA

SOIL PROFILE DESCRIPTION FORM

PROFILE NO:

Survey area :
Region :
District :
Location :

Mapping unit :

Map sheet no :
Coordinates :
Author (s) :

Airphoto no. :
Date :

Soil name :
Phase:
Classification : FAO :
Soil Taxonomy :

Season / weather conditions:

Soil moisture regime :
Soil temperature regime :

Landform :
Relief intensity :............ m
Elevation :...........m
Macrorelief :
Microrelief :

Parent material :

Geological formation:

SITE CHARACTERISTICS

Slope gradient(%) :
Type of slope :
Length of slope (m):
Position on slope :

SURFACE CHARACTERISTICS

Sealing/crusting : yes/no
thickness :......... mm; consist.: (d) (m)
Cracking :
Rock outcrops .... %
Surface stoniness .... %. Size .... cm

Ground water level : actual ....cm.
Perched: yes/no highest :........cm lowest .... cm.
Stagnating hor. : depth......... cm; design.........
Modified ground water level : yes/no

Nat. drainage class :
Run off :
Infiltration :
Seepage/Spring levels: yes/no

FLOODING / PONDING

Frequency :................ times/yr.
Duration : .... days. Depth: .... cm
In months :

Erosion : water/wind
type :
degree :
Deposition :

Nat. vegetation type:

Composition	Cover %	Dominant species
trees		
shrubs		
herbs		
grasses		
bare ground		

LAND USE/CROPPING SYSTEM

Soil fauna :

Human influences :
Photograph/slide no:

Remarks :

Brief description :

APPENDIX 7.2 Data analysis and Sample calculations

Table 7.6 Readily available soil moisture

Site: LITI Tengeru farm, having three major soil types, correspoding to three land units: Land unit 34C1 with Mollic Andosols (Tm), slope 9% ; Land unit 14C1 with Eutric Fluvisols (Je), slope 4% ; Land unit 11C2 with Pellic Vertisols (Vp) , slope 2.7%

1. Maximum Readily Available soil moisture (RAM)

Soil type	Horizon depth (cm)	AWC in % v/v or cm/m	AWC in cm/hor.	Total AWC in cm/1.2m or per root zone	RAM = 0.6*AWC in cm/1.2m
mollic	0 - 20	27.1	5.42	33.32	20.00
Andosols	0 - 120	27.9	27.9		
eutric	0 - 20	17.0	3.40	19.7	12.00
Fluvisol	20 - 85	17.0	11.05		
	85 - 120	15.0	5.25		
pellic	0 - 20	10.1	2.02	17.07	10.00
Vertisols	20 - 50	17.8	5.34		
	50 - 75	12.0	3.00		
	75 - 120	14.9	6.71		

Table 7.7 Sample calculation for determination of Soil Water balance

Soil: Mollic Andosols; Land unit: 34B1 Tm; Readily Available moisture (RAM)= 200 mm

Month	dekad	Rainfall= Pa	Eff. Pa=Pe	ETO	Pe-ETO	WCi[1]	Gd[2]	ML[3]
Dec 1979	3	12.2	11.0	40.7	-30.70	0	0	0
Jan 1980	1	1.1	0.99	41.0	-40.00	0	0	0
	2	14.1	12.69	39.0	-26.31	0	0.33	0
	3	12.9	11.61	45.1	-33.49	0	0.26	0
Feb 1980	4	9.0	8.1	41.0	-32.90	0	0.20	0
	5	84.7	76.23	40.0	36.23	36.23	1.91	1
	6	13.8	12.42	37.8	-24.62	11.61	1.23	1
March	7	49.6	44.64	41.0	3.64	14.25	1.37	1
	8	7.1	6.39	40.0	-33.61	0	0.51	0.5
	9	15.6	14.04	40.7	-26.66	0	0.34	0
April	10	49.2	44.28	34.0	10.28	10.28	1.30	1
	11	115.8	104.22	31.0	75.22	83.50	3.69	1
	12	113.7	102.33	30.0	72.33	155.83	6.19	1
May	13	51.7	46.53	27.0	19.52	175.36	7.49	1
	14	54.8	49.32	26.0	23.32	198.68	8.64	1
	15	37.4	33.66	28.6	5.06	200.00	8.12	1
Jun	16	1.8	1.44	25.0	-23.56	176.44	8.06	1
	17	0.9	0.81	25.0	-24.19	152.25	7.02	1
	18	0.2	0.18	24.0	-23.82	128.43	6.35	1
July	19	7.0	6.3	24.0	-17.70	110.70	5.61	1
	20	0.0	0.0	25.0	-25.00	85.47	4.40	1
	21	1.2	1.1	29.7	-28.62	57.11	2.95	1
August	22	32.8	29.52	28.0	1.52	58.63	3.14	1
	23	32.0	28.8	28.0	0.80	59.43	3.15	1
	24	8.5	7.74	33.0	-25.25	34.18	2.04	1
Sept	25	0.0	0.18	31.0	-30.82	2.23	1.10	1
	26	8.7	7.83	35.0	-22.17	0	0.29	0
	27	3.6	3.24	36.0	-32.76	0	0.09	0
October	28	2.2	1.98	37.0	-35.02	0	0.05	0
	29	0.0	0.0	39.0	-39.00	0	0.00	0
	30	15.8	14.22	45.1	-30.88	0	0.32	0
Nov.	31	33.2	29.88	39.0	-9.12	0	0.77	0.5
	32	39.0	35.1	38.0	-2.90	0	0.92	0.5
	33	1.4	1.26	37.0	-35.74	0	0.03	0
Dec.	34	9.4	8.46	37.0	-28.54	0	0.23	0
	35	25.0	22.5	36.0	-13.5	0	0.63	0.5
	36	0.8	0.72	40.7	-39.98	0	0.02	0

[1] WCi = Soil water balance (eqn. 3.3 and 3.4); [2] Gd = Growing period (see eqn. 3.5) [3] ML = 0 if Gd < 0.5; ML = 0.5 if 0.5 ≤ Gd < 1; ML = 1 if Gd ≥ 1.

Table 7.8 Moisture availability periods

Month	1979[2]*/80			1980*/81			1981/82			1982/83		
	Tm	Je	Vp	Tm	Je	Vp	Tm	Je	Vp	Tm	Je	Vp
Mar.	0.5	0.5	0.5	1	1	1	0	0	0	0	0	0
	1	1	1	0.5	0.5	0.5	1	1	1	0.5	0.5	0.5
	1	1	1	0	0	0	1	1	1	0.5	0.5	0.5
April	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
May.	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
Jun.	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
July	1	1	1	1	1	1	1	1	1	0.5	1	1
	1	1	1	1	1	0.5	1	1	0	1	1	1
	1	1	0.5	1	0.5	0	1	0	0	1	1	1
Aug.	1	1	0	1	1	1	1	0	0	1	1	1
	1	0	0	1	1	1	1	0	0	1	1	0
	1	0	0	1	0	0	0.5	0	0	1	0.5	0
Sept.	1	0.5	0.5	1	0	0	0	0	0	1	0	0
	1	0.5	0.5	0	0	0	0	0	0	1	0	0
	0.5	0	0	0	0	0	0	0	0	1	1	1
Oct.	0	0	0	0	0	0	0.5	0.5	0.5	1	1	1
	0	0	0	0	0	0	0.5	0.5	0.5	1	1	1
	0	0	0	0	0	0	0	0	0	0	0	0
Nov.	0	0	0	0.5	0.5	0.5	0	0	0	1	1	1
	0	0	0	0.5	0.5	0.5	0	0	0	1	1	1
	0	0	0	0	0	0	0	0	0	0	0	0
Dec.	0	0	0	0	0	0	0	0	0	1	1	1
	0	0	0	0.5	0.5	0.5	1	1	1	1	1	1
	0	0	0	0	0	0	0.5	0.5	0.5	1	1	1
Jan	0	0	0	0	0	0	0	0	0	1	1	1
	0	0	0	0	0	0	0	0	0	1	1	1
	0	0	0	0	0	0	0	0	0	1	0.5	0
Feb.	0	0	0	0	0	0	0	0		1	0	0
	1	1	1	0.5	0.5	0.5	0	0	0	1	0.5	0.5
	1	1	1	0	0	0	0	0	0	1	0	0
Total Days	215	190	180	240	220	200	220	180	170	290	270	250
Total season A	215	170	155	210	190	155	165	130	115	185	160	145
Total season B	0	0	0	10	10	10	15	15	15	160	145	120

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[2] Main season (A) started in February

Table 7.8 Continue ...

Month	1983/84			1984/85			1985/86			1986/87		
	Tm	Je	Vp	Tm	Je	Vp	Tm	Je	Vp	Tm	Je	Vp
Mar.	0.0	0.0	0.0	0	0	0	0	0	0	0.5	0.5	0.5
	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1	1	0.5	0.5	0.5
April	0.0	0.0	0.0	0	0	0	1	1	1	1	1	1
	1	1	1	0.5	0.5	0.5	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
May.	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
Jun.	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
July	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	0.5
	1	1	0.5	1	1	1	1	0.5	0	1	1	0
Aug.	1	0.5	0	1	1	0.5	1	0	0	1	0	0
	1	0	0	1	1	0	1	0	0	1	0	0
	0	0	0	0	0	0	1	0	0	1	0.5	0.5
Sept.	0	0	0	0	0	0	0	0	0	1	0.5	0.5
	0	0	0	0	0	0	0	0	0	1	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Oct.	0	0	0	0	0	0	1	1	1	0	0	0
	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5
	0	0	0	0	0	0	0	0	0	0	0	0
Nov.	0	0	0	0	0	0	1	1	1	0.5	0.5	0.5
	1	1	1	0.5	0.5	0.5	1	1	1	1	1	1
	1	1	1	0.5	0.5	0.5	1	1	1	1	1	1
Dec.	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1
	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1
	1	1	1	0	0	0	0	0	0	1	1	1
Jan	1	1	1	0	0	0	1	1	1	1	1	1
	1	1	1	1	0	0	0	1	1	1	1	1
	0.5	0.5	0.5	0	0	0	1	1	1	1	1	1
Feb.	0	0	0	0.5	0.5	0.5	1	1	1	1	1	1
	0.5	0.5	0.5	1	1	1	0	0	0	1	1	0.5
	0	0	0	0.5	0.5	0.5	0	0	0	0.5	0.5	0
Total Days /annual	220	220	200	220	220	210	250	230	210	300	270	260
Total season A	150	135	125	140	140	125	160	125	110	175	125	110
Total season B	95	95	95	30	30	30	130	130	130	120	120	100

Table 7.8 continue ...

Month	1987/88			1989/90			1990/91			1991/92		
	Tm	Je	Vp	Tm	Je	Vp	Tm	Je	Vp	Tm	Je	Vp
Mar.	1	1	1	0	0	0	1	1	1	0	0	0
	1	1	1	1	1	1	1	1	1	0	0	0
	0.5	0.5	0.5	1	1	1	1	1	1	1	1	1
April	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
May.	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
Jun.	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	0.5	1	1	1
July	1	1	1	1	1	1	1	1	0	1	1	1
	1	1	1	1	1	0.5	1	0	0	1	1	0.5
	1	1	1	1	0.5	0	1	0	0	1	1	1
Aug.	1	1	0	1	0	0	1	0	0	1	1	0.5
	1	1	1	1	0	0	1	0	0	0.5	0.5	0
	1	0.5	0	1	0	0	0	0	0	0	0	0
Sept.	1	0	0	0.5	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Oct.	0.5	0.5	0.5	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0.5	0.5	0.5	0	0	0	0	0	0
Nov.	1	1	1	0	0	0	0	0	0	0	0	0
	0	0	0	1	1	1	1	1	1	0	0	0
	0	0	0	1	1	1	0.5	0.5	0.5	0	0	0
Dec.	0	0	0	1	1	1	1	1	1	0	0	0
	0	0	0	0	0	0	1	1	1	1	1	1
	0	0	0	1	1	1	0.5	0.5	0.5	0	0	0
Jan	-	-	-	1	1	1	0	0	0	0	0	0
	-	-	-	1	1	1	0	0	0	0	0	0
	-	-	-	0	0	0	1	1	1	0	0	0
Feb.	-	-	-	0	0	0	0	0	0	0.5	0.5	0.5
	-	-	-	0	0	0	0	0	0	1	1	1
	-	-	-	1	1	1	0	0	0	0	0	0
Total Days /annual	215	190	180	240	220	200	220	180	170	290	270	250
Total season A	215	170	155	210	190	155	165	130	115	185	160	145
Total season B	0	0	0	10	10	10	15	15	15	160	145	120

Table 7.8 Continue ...

Month	1992/93			1993		
	Tm	Je	Vp	Tm	Je	Vp
Mar.	0	0	0	0.5	0.5	0.5
	0	0	0	0	0	0
	0	0	0	0	0	0
April	1	1	1	1	1	1
	1	1	1	1	1	1
	1	1	1	1	1	1
May.	1	1	1	1	1	1
	1	1	1	1	1	1
	1	1	1	1	1	1
Jun.	1	1	1	1	1	1
	1	1	1	1	1	1
	1	1	1	1	1	1
July	1	1	1	1	1	1
	1	1	1	1	1	0.5
	1	1	0	1	1	0
Aug.	1	0	0	0	0	0
	1	0	0	0	0	0
	1	0	0	0	0	0
Sept.	0.5	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
Oct.	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
Nov.	0	0	0	-	-	-
	1	1	1	-	-	-
	1	1	1	-	-	-
Dec.	0.5	0.5	0.5	-	-	-
	0	0	0	-	-	-
	0	0	0	-	-	-
Jan	0.5	0.5	0.5	-	-	-
	0.5	0.5	0.5	-	-	-
	0.5	0.5	0.5	-	-	-
Feb.	0.5	0.5	0.5	-	-	-
	0	0	0	-	-	-
	0	0	0	-	-	-
Total Days	210	170	160	-	-	-
Total season A	155	120	110	120	120	105
Total season B	30	30	30	00	0	0

Table 7.9: Probability of exceedence for moisture availability

Table 7.9a: Annual soil moisture probability of exceedence

Rank (n)	Growing length for different soil types					
	34B1(Tm) Growing length	(Fa)	14C1(Je) Growing length	(Fa)	11C2(Vp) growing length	Fa
1	300	8.9	270	7.7	260	3.9
2	290	11.5	270	7.7	250	11.5
3	280	19.2	260	19.3	230	19.2
4	270	26.9	230	30.8	210	34.6
5	250	42.3	230	30.8	210	34.6
6	250	42.3	220	50	210	34.6
7	250	42.3	220	50	200	57.8
8	240	57.7	220	50	200	57.8
9	220	69	210	65.4	200	57.8
10	220	69	190	73.0	180	73
11	215	80.1	180	80.1	170	80.1
12	210	88.5	170	88.5	160	88.5
13	170	96	170	96	160	96
Mean	243.5		218.5		203.1	
Std. dev.	36.5		34.6		31.2	

Table 7.9 continue...

b. Probability of exceedence for Main season(A) soil moisture balance.

Rank (n)	Growing length for different soil types					
	34B1(Tm) Growing length	(Fa)	14C1(Je) Growing length	(Fa)	11C2(Vp) Growing length	Fa
1	215	3.6	190	3.6	170	3.6
2	210	10.7	175	10.7	155	14.3
3	200	17.9	170	17.9	155	14.3
4	185	25.0	160	25.0	145	25.0
5	180	32.1	145	32.1	135	32.1
6	175	42.3	140	42.8	125	50.0
7	175	42.3	140	42.8	125	50.0
8	165	53.6	135	57.0	125	50.0
9	160	60.7	135	57.0	125	50.0
10	155	67.9	130	67.9	115	67.9
11	150	75.0	125	75.0	110	82.0
12	145	82.0	125	82.1	110	82.0
13	140	89.3	120	92.9	110	82.0
14	120	96.4	120	92.7	105	96.4
Mean	169.6		143.5		129.3	
Std. dev.	27.3		22.0		20.1	

Table 7.9 continue..

Tabl 7.9c: Short rain season (B) prob. of exceedence

Rank (n)	Growing length for different soil types					
	34B1(Tm) Growing length	(Fa)	14C1(Je) Growing length	Fa	11C2(Vp) Growing length	Fa
1	160	4.1	145	4.0	130	4.0
2	130	12.5	130	13.0	120	13.0
3	120	20.8	120	21.0	100	21.0
4	95	29.0	95	29.0	95	29.0
5	70	38.0	70	38.0	70	38.0
6	45	50.0	45	50.0	45	50.0
7	45	50.0	45	50.0	45	50.0
8	30	63.0	30	63.0	30	63.0
9	15	75.0	15	75.0	15	75.0
10	15	75.0	15	75.0	15	75.0
11	10	88.0	10	88.0	10	88.0
12	0	96.0	0	96.0	0	96.0
Mean	61.3		60.0		56.3	
Std. dev.	51.1		48.8		43.5	

Table 7.10: Soil erodibility (K) determination

Land unit	% silt	% Sand	% OM	Struc-ture	Permea-bility	K[2]
Vp	20	4	4.7	blocky	very slow	0.18
Je	50	5	3.2	fine	modera-te	0.20
Tm	60	10	7.4	fine	modera-te to rapid	0.21

2: Source : Wischmeier et al. (1971) In: Landon (1991)

Table 7.11 Soil loss by Universal Soil Loss Equation (USLE)

Soil unit	Erosi-vity factor R[1]	K	Slope length factor			Slope factor		Soil loss
			slope length x (m)	m	L	s%	S	RKLS
Tm	500	0.21	150	0.5	2.603	9.0	0.997	272.0
Je	500	0.20	100	0.4	1.828	4.0	0.349	64.0
Vp	500	0.18	200	0.3	1.936	2.7	0.234	40.7

1: Source: Nyenza (personal communication ,1994)

Table 7.12: Soil productive lifespan

1. Soil lifespan index

Soil	Effective depth (De)	Bulk density (Bd) top 20 cm	RKLS*100*Bd = soil loss (Al) in cm/year	De/Al (soil life span) in Years
Tm	130	0.87	3.13	41
Je	145	1.2	0.53	274
Vp	75	1.3	0.32	235

Appendix 7.3 Economic data

Table 7.13 Crop yields potential (t/ha/year)

Crop type	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Rainfed[1] potential	3	1	1.5	2	10	30	25	25	1.5	30	40 0.7	35 .5	40	19	20	25	50	55	20
Rainfed max recorded in the area	6	5	2.3	3	25	40	30	20	.9	25	36	40	36	12 0.3	20 0.3	20 1.5	50 2	35	20 0.9
Irrigated[2] potential	9	2	3.5	5	45	80	65	60	2	60	58	100	-	50	50	-	120	80	-
Irrigated recorded around	-	-	-	-	50	60	50	40	1.5	-	-	-	-	-	-	-	-	-	

1/ Source: Landon (1991)
2/ Source: JICA (1990)

Table 7.14 Land Utilization Type - Amount of input and yield

Description	Unit	Land utilization types																		
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Production Costs/Input (i) Seed/Seedling	kg/ha	25	60	10	10	0.2	0.2	0.2	1200	1500	600	5	5	20	6	5	5	2000	2000	6
1. Fertilizer	kg/ha	250	150	150	250	250	250	250	250	250	150	150	150	150	100	100	100	300	250	100
2. Planting/ Translating&Nursery	man day (md)	20	20	20	2	60	60	60	300	300	150	2	2	2	2	2	2	40	40	2
3. Weeding	md	30	15	30	30	50	50	50	60	30	30	10	10	10	10	10	10	20	20	30
4. Fertilization	md	10	66	6	10	10	10	10	10	10	6	2	2	2	2	2	2	15	10	4
5. Pit digging	md	-	-	-	-	-	-	-	1200	1500	600	-	-	-	-	-	-	-	-	-
6. Agro-chemicals -Insecticides	l/ha	1	1	-	1	[illegible]	1	1	-	[illegible]	[illegible]	1	[illegible]	2	[illegible]	[illegible]	1			[illegible]
-Fungicides	L/ha	-	-	-	-	-	2	2	-	3	-	-	-	2	2	-	-	1	-	1
-Nematodecides	kg/ha	-	-	-	-	-	10	15	15	-	-	-	-	15	10	10	10	10	5	-
-Rodenticides	kg/ha	-	-	1	-	-	-	-	-	-	-			0.2	0 2	0.2	0.2	0.2	0.2	0.2
7. Plant Protection	md	-	1	2	2	1	10	10	10	5	2	1	1	10	10	10	10	10	10	1
8. Harvesting (crop/seed)	md	20	20	30	30	30	20	60	120	60	60	150	150	120	120	120	150	-	-	60
-Green matter	md	-	-	-	-	-	-	-	-	-	-	150	150	120	120	120	120	200	200	30
9. Threshing/shelling	md	10	10	20	20	-	-	-	30	-	-	20	20	20	20	20	20	-	-	20
10. Packing bags	pcs	30	15	15	3	50	50	30	20	-	50	-	-	4	3	3	6	-	-	-
-Miscellaneous	%	15	15	15	15	20	20	20	20	15	15	15	15	20	15	15	15	20	20	15
11. Yield - Green Matter	t/ha	-	-	-	-	-	-	-	-	-	-	30	30	25	17.5	25	25	70	70	20
- Seed/crop	t/ha	3.0	1.5	1.5	3.0	10	30	20	1.2	25	35	0.4	0.4	0.4	0.3	0.3	0.6	-	-	0.8

Table 7.15 Common Inputs and Agrochemicals used in the area

Input/Agrochemicals	Application/ controls	Pests/ diseases/crop	Unit	Price/Unit	Amount/ha	Cost/ha (Tshs)
1. Tractor- Ploughing	Ploughing		acre	8,000	2.5	20,000
	harrowing		acre	6000	2.5	12,000
2. Man-day	Weeding		md	500	versatile	variable
	harvesting.		md	500	versatile	variable
	threshing		md	500	versatile	variable
						-
3. Fertilizer		-				
NPK	Growing		50kg	6000	150-400	15000-40 000
TSP	Planting		50kg	6000	150	15 000
4. Agrochemicals -Blue Copper	Fungicide	vegetables	kg	14.000	1kg	14000
-Kocide	Fungicide		kg	4,000	2kg	8000
-Dithane	Fungicide		kg	4,000	2kg	8000
-Furadon	Insecticide	Cutworm Nematodes	25 kg bag	30,000	10kg	15000
-Actelic	Insecticide		Lt	13,000	1lt	13000
-Karate	Insecticide	(beans)	Lt	7,000	1lt	4000
-Rogo're	Insecticide	Citrus	Lt	7,000	1lt	7000
-Basudin	Insecticide	Aphids	Lt	4,000	1lt	4000
-Rodenticide	Rodenticide	Ground moles	kg	4,000	200kg	1000

Table 7.16 Cost of seeds and price of crop product

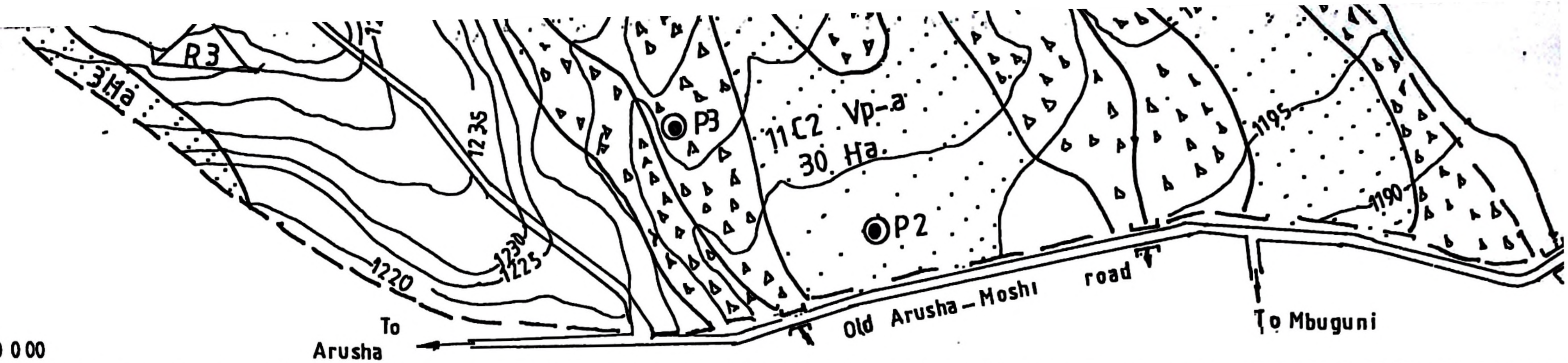
Crop type / LUT	Seed (Tshs/kg)	Agro-chemical (Tshs/ha)	crop/seed price Tshs/kg)	Green matter (GM) Tshs/kg
A: Maize	600	4 000	70	-
B: Beans	300	10 000	150	-
C: Sunflower	150	5 000	120	-
D: Sorghum	60	5 000	60	-
E: Onion	15 000	15 000	150	-
F: Cabbage	15 000	25 000	50	-
G: Tomato	15 000	40 000	50	-
H: Banana	100	20 000	50	-
I: Coffee (arabica)	100	40 000	750	-
J: Citrus	100	7 000	5	-
K: Rhodes grass (C. gayana)	3 000	5 000	3 000	15
L: Buffel grass (C. ciliaris)	3 000	5 000	3 000	15
M: Lucerne (M. sativa)	5 000	20 000	5 000	20
N: Desmodium intortum	5 000	10 000	5 000	20
O: Glycine wightii	5 000	10 000	5 000	20
P: Siratro	5 000	10 000	5 000	20
Q: Elephant grass (P. Purpureum)	10	15 000	-	6
R: Guatemala grass (T. laxum)	10	15 000	-	6
S: Setaria (S. splendida)	1 000	5 000	1 000	6

Table 7.17 Sample calculation for net farm income

1. Legume pasture: Lucerne (Medicago sativa)

Item	Unit	Amount	Price	Cost
A: Production costs				
1. Seed	Kg	20	5 000	25 000 #
2. Fertilizer		3	6 000	18 000
- NPK	50 kg bag			
-TSP				
3. Agrochemicals	lt	5000	20 000	
4. Ploughing				
- tillage	ha	1	20 000	5 000 #
- Harrowing	ha	1	12 500	3 125 #
5. Planting	md	2	500	1 000
6. Spraying	md	10	500	5 000
7. Fertilization	md	2	500	1 000
8. Weeding	md	10	500	5 000
9. Harvesting	md			
-GM		120	500	60 000
-Seed		120	500	60 000*
11. Threshing	md	20	500	10 000*
12. Sacks	pcs	6	500	3 000*
13. Miscellaneous 20%	Tshs	--	---	28 625 31 225*
B: Total cost				
- Green matter	Tshs	--	171 750	
- Seed			187 350	
C: Gross income				
-Green matter	25 kg	1 000	500	500 000
-Seeds	kg	400	5 000	2 000 000
D: Net income				
-Green matter	Tshs	--		328 250
- Seed	Tshs	--		1 812 650

\# cost spread over 4 years
* Additional cost for seed production



SCALE 1:10 000

Legend

- Soil Map unit 34 B1 Tm-s
- Soil Map unit 14 Cl Je
- Soil Map unit 11C2 VP-a

MAPPING SYMBOLS

3 4 B 1 Tm-s

TOPOGRAPHIC CLASS (3)
- 1 = 0-4 %
- 2 = 4 - 8 %
- 3 = > 8 %

DRAINAGE CLASS (4)
- 0= Very poorly drained
- 1= Poorly drained
- 2= Imperfectly drained
- 3= Moderately drained
- 4 = Well drained
- 5 = Some what excessively drained
- 6 = Excessively drained

TEXTURAL CLASS (B)

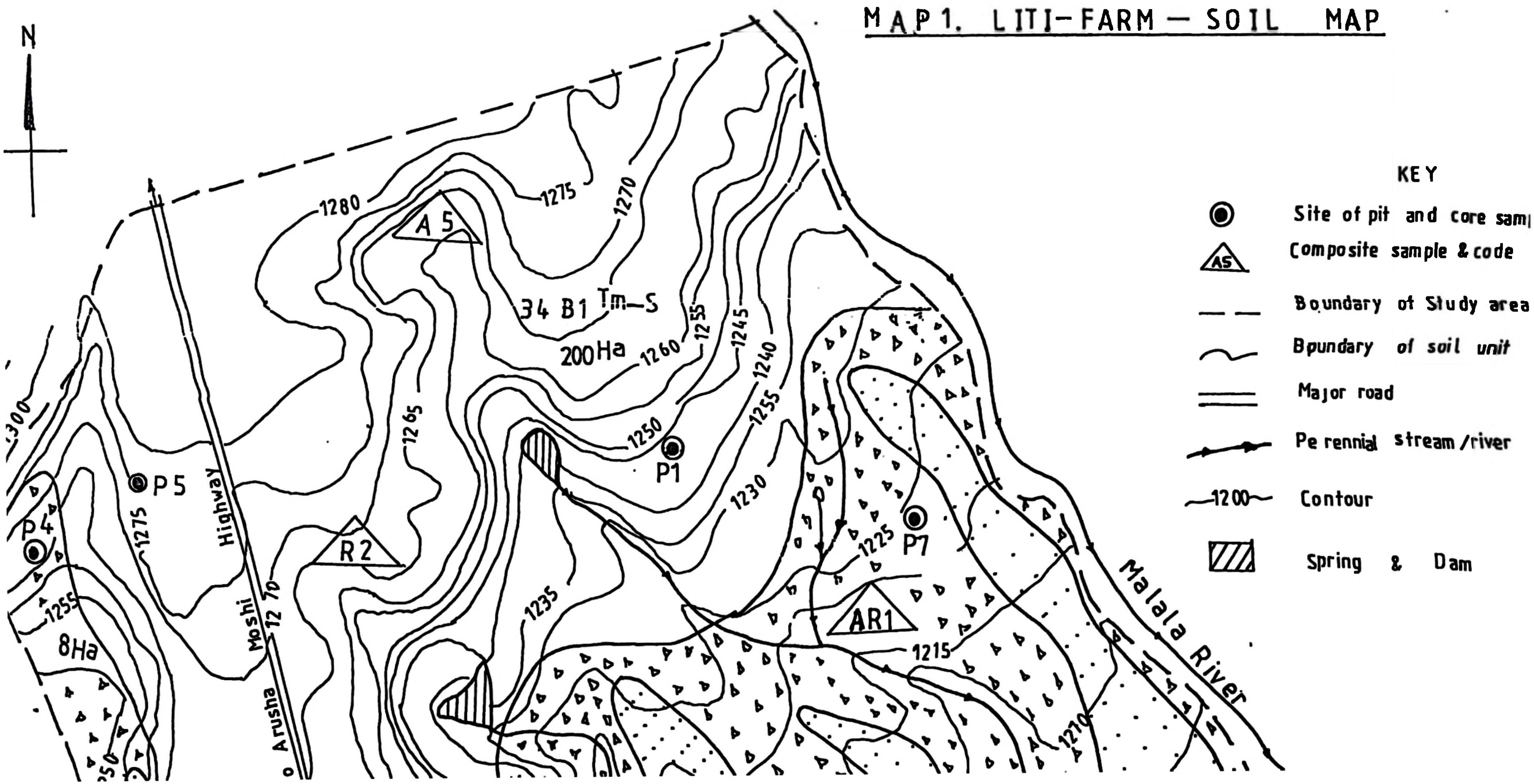
A = Coarse B Medium C = Fine

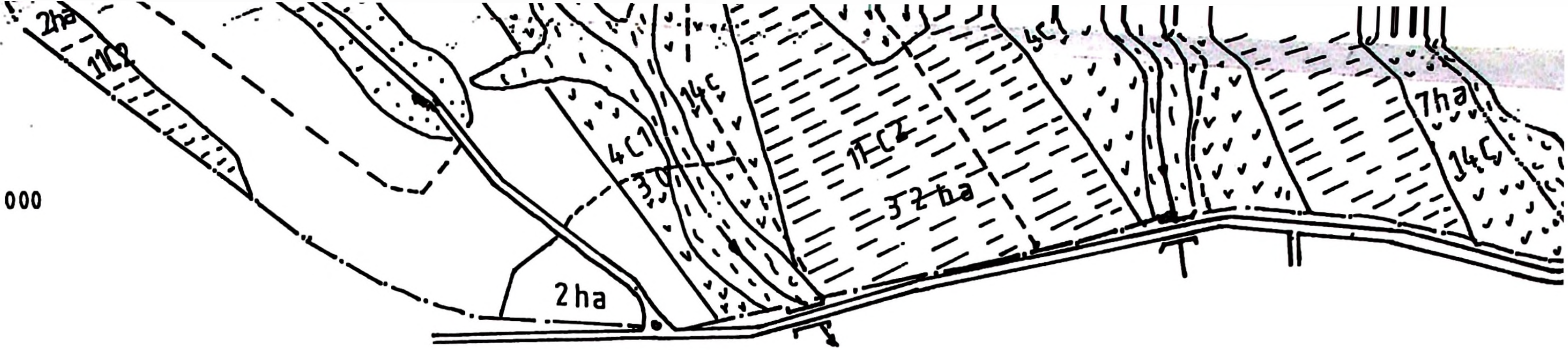
SOIL DEPTH CLASS (1)
- 1 = > 90 cm
- 2 = 60–90 cm
- 3 = 40 – 60 cm
- 4 = 25 – 40 cm
- 5 = > 25 cm

SOIL UNIT (Tm)
- Mollic Andosols (Tm)
- Pellic Vertisols (VP)
- Eutric Fluvisols (Je)

SOIL PHASE (s)
- s = stony
- a = sodic

MAP 1. LITI-FARM – SOIL MAP





Scale 1:10 000

LEGEND

SUITABILITY CLASS

S. SUITABLE LAND
S1 Highly suitable
S2 Moderately suitable
S3 Marginally suitable

SUBCLASS LIMITATION

e= erosion hazard
m= moisture availability
s = stoniness
v = pests and disease

NET FARM INCOME

S 1=> 500, 000 Tsh/ha
S2 = 250, 000 – 500 000/=
S3 = 100,000 – 250, 000/=
S4 25,000 – 100000 Tsh/ ha

LAND SUITABILITY CLASSIFICATION FOR RAINEED CROPS

LAND UNIT	LAND UTILIZATION TYPES									
	A·Maize	B·Beans	C·Sunflower	D:Soghum	E:Onion	F·Cabbage	G·Tomato	H·Banana	I Loffece	J:Litrus
34 B1 Tm	S2/S3es	S2/S3es	S2/S3es	S2/S3es	S1/S3e	S1/S3ev	S2/S3ev	S1/S3me	S1/S3me	S1/S3me
14 C1 Je	S1/S2e	S1/S2ev	S1/S2e	S1/S2e	S1	S1/S2ev	S1/S2 v	S1/S3m	S1/S3m	S1/S2m
J1 C2 VP	N I	S 3	N1	S 3	S13	S3/ NI	NI ·	N2	N2	N2
NET INCOME	S 4	S4	S 4	S4	S1	S1	S1	S1	S1	S1
	K: Rhodes grass	L:Buffet grass	M·Luterne —	N:Desmodium Intoctum	O:Glycine R Wightii	R Sirafro	Q Pennisetum Purpureum		R:Tripsacum Laxum	S:Giant Setaria
34 B1 Tm	S1/S2m	S1/S2m	S1/S3mve	S1/S2m	S1/S2mv	S1/S2me	S1/S3mev		S1/S2me	S1/S2e
14 C1 Je	S1/S2m	S1/S2m	S1/S2m	S1/S2m	S1/S2m	S1/S2m	S1/S2m		S1/S2m	S1/S2e
11 C2 VP	S1/S2	S1/S2m	S1/S3 --	S2/S3	S2/S3m	S3/N1	S3/N1		S3	S3
Net Income seed/ Gm	S1/S2	S1/S2	S1/S2	S1/S2	S1/S2	S1/S2 --	S3		S3	S1/S2

MAP2 LAND SUITABLITY MAP OF THE LITI TENGERU FARM