Soils and land use with particular attention to land evaluation for selected land use types in the Lake Naivasha Basin, Kenya

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By

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ABSTRACT

The main aim of this research was to investigate the relation between landscapes, soils, land uses, and land suitability; this is a broad description of “land evaluation”.An additional objective was to maximize the participation of farmers, farm managers, agronomists and other local experts in the land evaluation process.

The study area covered 5950 ha in the northeast corner of the lower Naivasha lake basin, beginning immediately north of Naivasha town, central Kenya. It encompasses three main landscapes according to the geopedological mapping approach of Zinck: a step-faulted plateau, a deltaic river plain and a lacustrine plain. These were divided by stereoscopic airphoto interpretation, supported by field checks, into map units defined by relief, lithology, and landform. In each of these map units, several land characteristics were measured in the field and laboratory to establish its dominant soil properties and soil classification according to the World Reference Base For Soil Resources (WRB). The product of the soil survey is a geometrically-correct map at 1:50 000 of the map units, with a legend describing their soils.

Both field survey and interviews with local experts were used to identify the major land use types (LUT) in the study area: pivot-irrigated cabbage for export and national markets, pivot-irrigated Lucerne for dairy fodder for national market, pivot-irrigated baby corn for fresh export, roses in green houses for cut flowers for export, and pivot-irrigated tomatoes for export. The first two of these were described as an expert model in the Automated Land Evaluation System (ALES).

Most of the factors used in evaluating land suitability were identified through interviews with local experts in the study area; this was supplemented as necessary by literature review. Among these are sealing hazard, soil toxicity, soil salinity, potential for using agricultural inputs, and erosion hazard; these were used in the maximum-limitation approach. Other factors for these adaptive LUTs were instead used in the economic land evaluation: nutrient availability, moisture availability, and soil workability.

Evaluation results show that different land areas are separated into different suitability classes, both physical (limitations to use that will not be corrected) and economic (based primarily on the gross margin). The final output is a map of overall suitability for the land use types and suitability maps of individual factors. There are clear problems with the dominant current land uses which suggest that they may not be indefinitely sustainable.

Capturing data from experts for the purpose of land evaluation requires good communication skills. Most experts were well-acquainted with the concept of land use requirements (although not by that name) and their diagnostic factors. The challenge for the land evaluator is to translate this information into the language of land evaluation, without prejudice.

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DEDICATED TO MY PARENTS, BROTHERS AND SISTER

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1 Introduction

Global concerns about food security, the quality of life for future generations and a growing awareness about environmental degradation are posing penetrating questions to the world of sciences (De Bie, Van Lanen, & Zuidema, 1996). Therefore, availability of proper land use information is required at various scales of planning.

There is no more fundamental a question in land evaluation than an assessment of the ability of the earth to provide proper nutrition for its human population in the years and decades to come. Agriculture is one of the world's most important activities supporting human life. On a global scale, agriculture has the proven potential to increase food supplies faster than the growth of the population, a pattern to be expected in the foreseeable future (Davidson, 1992).

Projections for the year 2000 and beyond suggest that, due to population increase and income growth, demand for food and other agricultural products will continue to rise by over 3% annually (Fresco, 1989) In most countries the diet is expected to diversify in favor of higher value commodities such as livestock and horticultural products. This will have important implications for future land use.

As observed by (Voortman, 1985), increased agricultural production can be achieved by more intensive use of the land and by bringing additional land into cultivation both of which imply substantial changes in land utilization. The sound planning of changes in land use requires a thorough knowledge of the natural resources, and a reliable estimate of what they are capable of producing, so that reliable predictions and recommendations can be made. In addition to production potential, the conservation of soil and water resources for use by future generations requires consideration in planning land development.

Today, one is witnessing a situation of changing demands on land use, of increased needs to deploy efforts in marginal areas and of growing concerns about environmental issues. Under these conditions, designing sustainable land use systems capable of meeting qualitatively and quantitatively expanding needs presents an enormous challenge to all those concerned- policy makers, planners and scientists (Voortman, 1985). What is needed is a clear assessment of the potential of the land and of the existing farming systems, as well as the identification of ways to attain these potentials, in order to develop adequate and sustainable land use plans.

Many developing countries like Kenya are trying to improve their national economies by producing non-traditional crops for export. However, there is very little expert knowledge on the best land use systems, which could lead to undue pressure on the land or inappropriate land use systems.

With such a background, it becomes very clear that land and its suitability for agricultural production is a very important aspect in agricultural production. One of the most important aspects of this research is to evaluate the land and study its potential and suitability for specific land use types and make this information available in a user-friendly format to land use planners and land users.

1.1 Problem Statement

Over the past fifty years, the population of the world has almost doubled a situation that leads to a very high demand for food production. To meet this challenge, there are two clear options as follows; 1) intensification of agricultural production and 2) exploration of new productive areas in order to increase agricultural production. The last option however, is not realistic because in many countries, expansion of agricultural land is restricted, and, where possibilities for expansion exist, impact of this expansion on the environment must be taken into consideration. In many countries the pressure on land is ever increasing which leads to a decrease in the area of agricultural land.

Many developing countries, especially in Africa, need to increase their agricultural production in order to feed a growing urban and rural population and to produce raw materials for local industry and export in sufficient quantities to sustain a healthy economy.

Kenya, the venue of my research project is equally affected by the same problem. In general, Kenya faces a severe constraint in availability of good agricultural land. This is further aggravated by the scarcity of irrigation water and suitable soils in the semi-arid areas of the country (Wokabi, 1994). It is obvious that land use planning has to be adapted. A thorough analysis of potentials and constraints of land for land use alternatives is needed before rational decisions can be made. Some of the most predominant commercial activities in the project area (around Lake Naivasha) include rain fed agriculture, dairy farming, and high value vegetable production and flower production. Because of the growing market for flowers and other high value horticultural products in Western Europe, pressure on the land is increasing. This leads to land use conflicts and environmental problems such as water shortages and chemical pollution through pesticides and other chemicals (ITC, 1998)

Land evaluation provides sets of data on potentials and constraints, which can contribute to decisions on a sustainable land use. Therefore, it becomes clear that in determining the best modes of sustainable land use, land suitability assessment for a particular use has an important role to play.

However one of the difficulties usually encountered in the land evaluation exercise is the identification of land use requirements and eliciting expert knowledge when there are no experiments. (Rossiter, 2001a) states that the problem is to elicit details of a mental process that the expert already carries out. It is therefore, not a coincidence that one of the objectives of this study is to find ways of translating into computable form the knowledge of experts for a FAO style land evaluation.

1.2 Objectives

1.To identify and characterize the major land use types in the study area and select important ones for future study.

2.To identify and characterize the soils in the study area and investigate their potentials and limitations for the identified land use types.

3.To study, based on interviews and literature, the factors necessary for a successful implementation of the identified land use types.

4.To identify the constraining factors for the land use types identified.

5.To find the best ways of eliciting and structuring expert knowledge for land evaluation from the types of experts in the study area.

1.3 Research Questions

1.What are the main land use types in the study area?

2.What are the main properties of the soils in the study area and how do they influence the suitability of the land for the selected land use types?

3.What characteristics and qualities of the land differentiate lands that are very suitable, suitable, marginal or not suitable for given land use types?

4.What are the main constraining factors for the land use types in the study area?

5.What are the best ways of eliciting and structuring expert knowledge for land evaluation and how do experts of different backgrounds conceptualize and communicate information on land and land suitability?

1.4 Hypothesis

1.Soils in the study area differ significantly in their properties and suitability

2.Different land use types in the study area can be distinguished through ground observations and interviews.

3.There are specific land qualities that differentiate lands into different suitability classes for specified land use types.

4.Through clear, logical and coherent land evaluation questionnaires it is possible to elicit expert knowledge for land evaluation.

2 Literature review

2.1 Soil Survey

Soil surveys are carried out to obtain information about the distribution of soil characteristics within a given area. These data are presented in form of soil maps and reports(Bregt, 1992) In general it may be stated that the objective of soil survey is to obtain a better understanding of spatial changes in the characteristics of the soil continuum so that soils may be used more efficiently for the benefit of mankind. The information obtained by soil surveying is used directly as a guide in planning land use for agriculture [International Soil Reference and Information Center, 1986 #50]. In this sense, soil survey provides the basis for developing an ecologically sound land use. In ecological research areas, where environmental degradation is the main problem, soil surveys will be an essential part of the natural resources inventories necessary for the evaluation of degradation process and for ascertaining possible curative measures. Hence, soil surveys are indispensable tool for evaluation and planning. In this context too, the long term monitoring of soil characteristics (such as structure, fertility etc), building upon a baseline of soil survey, plays an important role.

Soil survey describes the characteristics of the soils in a given area, classifies soils according to a standard system of classification, plots the boundaries of the soils on a map and makes predictions about the behavior of soils. (U.S. Department of Agriculture, 1993). The physiographic survey produces a description of the soils in form of the discrete spatial model without any information about the variation within the map unit(Bregt, 1992). The information collected in a soil survey helps in the development of land use plans and evaluates and predicts the effects of land use on the environment.

One approach to detailed and semi- detailed soil survey is based on the geopedologic approach suggested by (Zinck, 1988), which is based on the strong integration of geomorphology and pedology, using geomorphology as a tool to improve and soil survey. It is based on the hypothesis that boundaries drown by landscape analysis separate most of the variation in the soils, and sample areas are representative; their soil pattern can be reliably extrapolated to unvisited map units (Girma, 2001a). Geomorphology contributes to soil survey in the following ways: - Selection of sample areas, transects and traverses, tracing of soil boundaries on the basis of conceptual relationships between geoforms and soils, identification, monitoring and explanation of spatial variability (Zinck, 1988).

2.2 Land Use Systems

Analysis of land suitability combines a study of land (properties) with the study of land use and determines whether the compounded requirements of land use are adequately met by the compounded properties of the land. (Rossiter, 2001b) defines land as follows: An area of the earth’s surface, the characteristics of which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere, vertically above and below this area, including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of the past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by humans.

A distinction is made between adaptive and fixed land types. For adaptive land utilization types, the details of the LUS are modified according to the land evaluation unit, while for fixed, inputs and techniques are applied equally on all land areas. For both fixed and adaptive land utilization types, the expected outcome is different (Rossiter, 2001b).

Land use system is a combination of one land unit and one utilization type (with one set of land use requirements)(Driessen, , & Konijn., 1992), while land evaluation is the prediction of the performance of such a land use system over time (Rossiter, 2001c). As such, land evaluation provides a rational basis for taking land-use decisions based on analysis of relations between land use and land, giving estimates of required inputs and projected outputs. Land evaluation deals with two major aspects of land: physical resources such as, topography, and climate and social economic resources like farm size, management level, availability of manpower, market position and other human activities. The former can be considered as relatively stable properties, while the later are much more variable and dependent on social and political decisions. (Sys, Van Ranst, & Debaveye, 1991)

A land use system can therefore be defined as a specific land use practiced during a known period on a known and contiguous area of land with reasonably uniform land characteristics. To study the performance of land use (s), a land use system must be the basic entity of description (De Bie et al., 1996) However, the definition of a land use system suggested above differs from the one given by FAO which is: A specified land utilization type practiced on a given land unit, and associated with inputs, out puts and possibly land improvements.

2.3 The Concept of Land Suitability

According to (Rossiter, 2001b) land suitability is defined as the fitness of a given type of land for a specified land use type. This can be based on economic and physical metrics. An economic definition of suitability can be based on defined metrics of economic value, e.g., predicted gross margin, net present value, internal rate of return, benefit cost/ratio. A definition of land suitability is more arbitrary, being based on a specified method for combining land quality ratings into an overall rating. The idea is to give the land user a feel for how limiting, or how difficult to manage, the land is for the proposed land use type.

The need for optimum use of land has never been greater than at present, when rapid population growth and urban expansion are making available for agriculture a relatively scarce commodity. The increasing demand for intensification of existing cultivation and opening up of new areas of land can only be satisfied without damage to the environment if land is classified according to its suitability for different kinds of use (FAO, 1983)

The comparison of relevant land-use requirements with the associated land characteristics or land qualities is the essence of analysis of land-use systems. The outcome of this matching procedure forms the basis for assessing the suitability of the land for the defined use. Land suitability is meant to describe the adaptability of land to a specific land use.(Driessen et al., 1992).

The framework for land evaluation (FAO, 1976) recognizes four levels of generalization in classification of land suitability:

-Land suitability orders: A suitability order is simply a statement as to whether an evaluation unit is at all fit for a use or not. It gives no information about limitations or characteristics. ‘S’= Suitable, ‘N’= Not suitable for the land use.

-Land suitability classes indicating the degree of suitability within an order.

-Land suitability subclasses specifying the kind(s) of limitation or kinds of required improvement measures within classes

-Land suitability units indicating differences in required management within subclasses

According to FAO (1974) land suitability classes indicate the degree of suitability within an order. Arabic numbers reflect a sequence of decreasing suitability:

-S1 (highly suitable) – land having no significant limitations to sustained application of the defined use.

-S2 (moderately suitable) – land having limitations that in aggregate are moderately severe for sustained application of the defined use

-S3 (marginally suitable) – land having limitations that in aggregate are severe for sustained application of the defined use and will reduce productivity or benefits.

-N (not suitable) – land having limitations that may be surmountable in time but that cannot be corrected with existing knowledge at a currently acceptable cost.

-N2 (permanently not suitable) – land having limitations that appear so severe as to preclude any possibility of successful sustained application of the defined land use

The designation 'conditionally suitable is sometimes added if a land unit is unsuitable or poorly suitable for a particular use but would be suitable if certain conditions fulfilled.

Table 1 FAO physical suitability classes

S1 S2 S3	Suitable Moderately suitable Marginally suitable
N	Unsuitable

Table 2 FAO economic suitability classes

S1 S2 S3	Suitable Moderately suitable Marginally suitable
N1 N2	Suitable but not economically feasible Unsuitable

Land suitability subclasses indicate the kind of the limitations that seriously restrict the suitability of land; one or more lower-case letters are suffixed to the class symbol (e.g. S2m: moderately suitable land due to limited availability of moisture). There are no subclasses to class S1. If more than one severe limitations affects land-use, the limitations should be listed in the order of seriousness, e.g. S3me: marginally suitable land due to limited availability of moisture and erosion hazard.

2.4 The Concept Of Land Evaluation

Land evaluation is the prediction of land the performance over time under specific uses. These predictions are then used to guide strategic land use decisions (Rossiter, 2001b). The principal objective of land evaluation is to select the optimum land use for each land use type of land, taking into account both physical and socio-economic considerations and the conservation of environmental resources for future use.

Definitions

For a common understanding of most of the terms in land evaluation, this chapter attempts to give some definitions of most of the terms used by the FAO Framework.

Land use type (LUT): Synonym for the FAO's land utilization type, which is defined as a specific manner of occupying and using the land, with specified management methods in a defined technical and socio-economic setting. It may involve any number of activities and products, as long as they form part of one system of management (Rossiter, 2001b). FAO distinguishes simple land use type and compound land use type. A simple land use type is about one use at a time; in agricultural LUTs this means one crop species per cycle. A compound LUT means several uses at a time (intercropping) or more than one activity per cycle (relay or multiple cropping).

Furthermore, a land use type can be fixed or adaptive. In a fixed LUT, inputs and techniques are applied equally on all land areas while in an adaptive LUT inputs and techniques are adjusted according to the specific land area and current conditions

Land use requirements (LUR): A condition of the land necessary for successful and sustained implementation of a specific land use type. Each LUT is defined by a set of LURs.They are the 'demand' side of the land- land use equation: what the use requires of the land (FAO, 1983).

There are five criteria by which we can select land use requirements:

-Importance (relevance) for the use

-Existence of sub-optimal values in the study area

-Existence of differences in the corresponding land quality in the study area

-Availability of data with which to evaluate the corresponding land quality

-Availability of knowledge with which to evaluate the corresponding land quality

Land qualities (LQ): A complex attribute of land, which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use (FAO, 1983). It is thus, the ability of the land to fulfill specific requirements for a land use type. For each land use requirement, there is a corresponding land quality. Land qualities are the 'supply side' of the land- land use equation: what the land can offer to the use. Land qualities are usually complex attributes of the land, which means that they cannot be directly measured or estimated. Therefore, land qualities must be inferred from a set of diagnostic land characteristics.

Land characteristic (LC): According to (Rossiter, 2001c) this is a simple attribute of a land evaluation unit, which can be measured or estimated in a routine field or in a laboratory. It can be used to evaluate one or more land qualities. In general, the effects of a land characteristic on suitability are not direct, but through their effect on land qualities. This is because a single land characteristic may affect several qualities often in contradictory ways. The FAO framework does not allow the use of land characteristics directly to assess suitability, but it is generally clear to land qualities as an intermediate level of evaluation, both because the total complexity of the problem is broken down into more manageable units, and because land qualities in themselves provide useful information to the land evaluator.

Land mapping units (LMU): (Rossiter, 2001b) defines a land mapping unit as a specific area of land that can be delineated on a thematic map and whose land characteristics can be determined. These are sets of map delineations designated by a single name, and representing a single legend category.

2.5 The Automated Land Evaluation System (ALES)

"The automated land evaluation system, or ALES, is a computer programme that allows land evaluators to build the expert systems to evaluate land according to the method presented in Food and Agriculture Organization "Framework for land evaluation" (FAO, 1976). It is intended for use in project or regional scale land evaluation. The entities evaluated by ALES are map units, which may be defined either broadly (as in reconnaissance surveys and general feasibility studies) or narrowly (as in detailed resource surveys and farm scale planning" (Rossiter & Van Wambeke, 1997).

This system has the format of an expert system based again on the FAO framework for land evaluation. It allows the user to build decision trees, containing ratings for land qualities and requirements for land utilization types. The four major components are:

- A knowledge base (the actual expert system), containing descriptions of different land uses in both physical and economic terms
- A data base, containing information on the natural resources (mainly land)
- An inference algorithm, allowing matching of land and land uses
- An explanation facility, which permits analysis of the results.

The knowledge base is specified by the user and contains the relations between land and land use requirements, in which land use can either, be a single crop or a crop rotation. Land use requirements are defined in the system in terms of levels of limitations. Similar levels of limitations may originate from different combinations of land characteristics, as derived from the decision trees.

The database, to be developed by the user, contains information from natural resource surveys. Both discrete and continuous information can be handled by the system, which provides possibilities to generate missing information via decision trees.

In the inference algorithm, matching of land qualities and land use requirements takes place according to user-supplied procedures, which results in an evaluation matrix, that allows easy selection of the best land use for a particular land and the best land for a particular land use. Suitability is expressed quantitatively, according to the framework principles, and quantitatively in relation to a non-constrained yield or 'nominative' yield, for use in economic evaluation.

4. The explanation facility allows the user to analyze the results through a backward chain through the system. Interactive of this facility is possible to improve the evaluation procedure.

ALES is able to evaluate land in physical terms only, or in both physical and economic terms. In ALES, each evaluation consists of land utilization types (LUTs), i.e., proposed land uses, and a set of land mapping units, i.e., land areas being considered In physical evaluation, map units are assigned physical suitability classes, which indicate the relative suitability:’s1’, ‘s2’, ‘s3/n1’ and ‘n2’. ALES can also compute an economic evaluation following the computation of a physical evaluation. If components of the economic model (e.g. prices, optimum yields,) are missing, ALES will not be able to execute the economic evaluation. One of the limitations of ALES is that it has no input or output for maps.

It is necessary for evaluators to construct decision trees to infer each land quality from its set diagnostic land characteristics. These are hierarchical multi-way keys, in which values of the diagnostic LCs are the diagnostic criteria and the result is the severity level of the land quality to be evaluated (Rossiter, 2001b). Here is where the expert knowledge of the evaluator must be put into systematic form.

2.6 Eliciting expert knowledge for land evaluation

Land evaluation is a multi-disciplinary practice, an integrative and iterative process, the methodology of which requires close cooperation between people of different backgrounds- Land use planners, agronomists, research scientists, extensionists, farmers and socio-economists. These are all land use experts with different levels of knowledge on land suitability for different land use types. For a successful land evaluation project, the land evaluator must undertake to extract information from these people and transform it into a format compatible with the FAO land evaluation methodology. As observed by (Rossiter, 2001b) a land use expert is a person who has information about a land use or land quality in relation to the land. The expert must be committed to undergoing a series of interviews by the land evaluator, and later reviewing the results of the preliminary evaluation. A land evaluator must have a good knowledge of natural resources and land uses, be able to think logically and systematically.

It is not an easy task to get the expert knowledge from the experts and then structure it so that it may be used by the expert system. Current shortcomings of eliciting expert knowledge include barriers between specialists belonging to groups with different paradigms and scientific cultures (L. Fresco & Luning, 1990)

Farmers and other country people are a special category of experts: often intimately familiar with land use and land qualities in a restricted area, but usually with a poor understanding of the scientific (predictive) relations underlying the observed phenomena. Their observations can provide an excellent starting point for further investigation (Rossiter, 2001b)

3 Study area

The area around lake Naivasha is very suitable for carrying out investigations on the suitability of the area for irrigated agriculture.(Girma, 2001a) notes that there are a number of large commercial farms around the lake such as Sulmac, Oserian, Delamere, Longonot horticulture, Three points farms and Kijabe farms. These farms produce mainly flowers, foddercrops and vegetables under irrigation. Other activities in the area include tourism, extensive grazing, fishing, fodder production ranching and dairy farming. Therefore, the study area is suitable to provide adequate answers to the research questions stipulated in the introduction.

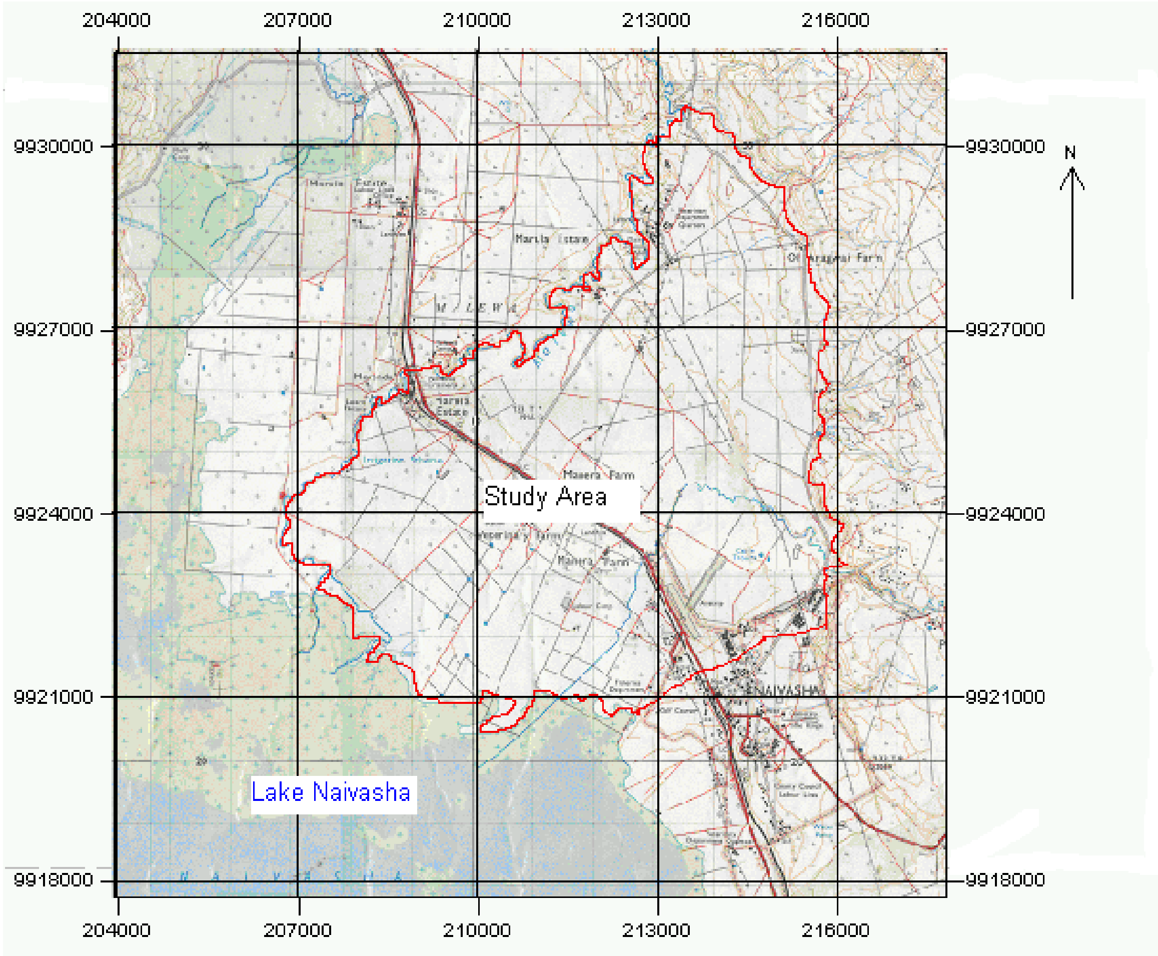

Figure 1 Location map of the study area (North East of Lake Naivasha, KENYA)

3.1 Location

The study area is located within the Lake Naivasha Basin. Naivasha is a shallow tropical freshwater lake situated in the Rift Valley in Kenya. The catchment's area is 3200km. The size of the lake varies between 80 and 160 square km as a response to the climatic inputs (ITC, 1998). The target area of this research is the agricultural area in the North Eastern part of the lake. The main commercial farms in this area in this area are Delamere, Three Point farm and Veg Africa. Horticulture, fodder and flower production are the main commercial activities in these farms.

3.2 Climate

The climate of this area is semi-arid. The mean monthly temperatures range from 15.5 to 17.8 degrees. The average annual rainfall is about 600mm.The evapo-transpiration is about 1360 mm/year, which clearly exceeds the rainfall and creates water deficit for plant growth (Kamoni, 1988) . As shown in table 3, the mean annual temperature ranges from 16- 18.3. The maximum temperature is 27degrees, while the minimum is 7.9 degrees. The area has two rainy seasons. The longest season extends from March to May and has a total rainfall of about 256mm, while the other season extends from August to November with a total rainfall of 194 mm.

Table 3The climatic conditions of Lake Naivasha basin

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Annual rainfall mm	24	39	59	113	84	41	34	44	44	47	59	39
Mean T, C	18	18	18	18	17.1	16	16	16	16.2	17	17	17
Max. TC	27	27	27	25	23.6	23	22	23	24.5	26	25	26
Min T,C	7.9	8.1	9.4	11	10.6	9.2	8.6	8.6	7.9	8.9	9.1	8.3
Eo(mm)	118	178	190	149	132	120	125	142	158	183	134	158
Et (mm)	79	119	127	99	88	80	83	95	105	122	89	105

Source (Kamoni, 1988)

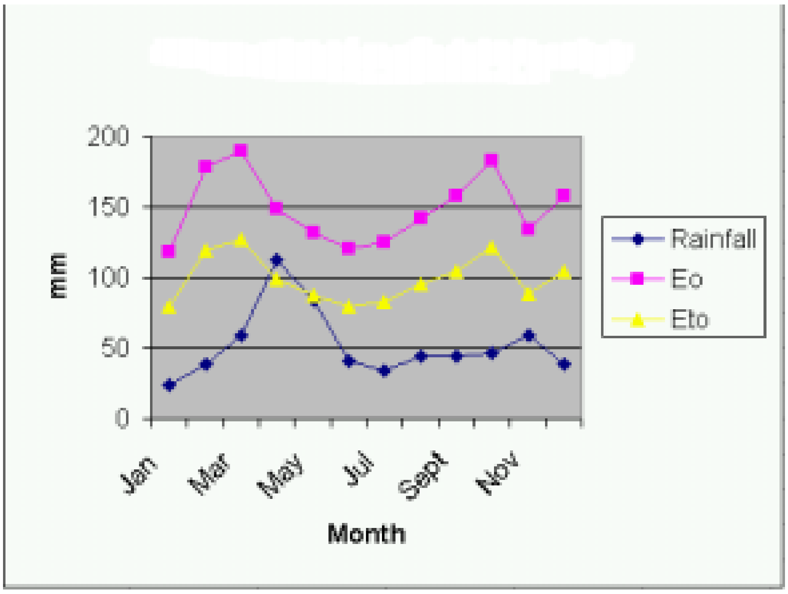

Figure 2 The pattern of rainfall graph in the study area

3.3 Hydrology

The main rivers in the study area are the Gilgil, Malewa and Karati rivers. The Karati River is ephemeral, and contributes very little inflow to the lake. The Gilgil and Malewa rivers collect runoff water from the Aberdare Mountains and their foothills to the NE of the lake, and discharge into the papyrus swamp, forming part of the northern lakeshore (DARLING, 1 : isotopic evidence / by W.G. Darling, from:, & Sciences, 1996) Other sources of water inputs into the lake include rainfall that occurs directly over the lake and through underground water movement. The lake catchment has an internal drainage system. Under ground water constitutes the main source of irrigation water.

3.4 Geology

Geologists have succeeded in making a reasonably detailed map of the area showing the distribution of the Pleistocene to Recent sediments and volcanic rocks, and of the faults that slice through them(Ledgard, 1988). The area embraces the two flanks of the Gregory Rift Valley, with the Kinangop plateau on the east and the Mau escarpment on the west. On the rift floor there are Lake Naivasha, Njorowa Gorge and the Eburu mountains (A O Thompson & R G Dodson, 1958).

According to (A O Thompson & R G Dodson, 1958) the rocks of the area fall into two main groups: 1) Lavas and pyroclastics and 2) Lacustrine deposits. The lavas range from under saturated basic rocks (tephrites) to acid rocks (rhyolites and obsidians). The pyroclastics, some consolidated and others incoherent, cover the greater part of the surface area, and compose great thickness in the flanks, particularly in the Mau escarpment, where they rise to the heights of over 10,000 feet.

The lake deposits, though covering large areas are not thick. Their configuration is closely allied to the present day Rift Valley lakes, which are the remnants of the much greater lakes that existed in the Pleistocene epoch.

The following major geological events in the history of the study area can be distinguished:

-Longonot volcanic formation (poorly exposed pyroclastics and lava)

-Kedog valley tuff formation

-Building of pyraclastic and lava cone (represented by the Akira pumice formation)

-Lava – Longonot trachyte formation

-Formation of summit crater (represented by the Longonot ash formation

3.5 Geomorphology

According to the geopedologic approach (Zinck, 1988), three main landscapes have been identified: The step faulted plateau, the Deltaic River plain and the lacustrine plain. (A O Thompson & R G Dodson, 1958) has however identified three major types of landscapes in Naivasha area: The Kinangop plateau on the eastern side, the Mau escarpment on the western side and the rift floor, situated in between

3.6 Soils

Different soil surveyors have carried out soil studies with varying scales of intensity. The soils of the Lake Naivasha are varied due to variation in climate, parent material, relief and the influence of man. According to (W. Siderius, 1980) the distribution of soils in the area is complex. Generally, soils of the study area can be grouped into two: Soils developed on the lacustrine plain and those developed on the volcanic plain. Soils developed on the lacustrine plain are moderately well drained to well drained, very deep, grayish brown to pale brown, clay loam to loam. Soils developed on the volcanic plain are well drained, moderately deep to very deep, dark brown to pale brown, with non calcareous to moderately calcareous topsoil and moderately to strong calcareous deep soil (Girma, 2001b)

In addition there are soils developed on the step faulted plateu and its outliers. These are shallow rocky and clayey. The types of soils in the area are Haplic Luvisols, Eutric Cambisols, Haplic Fluvisols dominating the lacustrine plain, and Haplic Andosols dominating the volcanic plain (ISRIC, 1998)

3.7 Land use

The study area has a variety of commercial activities (ITC, 1998).The main commercial farms in this area are Delamere, Three point farm and Veg Africa. The following land uses can be distinguished in the study area:

-Residential area

-High value intensive agricultural land (Horticulture and flower growing)

-Dairy farming

-Fodder production

-Beef production

Outside the irrigated zone the main use is extensive grazing and some smallholder grains. In chapter 5, details of two land use types are studied.

Figure 3 Ranching in the Deltaic River Plain

Figure 4 Pivot irrigation in the study area at Delamere Farm.

Most of the farms in the study use pivot irrigation. This is because drip irrigation is considered to be very expensive.

4 Methods and materials

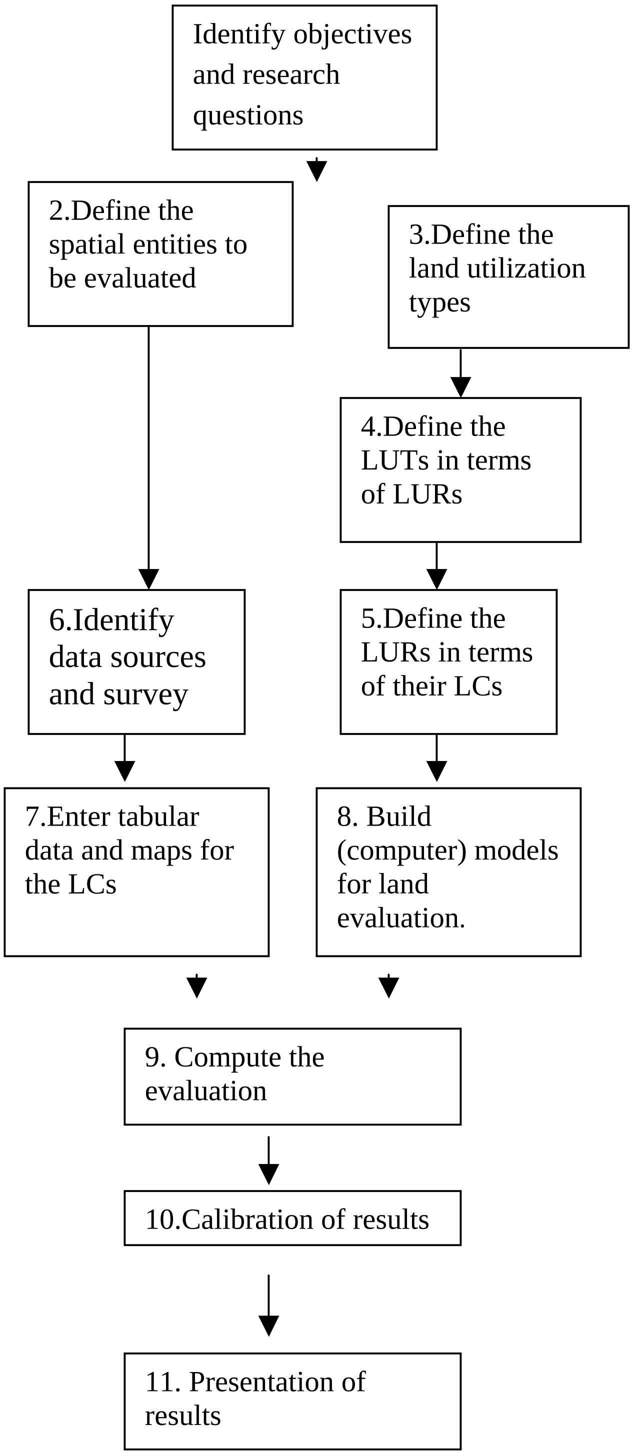

Figure 5 An illustration of the methodology followed during the research project

Source (Rossiter, 2001a)

The research project was divided into three stages namely: Pre-field work, fieldwork and post field work. A generalized schematic illustration of the main steps followed is shown in figure 5

4.1 Pre-field work

This was the first stage of the research work which included many activities such as proposal writing, literature search, collection of information about the study area (soils, geology, climate, land use) preparing interview forms and making a list of equipment required for the field work. The following were the materials required for a successful execution of the project:

-Topographic map of Navasha at the scale of 1:50 000 (1975) (BKS Surveys Ltd., 1975)

-Exploratory soil map and agro-climatic zone map of Kenya (semi detailed) at the scale of 1: 1000,000 (Sombroek, Braun, & van der pour, 1980)

-Geological map of the area (1:50,000), Ledgard , 1988

-Aerial photographs at the scale of 1: 50,000 (1972) and 1: 12,000 (1984)

-Satellite imagery (Landsat TM) January, 1995 and May 2000.

-Computer software: ILWIS, MS excel, MS word, Ales and Endnote-4

-Field equipment: GPS (Garmin XL), Slope meter, Altimeter, pH meter, measuring scale, soil sampling and digging tools.

One of the constituent activities of the pre-field work phase was aerial photo interpretation of the study area using the 1:50, 000 photos. Based on the geopedological approach (Zinck, 1988) a preliminary photo interpretation of the NE portion of Lake Naivasha was made.

In order to distinguish the boundaries of the study area, the topographic map (1: 50,000) 1975, was scanned with TIF format and georeferenced using georeference tiepoints (Affine transformation) and coordinate system Naiv. Using screen digitizing, the study area was carefully delineated. In delineating the study area, the Kinangop plateau formed the eastern boundary, the Malewa river formed the northern and western boundaries, while the Lake Naivasha formed the southern boundary.

Based on the preliminary aerial photo interpretation of the study area, a preliminary sampling scheme was made and consisted of transects of observation points from the north to the south and form the west to the east across the study area. The sampling scheme was later adjusted in the field.

4.2 Field work

The component parts of the fieldwork were soil survey and interviews.

4.2.1 Soil survey

The geopedological map, which was processed during the pre-fieldwork phase, was verified and modified in the field. New landforms such as abandoned river channel and overflow basins were included in the revised geopedological legend. Soil information was collected within the framework of the research objectives using a geopodological approach in which soil landscape relation stands central. Soil observations were made within the units identified by the aerial photo interpretation. Most of the sampling areas fell within the deltaic river plain, the lacustrine plain and the step-faulted plateau along the selected areas. Auger hole observations were made along transects and soil properties like pH, texture, color, consistence when wet and stoniness were recorded.

Representative profile pits were dug in each of the main mapping units from which samples for chemical and physical analysis were collected in special sampling bags. Soils were mainly described in mini-pits (0-80 cm) followed by an augering up to the depth of 120 to 150 cm. Soils were described according to the FAO guidelines for soil profile description (FAO, 1990). The world reference base for soil resources (ISRIC, 1998) was used to classify the soils.

At each sampling point, all the routine survey parameters and other characteristics required for land evaluation such as slope of the area, drainage, soil depth, soil color, texture, structure, stoniness, consistence, field pH, land use, horizon boundary etc., were recorded at the profile site. See the map in figure 6 showing the sample points.

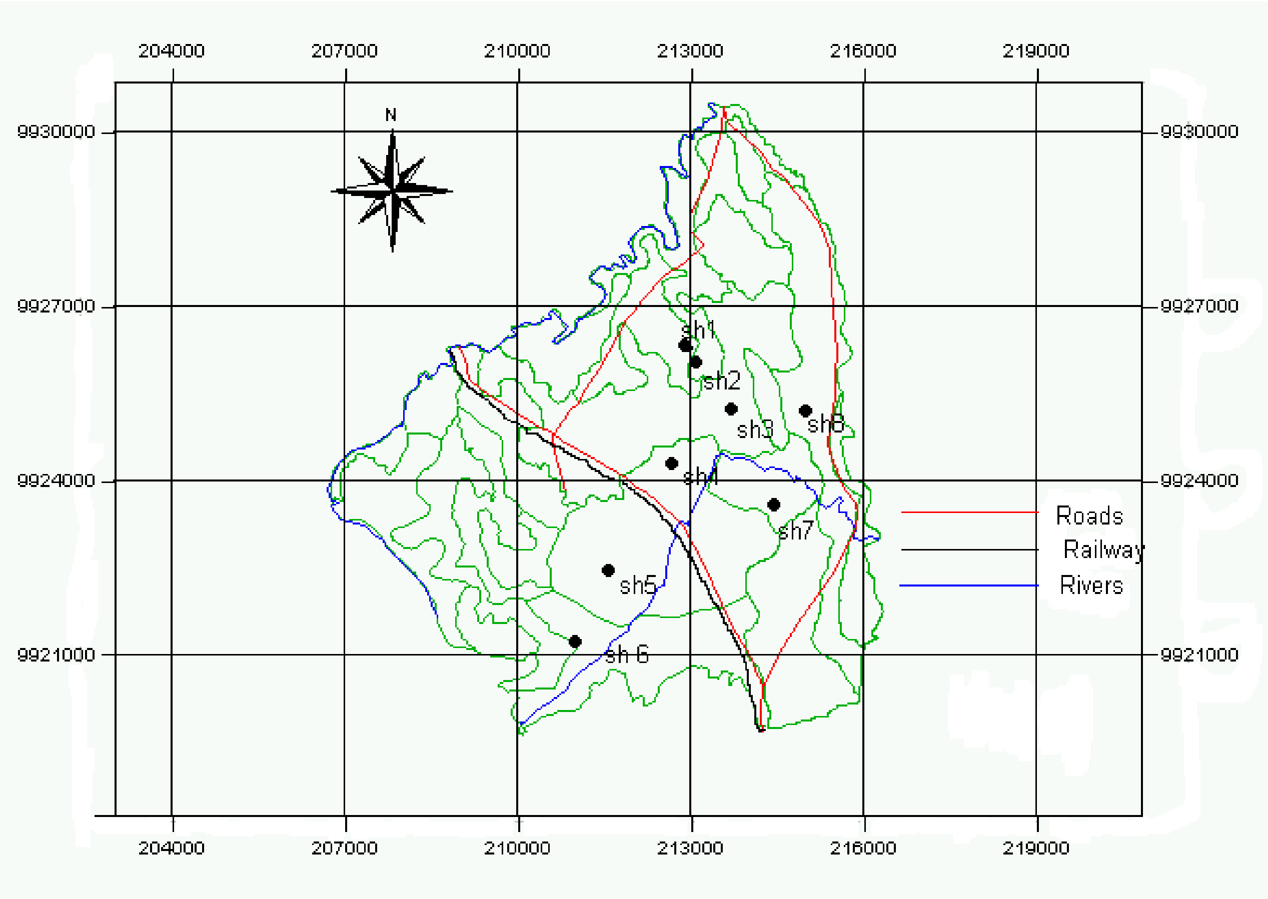

Figure 6Location of the main soil profiles. See details in appendix A

The detail and reliability of results are dictated by the time allocated in relation to the size of the study area (FAO, 1983). In this particular study, the total area under investigation is 5950 ha; time allocated was not adequate to produce all the information for a reliable prediction of land suitability.

4.2.2 Interviews

One of the main objectives of this research is to find the best ways of extracting knowledge from experts for the purpose of land evaluation. In the methodology, the first step was to inform the experts about the objectives and purpose of our study. Before any interviews could be conducted at any farm, an ITC staff member, who was also our field supervisor, had to introduce us to the farm owners. Farm owners/managers were informed that the end product of the interviews will be a land evaluation report, and that its quality would highly depend on their cooperation and willingness to provide the requested information. We also informed them that, they would receive a copy of the land evaluation report, which could be used as a reference in different aspects of farm management. As a result farm owners, managers and other experts were very willing to give us most of the information we required.

Secondly we asked the farm owner/Manager to give us a brief history of the farm and the current farm activities, farm maps, reports on previous surveys and any written materials about the soils, land use, management constraints etc.

Based on the interview forms prepared during the pre-fieldwork stage, interviews were conducted in order to establish the land use types, land use requirements, severity levels, land characteristics (diagnostic factors) and decision trees. Within the study area, there are three main farms namely: Three Point farm, Delamere and Veg Africa. Accordingly, interviews were conducted with the farmers, managers, agriculturists and workers on these farms. In order to make the interviewees prepare adequately for the interviews, appointments were made at least two days prior to the interview date.

During the interviews, the experts were given all the freedom to express themselves freely, without any interjections or objections from the evaluator. The contribution from the evaluator only came in form of suggestions and clarifications before recording the response.

During the interviews, it was very necessary to make the questions as clear as possible because some experts could not understand the questions in their current format. Before any response could be recorded, it was ensured that the respondent understood the question very clearly. Since most of the experts do not think in terms of land evaluation, most of the questions had to be re-phrased or simplified. The interviews were conducted either with individuals or with a group of experts.

Mainly farm owners answered management questions, agronomists and horticulturists answered environmental and agronomic questions. The experts could not answer some technical questions (mainly agronomic). Whenever this was the case, we tried to ask the same question in different ways. If no answer was given, we tried to suggest possible answers to the expert (This was the case on most soil related land qualities, on which we have some general knowledge from literature) after which we would let the respondent express his/her opinion in his own words. However, where we noticed genuine incompetence in the area addressed by the question, we skipped it to avoid constraining or disgracing the expert. Obviously, this would create some information gaps in the land evaluation process as well as the expert system. In such circumstances, and of course where possible, we have the prerogative to fill such gaps using information from other researchers.

Knowing that the land evaluation will be executed by an expert system, which requires information in a certain format, well structured, exhaustive and guided interviews were conducted. The interview forms are attached in appendix B

To avoid constraining and boring the respondents with a long discussion, we proposed the following schedule:

Table 4 Proposed schedule for conducting interviews with experts.

Day	*Hours*	*Topic*
Day 1	2 hours	Introduction, collection of farm reports and maps
Day 2	2 hours	Definition of land use types
Day 3	2 hours	Identification of land use requirements
Day 4	2 hours	Identification of diagnostic factors
Day 5	3 hours	Construction of decision trees
Day 6	30 minutes	Any follow up questions

4.3 Post-fieldwork

4.3.1 Laboratory analysis

Laboratory tests for physical and chemical analyses were conducted at the ITC laboratory. Before any analysis was done, all the samples were dried, crashed and sieved through a 2-mm sieve. The following parameters were analyzed in the laboratory [International Soil Reference and Information Centre, 1998 #79]:

- Particle size (USDA): Pipette method
- Organic carbon: Walkkley and black method
- pH – H2O: Measured in 1: 5 soil-water suspension
- EC: Measured in 1: 5 soil-water suspension
- Exchangeable bases: Varian Liberty 11 Sequential ICP- AES with axial plasma

The results of the laboratory analyses are shown in the appendix C

4.3.2 Creating geometrically-correct photo interpretations

After fieldwork, the aerial photographs were re-examined and some adjustments were made to the original photo interpretation based on observations in the field. The resulting interpretation overlays are not geometrically correct, because of the well-known problems of tilt, radial and relief displacement across the photo. They are also not georeferenced [Rossiter, 2001 #1]

After photo interpretation, ten tiepoints on the photographs were selected. These included mainly road junctions, bridges and buildings. These are points, which can be seen also on the topographic map and were also precisely marked on the overlay. Their coordinates were read from the topographic map with a precision of 0.25 mm for a 1:50,000-scale map. A steel millimeter ruler was used for this purpose.

The type of georeferencing performed was orthophoto taking into consideration the mountains and hills in the study area. Photos were scanned using an A3 scanner at a resolution of 1200 dots/inch. The overlays were scanned at a resolution of 300 dot/inch and stored in the directory as TIF files.

The principal distance of the camera was determined (152mm). The principal point and the fudicial marks were located, after which the distances from the principal point to the fudicial marks were measured : -10.6;10.65 cm(Top left), 10.6; 10.65 cm(top right), 10.6;-10.65 cm (bottom right) and –10.6; -10.6 cm (bottom left).

In ILWIS, a coordinate system 'NAIV' and a 20-m resolution digital elevation model 'DEMFINAL' which were produced by the ITC REM division was used for all the required ILWIS operations. The coordinate system has the same parameters as the topographic map: Projection: UTM zone 37 S and Datum: Arc 1960.

Both the photos and the overlays were georeferenced. During georeferencing, the principal distance and the fudicial marks indicated above were specified. Segments from the scanned overlay were traced, using on screen digitizing. This was done separately for each photo overlay. Using the ILWIS function glueseg, all the overlays were joined into one segment map. All the open polygons were closed, after which a new point file with a new domain (Legend categories) was created. For each polygon, label points were screen digitized, using the segment map as the background map. The segment map was polygonized using the point map as labels, resulting into a georefernced and geometrically correct polygon map. (See map in figure 8)

For the creation of an orthophoto mosaic, the georeferenced photos were resampled. The pixel size in the georefernced images was determined. Having resampled the photos, a geometrically correct, georeferenced photomosaic was made using an ILWIS operation 'Glueras'. The resulting orthophoto mosaic is shown in Figure 7

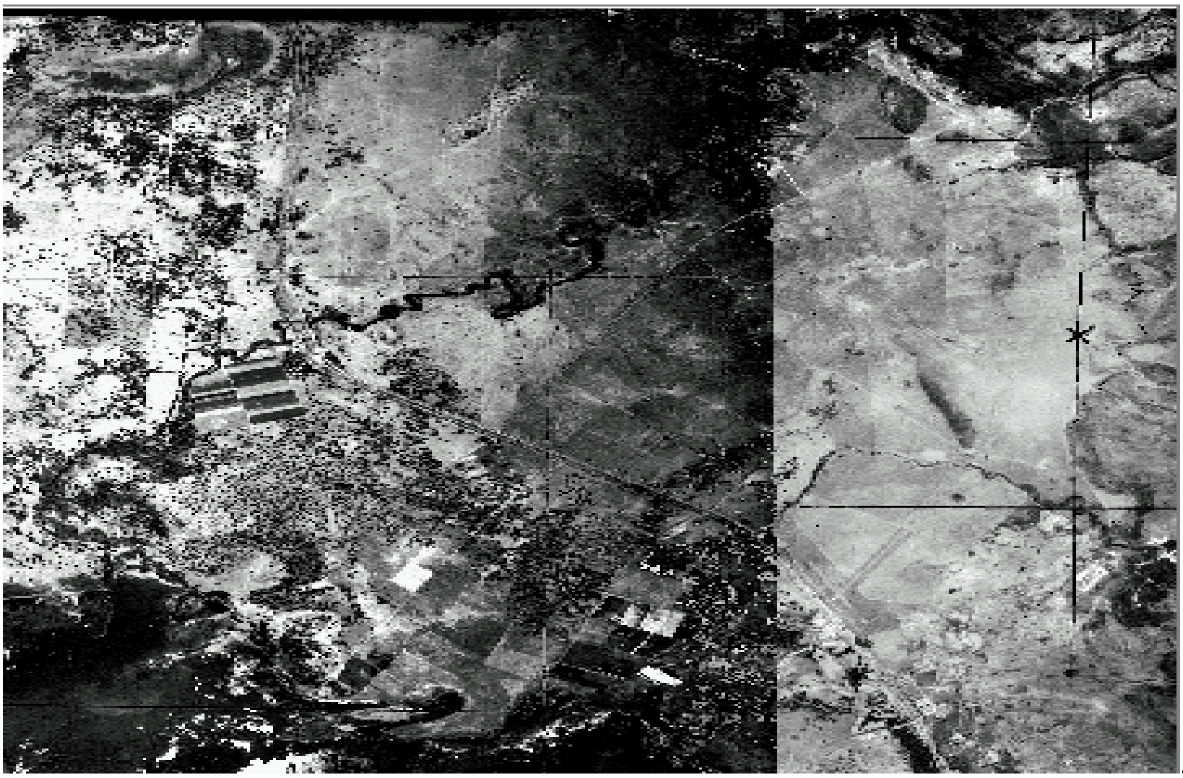

Figure 7 Orthophoto mosaic of the study area

4.3.3 Soil description and classification

The soils in different mapping units were described and classified according to the standard procedures outlined in the FAO guidelines for soil profile description (FAO, 1990) and the World Reference Base for soil resources [Centre, 1998 #79]. Detailed soil profile descriptions are attached in appendix

4.4 Mapping units

In this study, geopedological units were considered as the basic units for the evaluation of land suitability. A geopedological unit includes both geomorphology (landscape, relief, lithology and detailed land form) and soils. Soil survey was carried out using the geopedologic approach (Zinck, 1988). By this approach, it is assumed that landscape relations separate most of the variation in the soils, and sample areas are representative; so their soil pattern can be extrapolated to unvisited map units (Girma, 2001a). Some auger hole observations were carried out to verify map unit composition and type (consociation, association, or complex).

The principal data source were stereo pairs of photogrammetric airphotos. In addition, TM images, the exploratory soil map and the geological map of the study area were used to define the land-mapping units.

4.5 Identification and classification of land use types

In determining the land use types, a number of determinants were considered. Taking into account the limited amount of time, simple land use types were preferred. In defining the LUT, we used a checklist of headings suggested by (Rossiter, 2001b), adopted for the local conditions from prior knowledge from ITC staff (Hennmann, Siderius, Rossiter, Becht, Mannaerts). Some of the most important determinants considered are: Location, technology, produce, labor, cropping system, water supply, irrigation method, mechanization of operations, cultivation practices, size of farms, and so forth. (Refer to the questionnaires for field data collection). Obviously, only some of the determinants were used in a given situation. Information on these determinants was obtained through interviews from farmers, farm managers, and other agricultural experts.

4.6 Defining land use requirements

The intention was to identify and study between five to ten land use requirements for each identified land use type. However, during the interviews no limit was put on the number of land use requirements suggested by the respondents. This was left to the evaluator to determine which requirements to include in the expert system. The selection of the land use requirements were based on the following five criteria: (Rossiter, 2001b).

- Importance (relevance) for the use
- Existence of sub-optimal values in the study zone
- Existence of differences in the corresponding land quality in the study zone
- Availability of knowledge with which to evaluate the corresponding land quality.
- Availability of data with which to evaluate the corresponding land quality.

The land use requirements for specific land use types were established through extensive interviews with farmers, farm managers, agronomists and agronomic literature. Diagnostic characteristics were also established through interviews. This stage was very critical because the construction of decision trees stemmed from here.

4.7 Data analysis

Most of the diagnostic land characteristics were measured either directly during the soil survey or through laboratory tests. The tabular data and maps for the land characteristics were entered into ALES for analysis. With the help of this software, the evaluation was computed and its results calibrated. ALES predicted the performance of each land-mapping unit by establishing the suitability classes. ALES has no map input or output. However, with the help of the Integrated Land and Water Information System (ILWIS), a Geographical information system, the land suitability of the study area was spatially mapped. See suitability maps in figures 12-21

5 Results and discussion

5.1 Description of the landscapes

After API, a geopedological map (Fig.7) of the study area with corresponding legend was compiled.There are three main landscape units in the study area: Step faulted plateau, deltaic river plain and lacustrine plain.

Step faulted plateau (Lf)– The step-faulted plateau occurs in the eastern part of the study area, forming the lowest part of a sequence of step faulted plateaus of which the Kinangop plateau represents the highest level. Soils in this landscape are generally well drained and range from deep to (120cm) to very deep (150 cm) with a relatively coarse structure. Slopes vary from gently sloping (5%) to moderately steep (30%). The relatively low pH values in this landscape can be attributed to deposits from the Limuru trachyte.

In this landscape, three relief forms have been identified: outlier hills, scarp and footslope. At landform level, there are four map units with varying slope classes: Slope complex (45%), scarp (30 %), upper foot slope (5%) and lowerfoot slope (10%) This landscape includes outlier hills

Deltaic River plain (Pf) -- This landscape occupies the northern and western parts of the study area and is characterized by many fluvial related geomorphic features such as abandoned river channel, levees and overflow basins. It is topographically higher than the lacustrine plain, indicating that sediments were deposited as deltas in the higher lake stages. The deposition of fluvial materials from the Malewa River on to the lacustrine plain is clearly evident (A.O Thompson & R.G Dodson, 1958). The main relief types are in form of high river terraces and vales. Although no detailed soil descriptions were done in most of the polygons, soils are probably not so rich because there is very little cultivated agriculture in the area. Most of the area is used for ranching and grazing. Slopes vary between gently sloping (4%) and sloping (8%).

Lacustrine plain (Pl) – The lacustrine plain makes up the central part of the study area and is the largest landscape, covering more than 60 % of the study area. Most of the cultivated agricultural activities are found in this unit. It is therefore not a coincidence that most of the observation points were concentrated in this landscape. The three relief forms recognized in this unit are upper lacustrine plain, mid lacustrine plain and lower lacustrine. The topography ranges from flat (0%) to very gently sloping (2%). Generally, the soils are very deep and well drained, varying from silty clay to silty clay loam. However, in the lower lacustrine plain, especially near the lake the texture is coarser- mainly sandy clay loam.

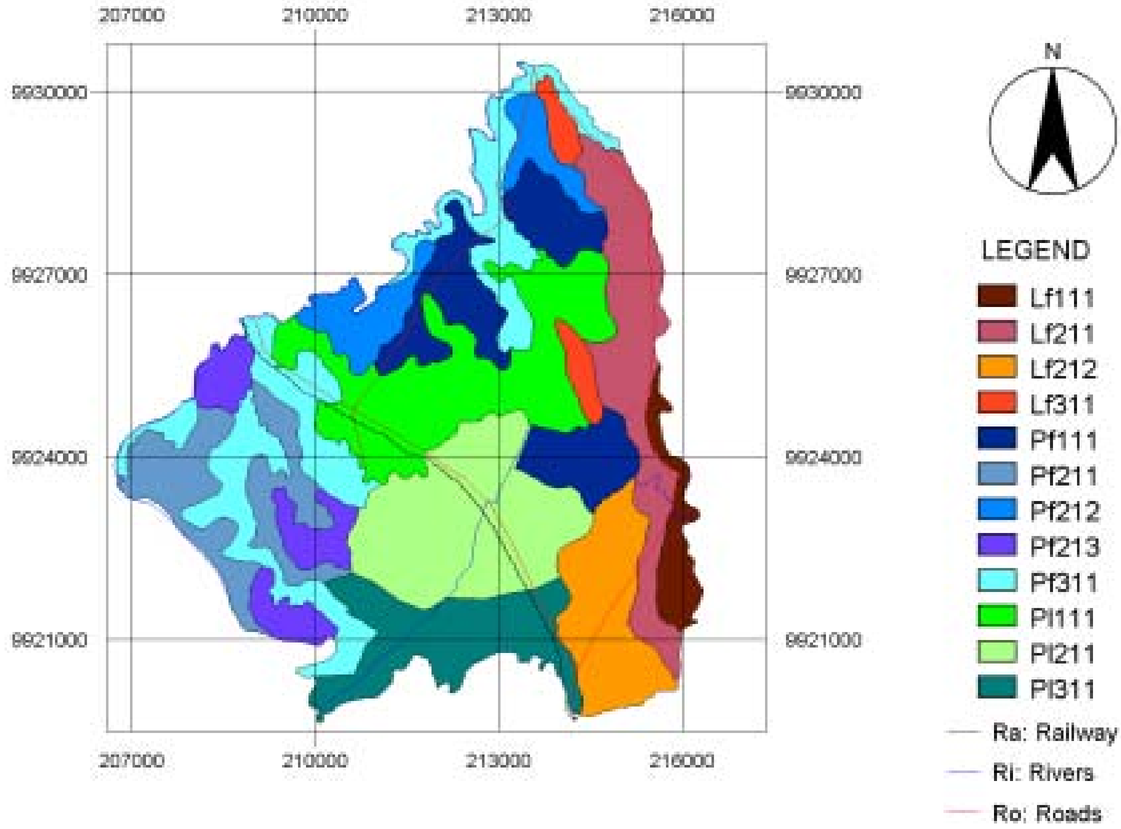

Figure 8 Geopedological map of the study area (North East of Lake Naivasha)

UTM ZONE 37 SOUTH
DATUM: ARC 1960
SCALE: 1: 50,000
C.M. SHEPANDE,
MARCH, 2002

Table 5 The geopedological map legend

Landscape	*Relief-type / Molding*	*Lithology/Facies*	*Landform*	*Code*
Step-faulted plateau	Scarp	Kinangop-turff, Eburu Pumice	Scarp	Lf 111
	Footslope	-do-	Upper footslope	Lf 211
		Kinangop-turff, pumice, Lacustrine deposits	Lower footslope	Lf 212
	Outlier hills	Limuru trachyte, Eburru pumice	Slope complex	Lf 311
Deltaic River Plain	High terrace	Fluvio-deltaic deposits	Tread riser complex	Pf 111
	Lower terrace	-do-	Tread	Pf 211
			Riser	Pf 212
			Overflow basin	Pf 213
	Vale	-do-	Abandoned river channel	Pf 311
Lacustrine Plain	High level	Lacustrine sediments	Level surfaces	Pl 111
	Mid level	-do-	-do-	Pl 211
	Low level	-do-	-do-	Pl 311

The cross section runs through the study area from the Kinangop Mountains (Point A) to Lake Naivasha (point B). The cross section below further shows the elevation variation in the area.

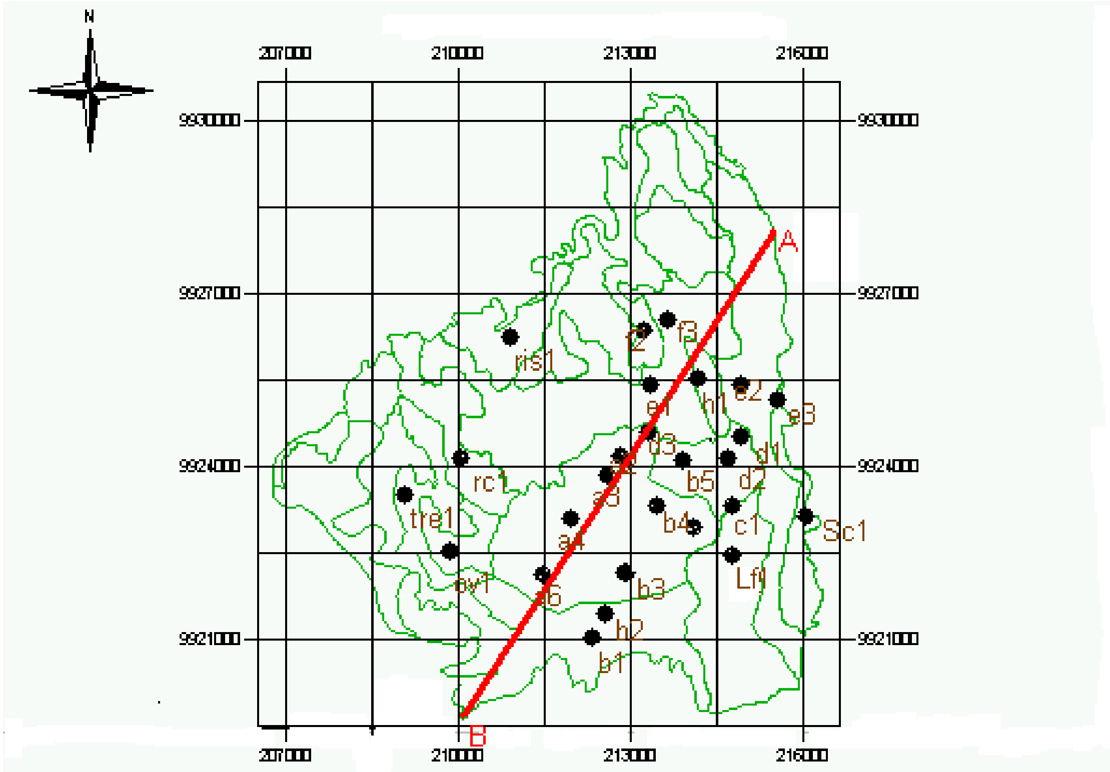

Figure 9Location of auger hole observation points and cross section through the study area.

Figure 10Graphical expression of the cross section through the study area.

5.2 Soils and land use in geopedological units

The soils in the landscapes have much in common. In the lacustrine plain for example, a buried 'A' horizon is quiet common in many profiles. Most of the map units are consociations. The homogeneity of the units is explained by the consistence of land use and vegetation. This is further confirmed by auger hole observations made in different parts of some of the units.

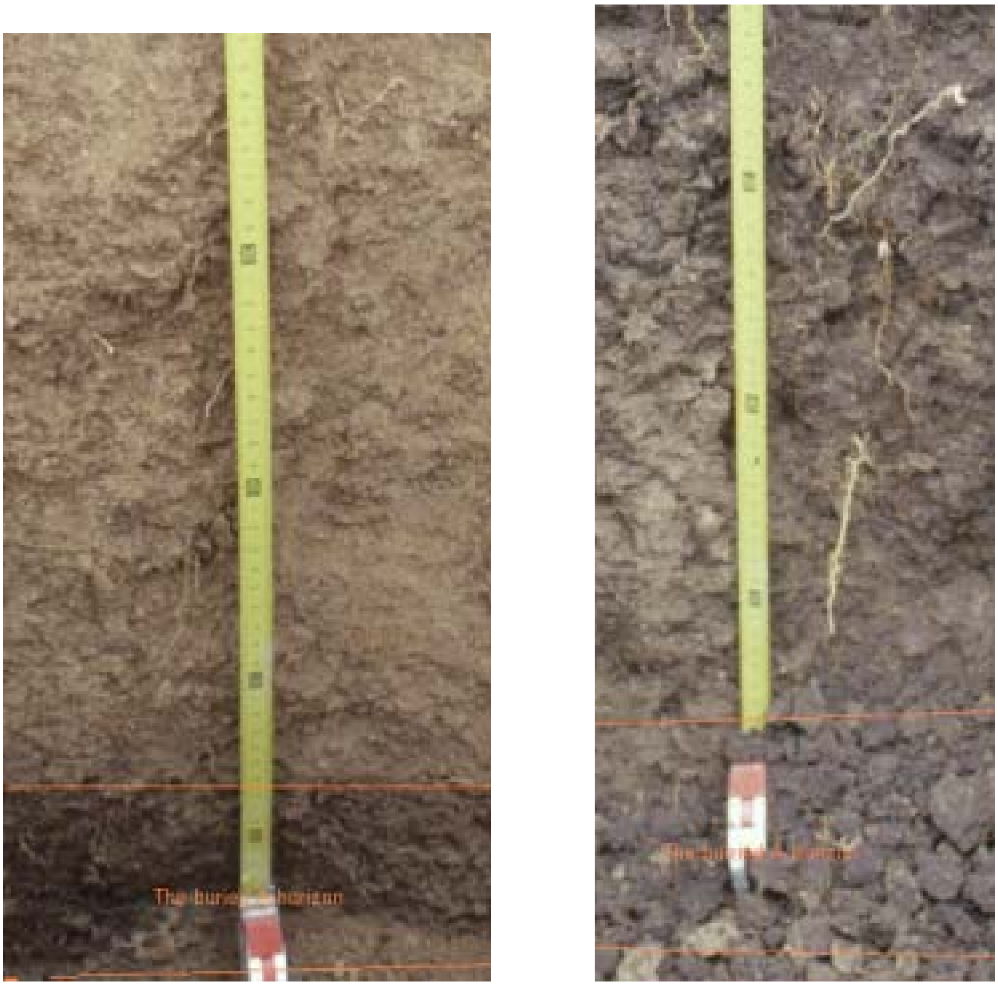

Figure 11 Soil profiles showing buried A horizons in profile No. Shep 4 and Shep 6 (See details in Appendix A)

Table 6 An estimate of legend (Map units and their characteristics)

GP Unit	*Organic matter content (%)*	*Particle size class*	*Soildepth (cm)*	*pH*	*EC, dS/m*	*Drainage class*	*Slope gradient %*
Lf 111	4.2	FS - VFS	20-30	5.0	1.3	Well drained	30
Lf 211	4.2	FS - VFS	>150	4.5	1.3	Well drained	5
Lf 212	3.2	MS	100-I20	5.0	0.8	Moderately well drained	8
Lf 311	3.2	CS	10-15	4	0.6	Well drained	45
Pf 111	3.4	FS	100	5.0	1.6	Well drained	8
Pf 211	3.4	FS	100-110	5.5	1.6	Well drained	4
Pf 212	3.2	MS	100-115	5.5	0.8	Well drained	8
Pf 213	8.6	VFS	> 150	6.5	1.5	Moderately well drained	4
Pf 311	8.6	VFS	>150	6.5	1.5	Imperfectly drained	4
Pl 111	5.6	VFS, Si	> 150	6.5	1.2	Moderately well - well drained	0.5
Pl 211	7.8	Si	>150	6.5	1.0	Moderately well - well drained	0
Pl 311	8.2	VFS	100-150	8.0	3.8	Moderately well-Well drained	0-1

Note : Not enough samples were taken to establish the true nature of the map units.

GP Unit	*Wet consistence*	*Dry consistence*	*Stoniness (%)*	*TEB (cmol /kg)*	*Crust thickness (mm)*	*Texture*	*Diatomite*
Lf 111	Sticky	Hard	20	29.4	0	FSC	Nil
Lf 211	Very sticky	Hard	0	46.3	0	SC	Nil
Lf 212	Slightly sticky	Slightly hard	15	41.2	2-5	SCL	Nil
Lf31	Not sticky	Loose	45	28.0	0	CS	Nil
Pf 111	Slightly sticky	SL. hard to hard	0	43.2	0	SCL	Nil
Pf 211	Slightly sticky	SL. Hard to hard	0	45.0	0	SCL	Nil
Pf 212	Slightly sticky	Slightly hard	5	41.2	0	SCL	Nil
Pf 213	Sticky	Slightly hard	0	73.0	0	CL	Nil
Pf 311	Sticky	Slightly hard	0	73.2	0	C	Nil
Pl 111	Slightly sticky	Slightly hard	0	71.2	2	SiCL	Below 40 cm
Pl 211	Slightly sticky	Very hard	0	83.1	0	SCL	Nil
Pl 311	Sticky	Slightly hard	0	91.5	2	SiC to SCL	Between 32-50 cm

As observed by (Bregt, 1992) landscape features such as landform, topography vegetation, land use and hydrology are a good indication of the nature of the nature of the soil and how and where it changes. On this basis we established the homogeneity of the different geopedological-mapping units.

Lf 111, Scarp of the step-faulted plateau

This unit has no agricultural significance due to its position in the terrain with a moderately steep slope (30%). The surface is stony; the soils in this map unit are well-drained, mainly sandy clay with organic matter content of about 4.2 %. The pH of the surface horizon is around 5.0. The EC of the upper horizon is around 1.3 d s/m. Soil color is brown (10YR

5/3). When wet the soils have a very sticky consistence. At the time of survey the unit was not used for any agricultural purposes. The size of this unit is 151 ha.

Lf 211, Upper footslope of the step-faulted plateau

Soils of this map unit are generally very deep and well drained. Soil color is very dark gray (7.5YR 3/1) or dark gray (7.5YR 4/1) when dry. The texture in all the observed horizons is silty clay. The structure of the upper horizon is strong and medium size, while the structure of the horizons beneath is moderate to weak. Due to their heavy texture, these soils are very sticky when wet. The pH is around 4.5 to 5.0. The electric conductivity is 1.3ds/mThe organic matter content in these soils is about4.2. Soils are generally friable when wet and hard when dry. Situated on a gentle slope (4-5 %), these soils are never saturated. The total area of this unit is 567 ha. The predominant land use in this map unit is irrigated agriculture (cabbage)

Lf 212, lower footslope of the step-faulted plateau

In this map unit, soils are mainly clay loam- sandy clay loam, mainly dark brown (7.5YR 3/2) and light reddish brown (5 YR 6/3) when dry. However, the soil in the lower horizon ranges from gray to pinkish gray. The soils are generally deep and well drained. Due to a rolling topography (10% slope), this unit is characterized with a moderately rapid run off. The soil structure is moderate with a slightly sticky consistence when wet. The field pH is 5.0. The electric conductivity is around 0.8 ds/m. The organic matter content in the upper horizon is around3.2%, while in the horizons beneath it is about 2.6 %. Sealing of medium thickness, about 2-5 mm is common. At the time of survey, this unit was mainly under irrigated agriculture. Its total area is 421 ha.

Lf311, outlier hills

In this mapping unit only auger hole observations were made due to the rocky nature of the hills. The soils of this unit are very shallow, less than 30cm due to underlying rocks. Course sand and gravel are predominant, the result of which soils are somewhat excessively drained. It has a steep slope of about 45%, with brown (10YR4/3) coarse sands. The Limuru trachyte and the Eburu pumice are the most common parent materials in this unit. The pH values in this area are as low as 4.0. The EC value is about 0.6 ds/m. Due to its poor soil conditions, this area is not used for any agricultural production. Drought resistant trees dominate the vegetation in this unit, an indication of water unavailability presumably due to excessive drainage. This unit occupies 115 ha.

Pf 111, tread/ riser complex of the deltaic river plain

In this map unit the soils are mainly sandy clay loam. They are darkish brown (10YR3/2) and brown (10YR4/3) when dry. The soils are deep (between 100-150 cm) and well drained. It neither receives nor sheds water. The slope of this tread/riser complex is 8%. The soil structure in this unit is moderate with a medium to coarse size. They have a slightly sticky consistence when wet. Field pH ranges from 5.0 to 5.5. The electric conductivity is around1.6 ds/m. The organic matter content is about 4.3 %. The main land use in this map unit is intensive grazing and ranching. Fluvial deposits from either the Malewa or the Karati River are very evident in this unit. It occupies 607 ha.

Pf 211, tread of the deltaic river plain.

The soils in this map unit have the same properties as the soils in map unit Pf111, but in unit, the slope is about 4 %. The soils are deep and well-drained and mainly sandy clay loam. Like in map unit Pf111, the main landuse is intensive grazing.It occupies 476 ha. With a well-drained system, the soil neither receives nor sheds water.

Pf 212, riser of the deltaic river plain

The soils in this map unit are mainly dark drown (7.5YR3/2) or reddish brown (5YR6/3) when dry. The lower horizons are dark gray (7.5 YR4/1) or pinkish gray (5YR7/2) when dry. The soils in the top horizon are clay loam while those in the deeper horizons are sandy clay loam. This unit has a rolling slope of 10%. The soil structure in the upper horizon is moderate, while that of lower horizon is weak to moderate. The organic matter content is about 3.2 % .The soils are generally deep and well drained. Malewa fluvial deposits, mainly in form of coarse round gravel is clearly evident in most parts of this unit. The consistence when wet is slightly sticky and plastic. The soil pH is around 7.0 with an electric conductivity of about 0.8 dS/m. It occupies 295 ha. The main landuse in this unit is intensive grazing.

Pf 213, overflow basin of the deltaic river plain

The soils in this map unit have the same properties as those in Pf 311. This can be attributed to the fact that the depositional environment in an overflow basin and abandoned river channel is the same. It has a slope of 3 to 5 %. The soils are very deep with a strong structure. There is a clear stratification of silt and clay properties. This can be attributed to the deposition of river materials. Its size is 288

Pf 311, abandoned river channel of the deltaic river plain

The soils of this map unit are very dark grayish brown (10YR 3/2) or dark gray (10YR4/2) when dry .It has a gentle slope of 4%. The soils are clay with a strong structure of medium size in all horizons. From the depth of 50 to 90 cm the soils are sandy clay. When wet, these soils are sticky and plastic. The soils are very deep, more than 150 cm and somewhat poorly drained due to their heavy texture. The field pH ranges form 5 to 6.5, with an electric conductivity of about 1.5 dS/m. Soils in this map unit have a very high organic matter content of 8.6%. The main land use in this map unit is intensive grazing and ranching. The area occupied by this unit is 939 ha.

Pl 111, higher part of the lacustrine plain

This is the highest part of the lacustrine plain and occupies 891 ha.. In this map unit, the soils in the upper horizon (0-20 cm) are mainly silty clay. From 20 to 40 cm the soil is silty clay loam. In the horizons beneath, the soil becomes silty loam, with some evidence of diatomite at the depth of 40 cm. There is sealing and ponding presumably due to diatomite and silt. The soils of this unit are black (7.5 YR2.5/1) or gray (7.5 YR 5/1) when dry. The soil structure in the upper horizon is strong, with a fine to medium size. The topography is almost flat, with slope of 0.5%. This unit neither receives nor sheds water. The soils are very deep, more than 150 cm, but somewhat poorly drained. They are sticky and very plastic when wet. The soils have a field pH of around 5.5, with an electric conductivity of 1.2 ds/m. The organic matter content is high (around 5.6%) .The landuse at the time of survey was irrigated agriculture (Roses).

Pl 211, middle part of the lacustrine plain

The soils in this map unit are dark brown (10YR 3/3) or grayish brown (10YR 5/2) when dry. They are mainly silty clay – silty clay loam, with a moderate structure.

The topography of this unit is flat and the slope is almost 0%. The buried Ah horizon, lying at the depth of 57 cm has a strong structure. The soils are moderately well drained very deep (more than 150 cm deep) and have a sticky consistence when wet. Field pH is between 5.5 and 6.5. The electric conductivity is 1.0 dS/m. The organic matter content is approximately 7.8 %. Due to its flat topography, this unit neither receives nor sheds water.

At the time of survey, there were two landuses in this map unit: A ploughed fallow and irrigated cabbage. It occupies 807 ha.

Pl 311, lower part of the lacustrine plain

Soils of this map unit are generally very deep and well drained. Situated on the edge of the Lake Naivasha, it has a very gentle slope of 2%. The soils are dark gray (5YR 4/1) or gray (10YR 5/1) when dry. The structure is weak to moderate. Texture is sandy clay loam. The soil texture in this unit is lighter than the texture in the two previous lacustrine map units (Pl. 111 & Pl. 211). The field pH is as high as 8.9, with an electric conductivity of as high as 3.8 ds/m. The organic matter content in the upper horizon is 8.2%. There is evidence of diatomite at the depth of 32 to 50 cm. Due to most of these factors; there is no cultivated agriculture in this unit. The main land use in this unit, which occupies 494 ha, is extensive grazing for diary cows.

5.3 Interviews with farmers and local experts

Collection of data through interviews was by far more difficult than collection of data through field surveys. The art of conducting interviews for the purpose of land evaluation is quite complex; it requires not only good professional understanding subject, but also very good communication skills. Since the idea is to extract expert knowledge from an individual and then use it in a land evaluation project, it is imperative that the respondent understands what is required of him.

Most of the data used in this research project was obtained through interviews from local experts. It is clear from the interviews we conducted that people with different backgrounds communicate information on land suitability differently. We noticed from the interviews, that understanding different land characteristics is one thing, while interpreting this same idea into land suitability is another. Most of the local experts that we interviewed demonstrated a high level of knowledge in different land characteristics. However, they do not interpret this knowledge in terms of land suitability.

This was on of the pitfalls during the process of eliciting information from the local experts in the study area. Our questionnaires, prepared prior to the interviews, contained land suitability oriented questions, thereby dictating the respondents to speak according to the format/ language of the questionnaires. This constrained some of the respondents and made it difficult for them to answer not because they did not know, but because they were not acquainted with the terminology in the questionnaire. Such circumstances demanded very good skills of communication and ability to ask the same question in two or more different ways.

We noticed from our survey, that questionnaires must contain simple and common language because information for land evaluation is sought from people of different academic and professional backgrounds. Questionnaires used during the fieldwork are attached in appendix B. Most of the questions had to be rephrased.

However, our survey revealed that, it is not just the terminologies or set of questions that are important in eliciting expert knowledge. The whole set-up for the interviews is equally vital. Our interviews were conducted either with individuals or a group of experts. Interviews with an individual expert seemed to be more productive. This allows an individual to express himself freely without any interference or intimidation from other experts.

The nature and quality of data that we collected through interviews was satisfactory and enabled us to conduct a land evaluation of two land use types selected. Most of the people interviewed have minimum of university education. Although some technical questions were not completely answered, we were satisfied with the information we received.

As shown in appendix B, the interview process had many stages starting with identification of land use types, ending with construction of decision trees. Flow of information from experts from experts varied according to different stages of the interview. It was much easier to define the land use types and their land use requirements, while it was more difficult to determine the severity levels and building decision trees for the land use requirements. Our participation in the process of building the decision tree included suggesting of possible answers to some of the questions. Because of the exhaustive nature of interviews, we only managed to study in detail two land use types.

There was consistency in the answers given by experts interviewed at different stages. For example, information given by experts from different farms on land use requirements for cabbage was almost the same. This is because these land use types are managed similarly on the different farms.

In total, eight people from three different farms were interviewed. Our original intention was to interview more people. This however, was not possible due to time limitation.

5.4 Description of land use types.

The interviews with different farmers revealed that the selection of land use types largely depend on the amount of resources available, agro-ecological conditions and availability of markets for the produce. For example, changing of land use types may be viewed as a risk by the farmer because new products imply that new markets must be found. Accordingly, the selection of land use types also depends on technology and capital available. A small scale farmer, for example, can not afford to establish or run a huge central pivot irrigation system.

5.4.1 LUT 1: Irrigated cabbage (Three Point Farm)

Irrigated cabbage is produced under pivot irrigation through out the year. Three-point farm has a total area of 297 ha, while the total pivot area is 216 ha. Cabbage (variety- Gloria) is rotated with tomatoes and roses. This is done to overcome problems of diseases and pests.

Planting/ transplanting is done weekly. The seedlings are transplanted when they are 3-4 weeks old. The growing cycle lasts for 120 days (three months). Harvesting is done almost daily.

Pivot irrigation is preferred in this land use type because under this system of irrigation, water loss is minimal. Farmers do not recommend drip irrigation because the irrigation pipes are very expensive. The sources of irrigation water are boreholes. In some periods of the year (June and July), some boreholes run out of water, which leads which leads to abandonment of certain pivots. It is during this period that farmers experience low production. Cabbage is grown mainly for European and local markets. The best marketing months for cabbage are January, February and March. In December, many local farmers produce rain-fed cabbage, leading to the congestion of the market with the produce.

Power source used for production is machinery. Almost All operations are mechanized. The only operations that are not mechanized are harvesting, cleaning and packaging. Three Point farm hires about 80 casual workers for this purpose.

The major inputs required for production are seeds (200 KSH/kg), herbicides (112 KSH/kg) and fertilizers (19200 KSH/ton.)The output for this LUT is cabbage heads. The yield is 30,000 pieces/ha. Each piece weighs about 3kg. The wholesale price for cabbage is 6.25 KSH/ piece. Hired casual workers are paid 100 KSH/day.

Apart form expenses incurred on inputs under optimum conditions, there are extra expenses on drainage, fertilizers, irrigation, soil preparation and lime for different severity levels. This is done on all limiting factors that can be improved. Repairing and maintenance of pivots is one of the significant by year input.

All the above details and other economic parameters were included in the ALES model for the evaluation of physical and economic suitability.

5.4.2 LUT2: Lucerne (Medicago Sativa) (Delamere Farm)

Delamere farm is one of the commercial farms located in the Lake Naivasha basin, Kenya. It is a corporately owned farm situated in the north east of the lake. The total pivot area of this farm is 468 ha, while area under Lucerne production is 88 ha, with 260 dairy cows. Lucerne is the main crop grown and is rotated with oats, sunflower and baby corn. Lucerne is produced through out the year under the central pivot irrigation system. Another crop produced at this farm is cabbage. The managers at this farm prefer the central pivot system to other irrigation systems. Reasons given are that, it is more efficient and less expensive.

The managers and experts singled out two main problems facing this farm. These are soil surface sealing and salinity. These problems have led to the abandonment of certain pivots. Details of these problems are discussed in the section of land use requirements for Lucerne production.

Most of the Lucerne is grown to feed dairy animals on the farm, while the rest is sold to other local farmers. During the dry season, the demand for Lucerne is very high. Generally, Lucerne has a life span of three years from the time of sowing. Flowering starts after 32-35 days. It should be allowed to have a 50% flowering in the first year of establishment before grazing or cutting.

Generally, seeds are sown on top of the soil by a broadcaster or seed drill, then lightly covered by harrows and rolled. The sowing rate is about 6 kg/ha. According the general manager, the main incentives required are seeds and herbicides. Lucerne is grown after heavily fertilized baby corn or oats. Application of high doses nitrogen fertilizer is discouraged as it reduces nitrogen fixation by the plant, stimulates weeds and has no effect on Lucerne yield. All operations from planting to cutting are mechanized. Packaging is done manually. The farm engages about 50 casual workers, mainly for packaging. Casual workers are paid 100 SH/day.

The output of this LUT is Lucerne hay. The average yield of Lucerne is 20tons /ha. It is packed in bales. Each bale weighs about 19 kg. Lucerne is sold at a rate of 250 KSH/bale. Among the expenses incurred in Lucerne production, the following are the most important ones: Seeds=250SH/kg; Herbicides=112SH/kg.

In this LUT, just like in cabbage, there are extra expenses on fertilizers, irrigation and soil preparation for different severity levels.

5.4.3 General characteristics of the LUTs

Conceptually, the two land use types can be regarded as adaptive. As revealed by our investigation, the land use systems for the same LUT vary according to different land areas. The two LUTs exhibit a very flexible system of exploitation, which is applied differently to different land areas according to their characteristics.

By adjusting the details of the land use according to the land area, the number and type of operations are different on different land areas. This adaptive pattern is very evident for the two LUTs. At Three Point Farm for instance, different land areas of different nutrient levels are fertigated with different doses of fertilizer. At Delamere Farm, some land areas have increased incidence of sealing, resulting in decreased water infiltration and soil water storage. Accordingly, the frequency and intensity of irrigation is adjusted.

The farms at which we conducted our research (Delamere Farm and Three Point Farm) are operated by managers with degree level agricultural education and show significant inclination towards change. They easily adopt different and better methods of management under different circumstances. For example, cabbage and baby corn in areas with sealing problems are being replaced by sunflower, which according to the local experts, would perform relatively better under the same conditions.

5.5 Land use requirements

Land use requirements and their severity levels were obtained for each land utilization type selected on the basis of information collected through interviews during the fieldwork. Accordingly, the land characteristics and severity levels for each land quality were determined.

Considering that the information was obtained from people with different backgrounds and working experience, a review was made of the information obtained through interviews to ensure its compatibility with the ALES format. Although some statements given during the interviews were updated (not changed or manipulated) into a professionally acceptable format, the original ideas and basic concepts expressed by the respondents were maintained. Respondents, who received a copy of the questionnaire prior to the interview date, provided better answers on technical questions than those who did not. The procedure followed during the interviews is illustrated in Appendix B. Most of the land qualities and diagnostic factors, as well as factor ratings established during the interviews are presented in the tables. These were used as the basis for decision trees.

Table 7 Land related qualities for Cabbage

Factor rating						
Land quality	Diagnostic factor	S1	S2	S3	N	Source
Moisture availability	Particle size, class	SC, VFS	FS	MS	CS, VCS	Interview
Oxygen availability	Soil drainage,clas s	Excessively drained, Well drained	Moderately well drained	Imperfect ly drained	Poorly drained	Interview
Nutrient availability	Soil reaction,pH	5.5-7.0	7.0-7.5 5.5- 5.5	7.5-8.0 4.4-5.0	8.5-9.5; 3.5-4.0	Interview
	O.M,%	>4.0	2.5-4.0	1.5-2.5	<1.5	Interview
	T.Ex.Bases, Cmol/kg	> 100	70-100	40-70	<40	Literature
Rooting conditions	Soil texture, class	S, LS, SL, SiL, SCL, CL, sicl	SC	SiC, C	Heavy clays	Interview

	Subsurface stones,%	<5.0	5- 15	15-30	>30	Interview
Potential for mechanization	Slope,%	0-9	9-18	18-32	>32	Interview
	Surface stones, %	0-5	5-15	15-50	>50	Interview
Soil workability	Wet consistence ,Class(sticki	Non-sticky	Slightly sticky	Sticky	Very sticky	Interview
	Dry consistence ,class	Loose -soft	Slightly hard	Hard	Very hard	Interview
Erosion hazard	Slope,%	<3	3-8	9-16	>16	Interview
	Erosion, class	Slight	Moderate	Severe	-	Interview
SEALING HAZARD	Texture, class	S, LS, C, SiC SC,	SL, SCL,	Si, Sil, L	-	Interview
	Crusts,mm	<1	1-2	2-5	>5	Interview
Soil toxicity	pH	6.0- 7.0	7.0-7.5; 5.0- 5.5	7.5-8.0 4.4-5.0	8.5-9.5 3.4-4.0	Interview/ Literature

Table 8Land related qualities for Lucerne

Factor rating						
Land quality	Diagnostic Factor	S1	S2	S3	N	Source
Moisture availability	Particle size,Class	C, Si ,VFS	FS	MS	CS, VCS	Interview
Oxygen Availability	Drainage, Class	Excessively well drained	M/W drained	Imperf. drained	Poorly drained	Interview
Rooting conditions	Soil texture, class	S, SL, L, SiL, CL,	SC	SiC, C	-	Interview/ Literature
	Minimum Rooting depth,cm	>90	60-90	30-60	<30	Interview/ Literature

Soil workability	Wet consistence, class	Not sticky	Slightly sticy	Sticky	Very sticky	Interview/ Literature
	Dry consistence Class	Loose/ soft	Slightly hard	Hard	Very hard	Interview
Sealing hazard	Texture, class	S, LS, C, SiC, SC	SL, SCL	Si, SiL, L	-	Interview/Literature
	Thickness of crusts,mm	<1	1-2	2-5	>5	Interview
	Incidence of diatomite	Absent			Present	Literature
Salinity hazard	E.C, dS/m	1.8>	1.8-3.4	3.5-7.0	7-12	Literature

5.6 Building models in the Automated Land Evaluation System (ALES)

The data obtained through interviews during the fieldwork was processed and transferred to ALES. Models were built in ALES for each of the selected land use types. This, however, was not a straightforward step. One of the bottle necks experienced was that some of the questions were not adequately answered during the interviews. Information from literature and other researchers was sought to fill such gaps.

5.6.1 Construction of decision trees

At this stage, we undertook to set up decision procedures by which ALES can asses the suitability of each land-mapping unit. This involves the construction of decision trees for each land use requirement based on expert knowledge. Each land use type has different land use requirements. Accordingly, different decision trees were constructed for each land use requirement depending on the land use type. The starting point were the LUR and their diagnostic properties shown in Tables 6 and 7; however, these were expanded and modified according to other information from literature and field experience.

For cabbage, the following land use requirements were identified and included in the land evaluation: Erosion hazard, moisture availability, nutrient availability, oxygen availability, potential for using agricultural implements, rooting conditions, sealing hazard, soil toxicities and soil workability. For Lucerne, an additional land use requirement of salinity hazard was included.

For both land use types, limiting factors that can be improved or corrected (moisture availability, nutrient availability, oxygen availability and soil workability) were not included in the maximum limitation. Only factors that that cannot be improved (sealing hazard, rooting conditions, soil toxicity and potential for using agricultural inputs) were included in the maximum limitation. These were given yield-limiting factors according to different severity levels.

Decision trees for the different land use requirements are shown in appendix E

5.7 Results of physical and economic land evaluation

The overall physical suitability of the land-mapping units shows no significant difference for the two land use types. Out of the twelve land mapping units, eight are moderately suitable, one is marginally suitable, while four are not suitable for both land use types. The suitability classes are based on maximum limitation of factors that cannot be corrected.

Economic land suitability was also analyzed based gross margin and benefit cost ratio. Economic land suitability classification based on these parameters shows that most of the land-mapping units are moderately suitable for cabbage and highly suitable for Lucerne. Three l map units Lf 111, Lf 311 and Pl 311 are physically unsuitable.

The first two map units (Lf111and Lf 311 are situated in the step faulted plateau); they are quite rocky and stony. The other map unit Pl311 is located on the lacustrine plain.

The tables below illustrate the suitability of the various land-mapping units for the two land use types.

Table 9 Physical and economic land suitability for cabbage

GP map unit	*Physical suitability*	*Yield (heads/ ha)*	*Gross margin (KSh /ha /year)*	*Suitability class (based on gross margin)*	*B/C Ratio*	*Suitability class (basedon B/C ratio)*
Lf 111	4EH/PI	0	0	N2	0	N2
Lf 211	2EH/CR/ST	27,000	276,353.33	S2	2.1	S2
Lf 212	3EH/PI/RC	24,000	229,010.00	S2	1.94	S3
Lf 311	4EH/PI/RC	0	0	N2	0	N2
Pf 111	2EH/RC/ST	27,000	264,193.33	S2	1.99	S3
Pf 211	2EH/RC/ST	27,000	264.193.33	S2	1.99	S3
Pf 212	2EH/RC/ST	27,000	264,193.33	S2	1.99	S3
Pf 213	2EH/RC	27,000	283,420.00	S2	2.16	S2
Pf 311	2EH/RC	27,000	283,420.00	S2	2.16	S2
Pl 11	2RC/SH	27,000	293,353.33	S2	2.26	S2
Pl 211	2RC/SH	27,000	293,020,00	S2	2.26	S2
Pl 311	4 ST	0	0	N2	0	N2

Table 10 Physical and economic suitability for Lucerne

Land unit	*Physical suitability*	*Yields bales/ha*	*Gross Margin,KSH/ha/yr*	*Suitability class based on gross margin*	*B/C ratio*	*Suitability class based on B/C ratio*
Lf 111	4EH/PI/RC	0	0	N2	0	N2
Lf 211	2 EH/ST	1,052.60	847,243.33	S1	4.89	S1
Lf212	3EH/PI	841.60	646,486.00	S1	4.04	S1
Lf 311	4EH/PI/RC	0	0	N2	0	N2
Pf 111	2EH//ST	1,052.00	834,603.33	S1	4.61	S1
Pf211	2EH/ST	1,052.00	834,603.33	S1	4.61	S1
Pf212	2EH/ST	1,052.00	834,603.33	S1	4.61	S1
Pf213	2EH/RC	841.60	652,326.00	S1	4.23	S1
Pf311	2EH/RC	841.60	652,326.00	S1	4.23	S1
Pl 111	2RC/SH	841.60	660,819.33	S1	4.43	S1
Pl211	2RC/SH	841.60	660,486.00	S1	4.42	S1
Pl 311	4SA/ST	0	0	N2	0	N2

Key for the table:

EH- Erosion hazard; RC-Rooting conditions; PI- Potential for using agricultural implements; SH- Sealing hazard; SA-Soil salinity; ST- Soil toxicity

5.7.1 Suitability of various map units

As shown in the tables 10and 9, all the twelve mapping units were evaluated for their suitability for cabbage and Lucerne. It is evident from the results presented above that the overall physical suitability of the land-mapping units does not differ significantly.

Map unit **Lf 111** (Step-faulted plateau, Scarp) is physically unsuitable for both land use types. For cabbage, this unit has suitability subclass of **4EH/PI**. This shows that the land area is physically unsuitable for cabbage due to high erosion hazard and very low potential for using agricultural inputs. In relation to rooting conditions, this mapping unit is marginally suitable for cabbage. For Lucerne, the suitability subclass of this mapping unit is **4EH/PI/RC**, indicating that this unit is physically unsuitable for lucerne due to high erosion hazard, low potential for mechanised operations and poor rooting conditions. The poor rating of this map unit coincides with our findings during our field survey. This map unit is actually a scarp, with a slope percent of about 30%. Consequently, it has a very high erosion hazard and very low potential for using agricultural implements. It was established during our interviews with the farmers that almost all operations for both land use types are mechanised. It is not a coincidence that our ALES model poorly rates the suitability of this unit.

Furthermore, the effective soil depth recorded for this map unit about 50 cm. This depth is by far inadequate for a deep-rooted crop like lucerne. This problem is compounded high incidence of surface stones, estimated at 20%. This map unit is currently not used for any agricultural purpose.

Map unit **Lf 211** (Step-Faulted Plateau, upper footslope) is rated as moderately suitable (S2) for both LUTs. For cabbage, this map unit has a suitability subclass of **2EH/RC/ST.** This indicates that the factors that are maximally limiting for this land use type are erosion hazard, rooting conditions and soil toxicity. This map unit has a slope of around 5%. A slope of this magnitude is moderately susceptible to erosion. The rooting conditions for cabbage in this map unit fall below the optimum because of the fine soil texture. The soil texture in this map unit is predominately silty clay, which does not provide optimum conditions for root growth. An additional limiting factor for cabbage in this unit is soil toxicity. This toxicity is expressed in form of hydrogen ions. As revealed by our field tests, the pH of this unit is around 4.5, which does not meet the optimum pH requirements for cabbage.The map unit is also moderately suitable **2EH/ST** for lucerne, attributed to erosion hazard and soil toxicity as the main limiting factors.

In terms of economic suitability based on gross margin and benefit cost ratio, this unit is rated as moderately suitable (S2) for cabbage and highly suitable (S1) for lucerne. At the time of our survey, the map unit was under cabbage production.

Map unit **Lf212** (Step-Faulted Plateau, lower footslope) is rated as marginally suitable (S3) for both land usetypes. The main limiting factors for both LUTs in this map are erosion hazard and low potential for using agricultural implements. For cabbage, the suitability subclass is **3EH/PI/RC**. With a slope of 8-10 %, this map unit is characterised with a moderately rapid run off, resulting into higher erosion hazard. Furthermore, our study revealed that this unit is characterised with both surface and subsurface stones. This reduces the potential for using agricultural implements, and according to the local experts in the study area, this inhibits root growth for both Lucerne and cabbage. At the time of our survey, this unit was used irrigated Lucerne.

Based on the gross margin, the map unit is moderately suitable (S2) for cabbage and highly suitable (S1) for Lucerne.

Map unit **Lf 311** (Step faulted plateau, outlier hills) is physically unsuitable for both land use types. Its suitability subclass for both cabbage and Lucerne is **4EH/PI/RC**. The most limiting factors for both LUTs in this map unit are erosion hazard, potential for using agricultural implements and rooting conditions. This map unit is mainly a slope complex with a slope of about 45 %. This land characteristic increases erosion hazard and lowers the potential for using agricultural implements. This unit is very stony and rocky (60 %), thereby further reducing the potential for mechanical operations. The effective soil depth ranges between 10 to 15 cm, which is too shallow to support both Lucerne and cabbage growth.

According to the geological map of the study area, the lithology of this map unit is Limuru trachyte, which is acidic in nature. Our field tests recorded very low pH of 4.0-4.5. Consequently, for the soil toxicity factor, this unit is rated as marginally suitable for both LUTs. This unit is not used for any agricultural purposes. Some sections of this land area are dominated by drought resistant tree species Euphobia Decary.

Map unit **Pf 111** (Deltaic River Plain, tread riser complex) is rated as moderately suitable, **2EH/ST** for both land use types. The factors that are maximally limiting for the two LUTs are erosion hazard and soil toxicity related with soil reaction. The map unit has a slope of about 8 %. According to our model, it has a moderate erosion hazard. The pH recorded for this map unit is around 5.0 which is below the optimum requirement for both LUTs. Based on gross margin, the economic suitability is for cabbage is S2, while for Lucerne, the economic suitability is S1.

Map unit **Pf 211** (Deltaic River Plain, tread) This map unit is moderately suitable (S2) for both LUTs and has much in common with the map unit Pf 111. Its physical suitability subclass is also **2EH/ST**, indicating that the most limiting factors are erosion hazard and soil toxicity. It has a rolling slope of around 4% and a pH of about 5.5. Generally there are no severe limitations for the two land use types in this unit. Based on gross margin, this map unit is moderately suitable for cabbage and highly suitable for Lucerne.

Map unit **Pf212** (Deltaic River Plain, riser). This unit is also rated as moderately suitable (S2) for both Lucerne and cabbage. Its physical suitability subclass is **2EH/ST**, pointing to erosion hazard and soil toxicity as the major limiting factors. The pH of this map unit is around 5.5, while its slope is about 8 %. Subsurface stones further limit cabbage growth. 5 % stoniness was recorded for this map unit which. This land characteristic has a negative influence on the rooting conditions. For this reason, the physical suitability subclass for cabbage is **2EH/ST/RC.** From the viewpoint of economic suitability based on gross margin, this map unit is moderately suitable (S2) for cabbage and highly suitable (S1) for Lucerne.

Map unit **Pf 213** (Deltaic River Plain, overflow basin) is moderately suitable (S2) for both land use types (**2EH/RC**). With a slope of 4-5 %, this map unit has a moderate erosion hazard. This unit is mainly bordered by elevated geoforms, which increase water run-in to this unit, resulting in increased erosion hazard. Another factor that is maximally limiting is rooting conditions, which in this case is influenced by the textural class. The textural class for this map unit is clay. Fine textured soils tend to inhibit root growth through their resistance to root penetration. This map unit is moderately suitable for cabbage and highly suitable for Lucerne.

Map unit **Pf 311** (Deltaic River Plain, Abandoned river course) is rated as moderately suitable (S2) for both land use types. Its physical suitability subclass is **2EH/RC.** The most limiting factors in this map unit are erosion hazard and rooting conditions. Although our model considers this map unit to be susceptible to erosion, no erosion was observed during our survey. This is presumably due to clay, which is dominant in this map unit. Generally, clay soils offer resistance to soil erosion (Shrestha, 2000). On the other hand, fine texture has a negative influence on the rooting conditions. For this reason, this map unit has rooting conditions below optimum.

Map unit **Pl 111** has a physical suitability subclass of **2RC/SH**. This suitability subclass applies to both land use types. According to our model, rooting conditions are moderately suitable for cabbage and Lucerne. Rooting conditions were inferred mainly from the soil texture. Data collected show that the topsoil contains more silty clay, giving rise to silty clay loams with increasing depth. According to the local experts, surface stones and soil depth are not a problem in the lacustrine plain. This was verified during our survey. Sealing hazard is the other limiting factor in this map unit. According to information obtained through interviews, soil texture,organic matter and diatomite are the main factors that influence sealing. Data collected in this map unit show that the dominant soil textural class is silty clay loam, which is very susceptible to sealing. Diatomite was noticed at the depth of 40 cm. According to local expert knowledge, the incidence of diatomite increases the risk of sealing. Economic assessment based on gross margin and benefit cost ratio, shows that the area is moderately suitable for cabbage and highly suitable Lucerne.

Map unit **Pl 211** (Lacustrine plain, mid level) is also moderately suitable (S2) for both land use types. Its physical suitability subclass is **2RC/SH**. This map unit is situated in the lacustrine plain. Just like map unit Pl 111, the main limiting factors are rooting conditions and sealing hazard. The incidence of diatomite is not very pronounced in this map unit. It is assumed by this study, that sealing is mainly influenced by silty clay loam, which is the dominant soil textural class in this map unit. Furthermore, silty clay loam, according to our model, does not provide optimum rooting conditions. For these reasons, rating this map unit as moderately suitable for both land use types is justifiable.

Map unit **Pl 311** (Lacustrine plain, low level) is situated more to the south of the study area, bordering Lake Naivasha. In terms of land qualities, there is a sharp boundary between this unit and the two lacustrine units discussed above. This unit is rated as physically unsuitable for both land use types. Its physical suitability subclass is **4ST/SH**. The most limiting factors in this unit are soil toxicity and sealing hazard. The other limiting factors is soil salinity **3/SA.** The data available show that this map unit has very high pH values ranging from 8.0-8.9. In our model, high levels of alkalinity were considered to be very high; for this reason, this unit is rated as physically unsuitable. In addition, the electric conductivity recorded is 3.8 dS/m. This value is high enough to make the map unit only marginally suitable for the two land use types. This unit, like the other two lacustrine units, is not spared from the problem of sealing. There is evidence of diatomite at the depth of 32 50 cm. According to our model, the combination diatomite and sandy clay loam makes this unit physically suitable for both land use types.

5.7.2 Overall physical suitability for the LUTs

The suitability of a tract of land is determined by a number of land qualities, which are combinations of individual land characteristics, and are distinct from other land qualities in their influence on the suitability of for a specific kind of land use. (International Society of Soil Science, 1988).

Our final suitability assessment separated the study area into three suitability classes for the two land use types. These are: Moderate (S2), marginal (S3) and not suitable (N). Different land qualities showed different influence on the suitability of various land areas for the land use types. According to the findings of this research work, the overall physical suitability classes are the same for both cabbage and Lucerne. The following map units Lf 111(scarp), Lf 311 (outlier hill) and Pl 311(Low lacustrine) are physically unsuitable for both land use types.

The poor rating of the map unit Lf 111 is due to the following factors: high erosion hazard, low potential for using agricultural implements and poor rooting conditions. This unit has a steep slope and shallow soils. Map unit Lf 311 is a slope complex with very a very steep slope and very shallow soils. Map unit Pl 311 is physically unsuitable because of such poor land qualities as sealing hazard soil toxicity and soil salinity. According to our findings during the survey, most of the pivots have been abandoned due to sealing and soil salinity caused by under ground water irrigation. Data recorded for this map unit show that the area is very flat Due to this, removal of salts through drainage may be very slow.

Map unit Lf 212 is the only one rated as marginally suitable (S3) for both land use types. Factors responsible for its marginal suitability are erosion hazard, potential for using agricultural implements and rooting conditions.

Map units Pl 111, Pl 211, Lf 211 and all the map units situated on the deltaic river plain (Pf 111, Pf 211, Pf 212, Pf 213, Pf 311) are rated as moderately suitable for both land use types. According to our findings during the survey, most of the agricultural activities, including cabbage and Lucerne cultivation are concentrated in these land areas.

One point worth noting is that, the overall physical suitability for both cabbage and Lucerne is the same in all the map units. This may be an indication that the land use requirements for both LUTs in the area are quite similar. Already, one indication supporting this assumption is that both crops are grown at the three different farms on which the survey was conducted. Furthermore, farmers at Delamere Farm, on which Lucerne and cabbage are grown, mentioned that both LUTs suffer from similar problems such as salinity, alkalinity and sealing hazard.

On the other hand, there are some noticeable features indicating differences in terms of land use requirements. For example map unit Lf 111, characterised with shallow soils (20- 30cm) is rated as unsuitable for Lucerne based on the factor of rooting depth, while for cabbage, the same map unit is rated as moderately suitable. This is attributed to the fact that, Lucerne is a deep root crop, while cabbage is not.

Results of the evaluation show that there are no land areas, which are highly suitable (S1) for both land use types. Another observation is that, the pattern of suitability subclasses is related to the different landscapes. For instance, the main limiting factors in the step-faulted plateau are erosion hazard and poor conditions for using agricultural implements. In the Deltaic Fluvial Plain, the map units have moderate limitations due to erosion hazard and rooting conditions. On the lacustrine plain, the main problem affecting all the map units is sealing hazard.

Other factors studied in this project include soil workability, nutrient availability and moisture availability. These however, are factors, which can be corrected and were not included in maximum limitation.

Maps summarizing the results of the evaluation in a simplified form are presented in figures 12-21. The overall physical suitability map shows areas, which are moderately, marginally and not suitable for the two land use types. As observed during our field survey, all the activities are concentrated in the land areas rated by our model as moderately suitable. Although economic land evaluation is not the main focus of this research work, economic suitability based on gross margin has been established for both land use types. Refer to figures 13 and 14.

5.8 Influence of individual factors on the LUTs

The separation of the land evaluation area into different suitability classes depends on individual factors (land qualities) and their effects on crops and land use types. It is clear from the land qualities discussed above, that they are not exclusively related to crop requirements. Sealing hazard, erosion hazard, toxicity and soil salinity are mainly related to conservation requirements, soil workability and potential for using agricultural implements are management requirements.

Our investigation revealed that, these factors, at their sub optimal levels have similar (negative) effects on both land use types. The point being emphasized is that, although the two crops are biologically and botanically different, they are equally affected by this environmental and management problems. It is not a coincidence that most of the summary maps of individual factors (qualities) common for the two land use types. See maps in figures 12-21. However, the two land use types differ on the basis of certain land use requirements, for example rooting conditions.

Most of the farmers interviewed lamented over the problem of sealing in the area. This is what attracts me to discuss this subject a little further. The main effect of sealing is poor water infiltration, leading to root zone drought, resistance to seedling emergence, water loss and sheet erosion.

Sealing is defined as the orientation and packing of dispersed soil particles, which have disintegrated due to the impact of raindrops or high-energy water drops from irrigation (Wearing, 2001). Most of the farms in the study area use pivot irrigation system. The intensity and kinetic energy produced by pivot irrigation drops can be too high and cause severe crusting. Some local experts within the study area suggested that lacustrine materials are generally prone to sealing because particles have already been sorted out.

However, our findings during the survey suggest that, most of the map units prone to sealing are dominated by silty clay, silty clay loam and silty loamy soils. This leads to our assumption that there is strong correlation between sealing and soil texture.

Another school of thought is that sealing is aggravated by diatomite. Local experts in the study area including farm managers expressed this theory. According to (Dolley, 2001), diatomite is a chalk like, soft, friable, earthy, and very fine-grained siliceous sedimentary rock, usually light in colour (white if pure, commonly buff to gray in situ, and rarely black). It is very porous and low in density. The actual mechanism of how diatomite influences sealing is out side the scope of this particular study. However, data recorded during fieldwork confirm that all maps, in which diatomite was noticed are prone to sealing. For this reason, diatomite was one of the considered in the construction of decision trees. Details on soil profiles are in appendix A.

As already explained in section 5.7.1, the role played by other land qualities such as erosion hazard, rooting conditions, soil salinity, soil toxicity and potential for using agricultural implements can not be overemphased.

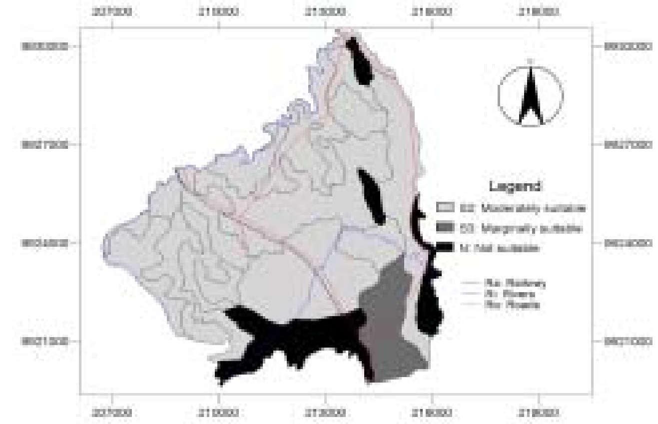

Figure 12 Overall physical suitability map for Cabbage and Lucerne

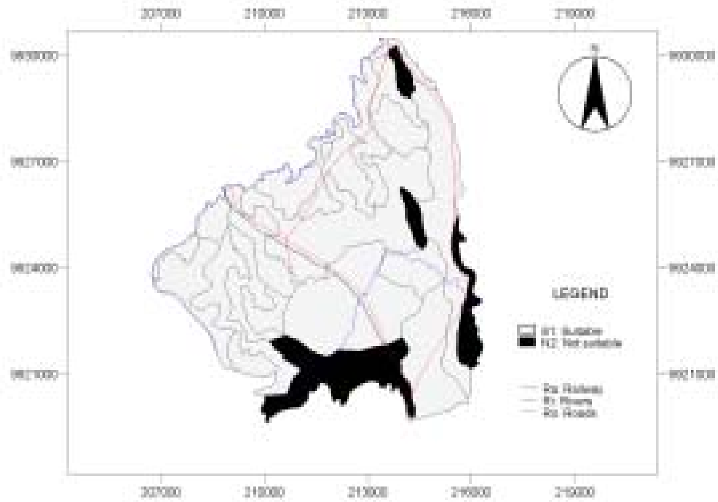

Figure 13Suitability map for Lucerne based on gross margin

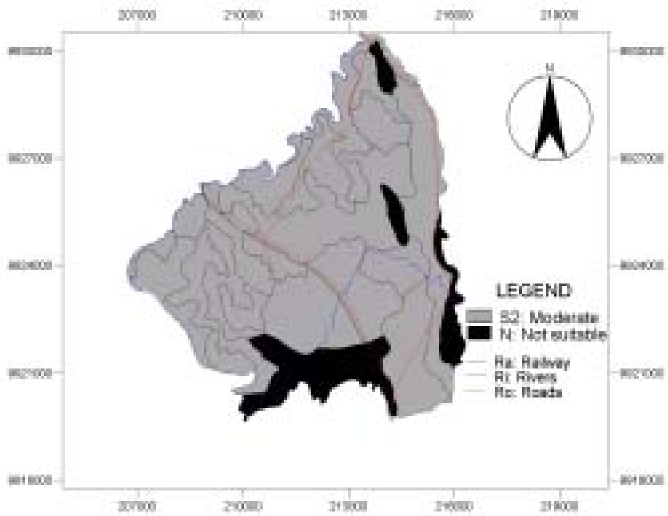

Figure 14Suitability map for cabbage based on gross margin

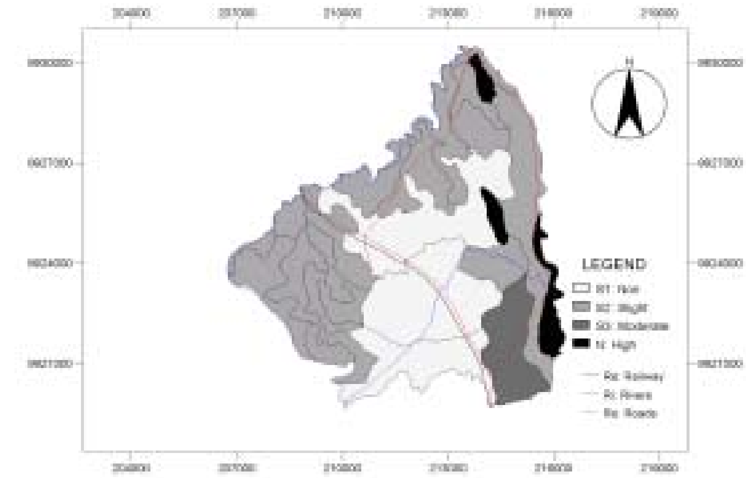

Figure 15 Erosion hazard map

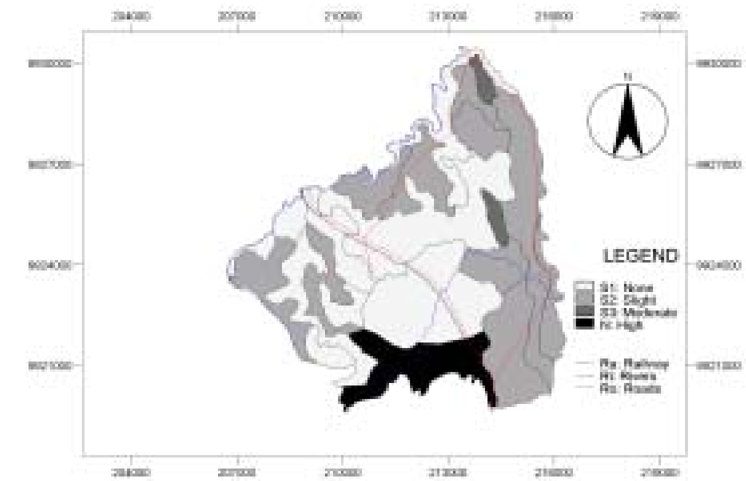

Figure 16 Soil Toxicity map

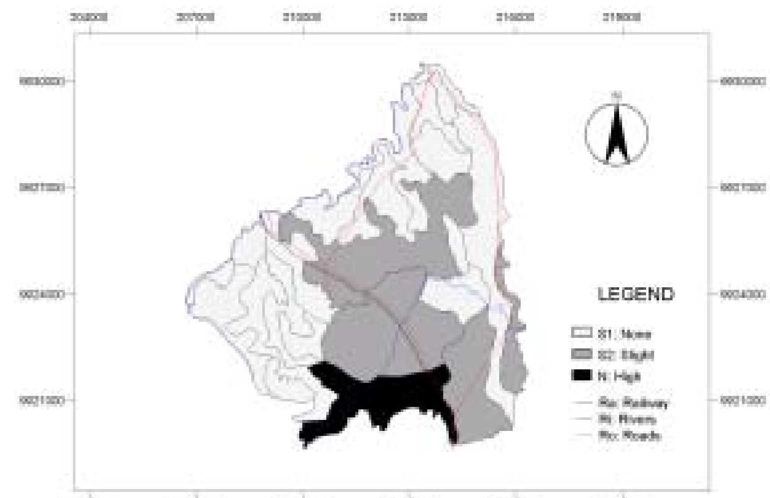

Figure 17 Sealing hazard map

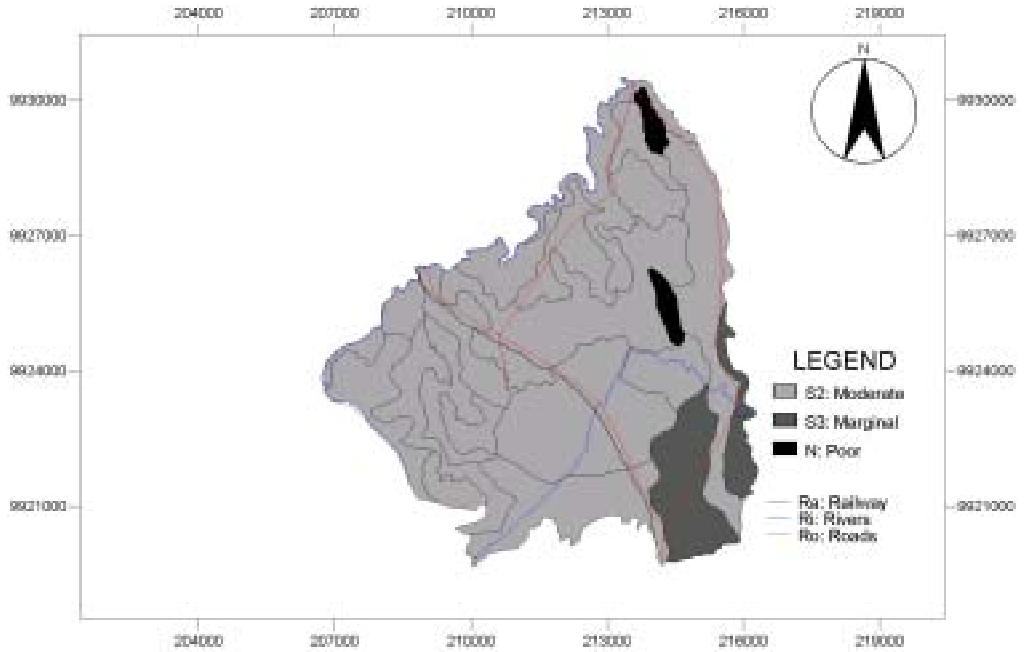

Figure 18 Rooting conditions for cabbage

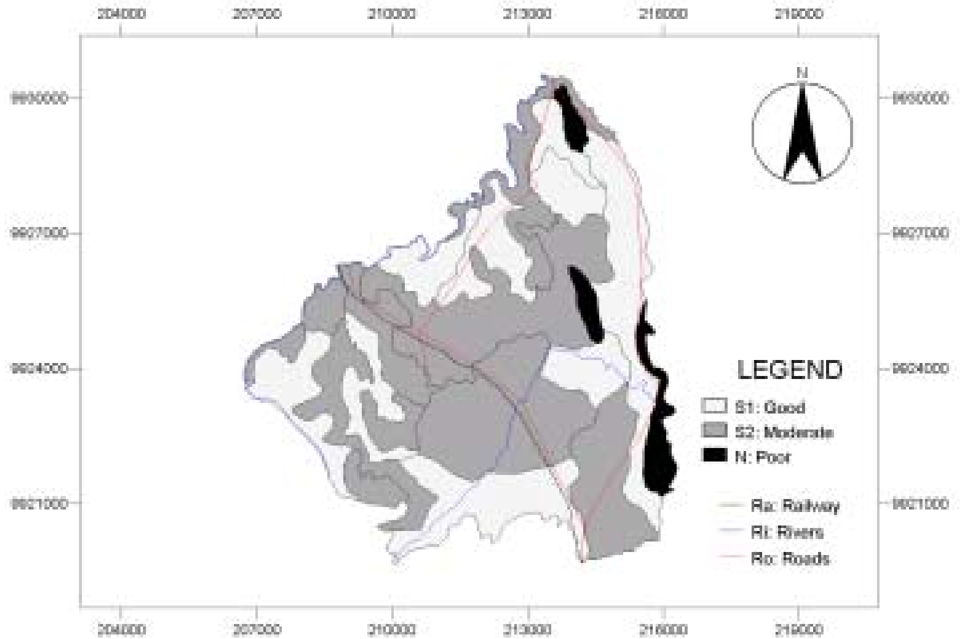

Figure 19Rooting conditions for Lucerne

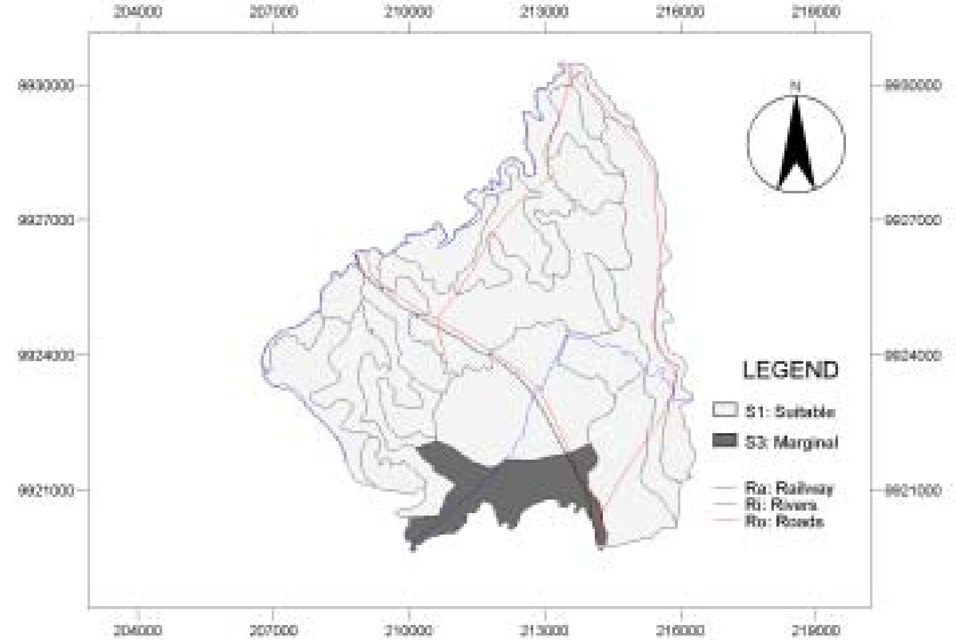

Figure 20 Map for salinity hazard

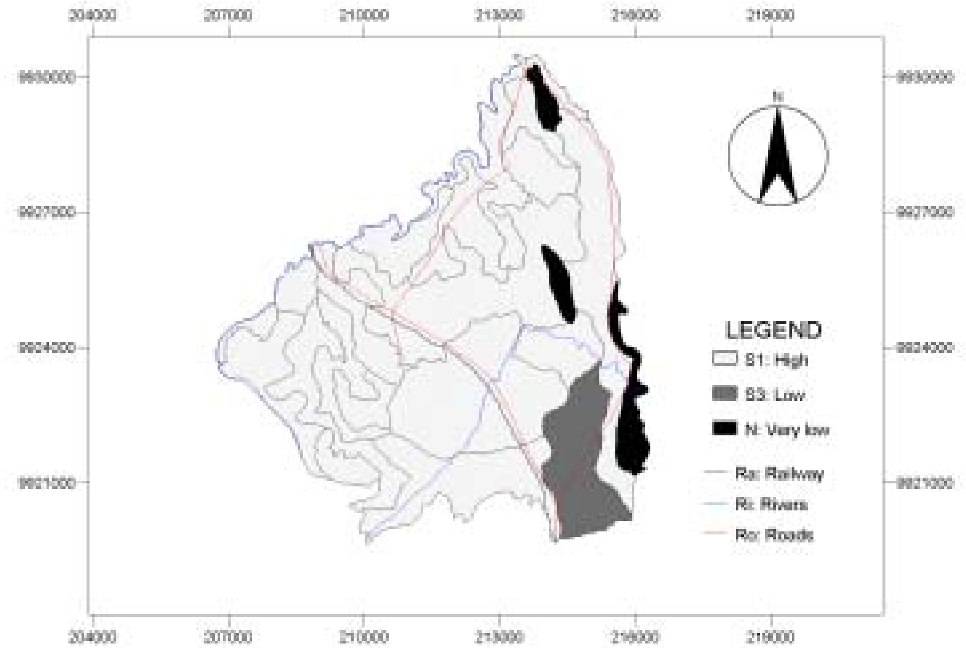

Figure 21 Potential for using agricultural implements

6 Conclusion and recommendations

6.1 Conclusion

The main rationale of this research work is to investigate the suitability of a land evaluation area and to determine factors that differentiate the land area into different suitability classes for selected land use types. The entire work was structured in such a way that permitted full participation of the farmers, farm managers, agronomists and other local experts.

Cognizant of the above, a study area with diverse land characteristics was chosen for the execution of this research project. Local experts were engaged right from the beginning of our fieldwork. They participated in the definition of land use types, land use requirements, diagnostic characteristics and building of decision trees. Through our field survey and interviews with local experts, major land use types in the study area were identified: Production of high value cabbage under pivot irrigation, pivot irrigated Lucerne for dairy animals, irrigated baby corn for export, production of roses in green houses, production of pivot irrigated tomatoes for export. Due to limited amount of time only two land use types have been considered for a detailed study. The successful identification and definition of land use types validates the hypothesis that land use types in the study area can be distinguished through interviews and ground observations.

The study area encompasses three main landscapes: The step faulted plateau, the Deltaic River Plain and the lacustrine plain. Accordingly, map units in these areas also vary in their relief, terrain, topogragraphy, parent material and vegetation. Due to this variation, different map units in the study area exhibited different levels of suitability for the land use types under investigation. Furthermore, our discussion in section 5.2 shows that soils in different map units differ from each other in terms of different land characteristics such as organic matter, pH, electric conductivity, drainage class, soil depth and soil consistence. These differences in land characteristics cause the land use types to perform with different levels of success in different land areas. We can therefore conclude that, soils in the study area differ in properties and suitability for the land use types under investigation.

Different land qualities discussed in this research work have significant influence on land suitability and performance of land use types. Most of these factors were identified through interviews and analyzed with the Automated Land Evaluation System. Evaluation results show that different land qualities separate land areas into different suitability classes. Based on the land qualities in different land areas, three physical suitability classes were identified for cabbage and Lucerne.

Capturing data from experts for the purpose of land evaluation requires very good communication skills. Our findings during the interviews reveal that many experts are well acquainted with land use requirements and their diagnostic factors. Their difficulty is to express this knowledge in the language of land evaluation. Our survey shows that very simple and flexible questionnaires, supplemented with oral questions in simple language can help to capture good land evaluation concepts from experts. We also found it more constructive to carry out the interviews in phases. Where time allows, this should be spread over a few days to allow the respondents prepare themselves adequately for the next interview. In addition, this allows the respondents, who are usually very busy people to attend to other issues. Table 4 shows the proposed schedule for conducting interviews local experts.

Most of the data used in this research was obtained through interviews with farmers and other local experts, validating the hypotheses that through clear, simple and well-organized questionnaires, it is possible to elicit and structure expert knowledge for land evaluation.

6.2 Recommendations

Taking into account the information obtained through interviews, field survey and the land evaluation results, some recommendations can be made within the scope of this study.

One of the most serious problems faced by the farmers in this area is sealing. As already discussed, high energy water drops from pivot irrigation aggravates the problem of sealing. To minimize this problem, recommends a reduction in the area under pivot irrigation. Pivot irrigation in areas, which are very prone to sealing, should be replaced by drip irrigation. The managers at Veg-Afriaca have already taken an initiative by introducing drip irrigation. Although farmers argue that drip irrigation is more expensive, its benefits in reducing sealing and crusting should not be underrated.

Numerous studies have shown that, as organic matter content increases, most soil physical properties are improved. The positive effect of organic matter on aggregate stability and resistence to sealing has been clearly shown in the Central African Republic (FAO, 2000). The application of gypsum is very effective in combating sealing and water run-off. However, caution should be taken not to apply gypsum in areas that have salinity problems.

Another problem facing the farmers in the area is salinity caused by irrigation water. It is recommended to suspend irrigation practices in affected areas and introduce alternative land use types such as grazing for dairy animals.

The amount of time allocated for this study (21) was not enough to collect all the required data to make very accurate prediction about the land suitability. The next step is to present and discuss the preliminary results of the evaluation with the farmers.

Despite the progress made in the present work, there are certainly many interesting features remaining for future investigation in this area. The study of diatomite and its role in water management problems can make an interesting research work. We would also recommend to model irrigation requirements for the study area using a suitable software for computing crop water requirements.

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Appendix

Appendix A SOIL PROFILE DESCRIPTIONS

A) Information on soil profile site

Profile ID	**Naiv/2001/Shep-001**
Date of examination	September 21, 2001
Type of observation	Mini-pit
Authors	C.M. Shepande, R. Hennemann, J. Torrion and S. Mohammed Ahmed
Location	212984, 9926258 (UTM, ARC 1960) KARI Range land, about 1 km north of Three Point Farm, Naivasha.
Altitude	1,957m above sea level
Geopedological unit	Pf 111, Deltaic River Plain
Topography	8%, sloping, convex slope
Micro-topography	Nil
Parent material	Malewa deltaic alluvial deposits
Vegetation	Good grass cover >80 %, with few woody species.
Land use	Extensive grazing and ranching

B) General information on soil profile

Classification WRB	Umbric Fluvisol
Diagnostic Criteria	Umbric A, Fluvic soil material
Human influence	Partial clearing and disturbance of vegetation
Effective soil depth	Deep (100- 150 cm)
Drainage class	Well drained
Internal drainage	Saturated for short periods in most years. Permeability is moderately slow.
External drainage	Neither receiving nor shedding water.
Ground water depth	Very deep (> 150 cm)
Surface stones	Common, mainly coarse gravel
Rock outcrops	Nil
Evidence of erosion	About 5-10 % area affected by moderate sheet erosion
Sealing/crusting	None

Moisture condition — The soil was very dry at the time of investigation

C. Soil profile description

Horizon	Depth (cm)	Description
Ah	0-20	Very dark grayish brown (10YR3/2) when moist and brown (10YR4/3) when dry, sandy clay loam; moderate, medium to coarse subangular blocky; plastic and slightly sticky when wet; friable when moist and hard when dry. Very few and coarse roots; Non-calcareous, few biological activities; pH 5.0; smooth and clear boundary.
AB	20-34	Dark brown when moist (10YR3/3) and dark brown when dry (10YR 3/1), Sand clay loam; moderate, fine to medium, subangular blocky. Plastic and slightly sticky when wet, friable when moist and slightly hard when dry; common, fine roots; Non calcareous with few biological activities; pH 5.5;
2Ah	34-70+	Very dark gray when moist (10YR 3/1) and dark gray when dry (10YR4/1); sandy clay loam; moderate, very fine to fine and subangular blocky, Plastic and slightly sticky when wet. Friable when moist and slightly hard when dry. Common, fine roots; non-calcareous, few biological activities. PH 6.5; wavy and diffused boundary.

Soil auguring

C1	70- 110	Very dark gray (10 YR 3/2) when moist and dark gray (10YR 4/2) when dry; sandy clay loam, plastic and slightly sticky and slightly sticky when wet; non-calcareous; pH 6.5.
C2	110-130	Dark brown (10YR3 /3) when moist and brown (10YR4/3 when dry. sandy loam; Slightly plastic and slightly sticky when wet; pH 6.5.

A) Information on soil profile site

Profile ID	**Naiv/2001/Shep-002**
Date of examination	September 21, 2001
Type of observation	Mini-pit
Authors	C.M. Shepande and R. Hennemann
Location	213067, 9926039 (ARC 1960), KARI farm, about 800m north of the Three-Point Farm.
Altitude	1944 m above sea level
Geopedological unit	Pf311, abandoned river channel of the Deltaic River Plain
Topography	4% slope, Gently sloping, concave slope.
Microtopography	No micro relief
Parent material	Malewa deltaic fluvial deposits
Vegetation	Good grass cover of >80 % with few woody species.
Land use	Extensive grazing and ranching

B) General information on soil profile

Classification WRB	Mollic fluvisol
Diagnostic Criteria WRB	Mollic A, Fluvic soil Material.
Human influence	Partial clearing and disturbance of vegetation
Effective soil depth	Very deep (more than 150 cm)
Drainage class	Somewhat poorly drained
Internal drainage	Saturated for shot periods in most years
External drainage	Neither receiving nor shedding water
Ground water depth	Very deep, (>150 cm)
Surface stones	Nil
Rock outcrops	Nil
Evidence of erosion	None
Sealing/crusting	Nil
Moisture condition	Slightly moist

C) Soil profile description

Horizon	Depth (cm)	Description
Ah	0-17	Very dark grayish brown (10YR 3/2 when moist and dark gray (10 YR4/1) when dry. Clay, strong, Medium size and subangular blocky. Plastic and sticky when wet; friable when moist and slightly hard when dry. Common, coarse roots, few biological activities. Non-calcareous, pH 6.5 Smooth and clear boundary.
AB	17-50	Very dark grayish brown (10YR 3/2) when moist, and dark grayish brown (10YR4/2) when dry. Clay, strong, medium to fine size and subagular blocky; plastic and sticky when wet; friable when moist and slightly hard when dry. Common, fine roots. Non- calcareous. PH 5.0, clear and gradual boundary
Cu1	50-70	Dark brown (10YR3/3) when moist and light brownish gray (10 YR 6/2) when dry. Sandy clay; fine size, strong and subangular blocky. Plastic and slightly sticky when wet; friable when moist and slightly hard when dry; few, fine roots. PH 5.0; Gradual and clear boundary
Cu2	70-90+	Dark brown (10YR 3/3) when moist and yellowish brown (10 YR 5/4) when dry. Sandy clay, fine size, strong and subangular blocky. Plastic and slightly sticky when wet. When moist, it is friable and slightly hard when dry, pH 6.5.

A) Information on soil profile site

Profile ID	**Naiv/2001/Shep-003**
Date of examination	October 3, 2001
Type of observation	Mini-pit
Authors	C.M Shepande, R. Hennemann
Location	213743, 992520 6 (UTM, ARC 1960) Three point farm, 300 m west of the main office
Altitude	1924 m above sea level
Geopedological unit	Pl.111, upper part of the Lacustrine Plain
Topography	0.5%, nearly level, straight
Microtopography	No micro-relief
Parent material	Lacustrine Deposits
Vegetation	None
Land use	Flowers/rose production

B) General information on soil profile

Classification WRB	Mollic Fluvisol
Diagnostic Criteria WRB	Mollic A, Fluvic soil material
Human influence	Complete clearing for cultivated agriculture
Effective soil depth	Very deep; more than 150 cm
Drainage class	Moderately Well drained,
Internal drainage	Saturated for short periods in most years
External drainage	There is evidence of ponding.
Ground water depth	Very deep, (> 150 cm)
Surface stones	Nil
Rock outcrops	Nil
Evidence of erosion	None
Sealing/crusting	Crusting is evident due to silt
Moisture condition	The soil was wet at the time of investigation.

C) Soil profile description

Horizon	Depth (cm)	Description
Ah	0-20	Black when moist (7.5 YR 2.5/1) Gray (7.5YR 5/1) when dry. Silty clay loam; moderately strong, fine to medium size and subangular blocky. Sticky and very plastic. Friable when moist. Hard when dry. Roots are few and very fine. Non-calcareous. PH 5.5; smooth and clear boundary
AB	20-40	Brown when moist (7.5 YR 4/2) and gray (7.5YR 6/1) when dry; Silty clay loam; fine to medium size, moderately strong and subangular blocky. Sticky and very plastic when wet, friable when moist. Non-calcareous. Roots are very few and very fine. PH 5.5,smooth and clear boundary
C1	40-60	Brown when moist (7.5YR 5/3) and light gray (10YR7/1) when dry. Silty loam, weak, fine to medium and subangular blocky. Sticky and plastic when wet. Very friable when moist. Roots are very fine and very few. Non-calcareous. pH 5.5. Some diatomite mixed with the soil, clear and wavy boundary.
C2	60-74+	Brown when moist (7.5YR 5/4) and pinkish gray (10YR 7/1) when dry. Silty loam, weak, fine to medium and subangular blocky. Sticky and plastic when moist; Very friable when moist and hard when dry. Roots are very fine and very few. Non-calcareous. pH 5.5

A) Information on soil profile site

Profile ID	**Naiv/2001/Shep-00 4**
Date of examination	October 3, 2001
Type of observation	Mini-pit
Authors	C.M Shepande, R. Hennemann
Location	212910, 9924310 (UTM, ARC 1960) Delamere farm, 1km north of the petrol station.
Altitude	1903 m above sea level
Geopedological unit	Pl.211, middle part of the Lacustrine Plain
Topography	0% slope, Flat
Microtopography	No micro-relief
Parent material	Lacustrine deposits
Vegetation	Almost 80 Grassland, with isolated wooded areas.
Land use	Intensive grazing for dairy animals.

B) General information on soil profile

Classification WRB	Mollic Fluvisol
Diagnostic Criteria WRB	Mollic A, Fluvic Soil Material
Human influence	Partial clearing and disturbance of vegetation
Effective soil depth	Very deep, more than 150 cm
Drainage class	Well drained
Internal drainage	Saturated for short periods in most years.
External drainage	Neither receiving nor shedding water.
Ground water depth	Very deep, more than 150 cm
Surface stones	Nil
Rock outcrops	Nil
Evidence of erosion	None
Sealing/non	None
Moisture condition	Topsoil (0-30 cm) is moist; below 30 cm the soil is dry.

C) Soil profile description

Horizon	Depth (cm)	Description
Ah	0-4	Dark brown (10YR 3/3) when moist, Grayish brown (10YR 5/2) when dry. Silty clay loam; Moderate, Coarse to medium subangular blocky. Slightly sticky and slightly plastic when wet; Very hard when dry and friable when moist; common, fine roots. pH 5.0. Non-calcareous. Smooth and clear boundary;
AB	4-14	Dark gray (10YR 4/1) when moist, dark grayish brown (10YR4/2) when dry. Silty clay loam; Moderate, medium size subangular blocky. Slightly sticky and plastic when wet. Common, fine roots. PH5.5. Non-calcareous. Clear and wavy boundary.
C	14-40	Dark gray (10 YR 4/1) when moist, brown (10YR 4/3) when dry. Silty clay loam; Weak, medium to fine size, subangular blocky. Slightly sticky and plastic when wet; few very fine Roots. pH 5.5. Non calcareous; gradual and smooth boundary
2Ah	40- 57	Dark brown (10YR 3/3) when moist and grayish brown (10YR 5/2) when dry; Silty clay loam; strong, medium size subangular blocky; slightly sticky and slightly plastic; few, very fine roots; pH 6.0; clear and wavy boundary
2AB	57- 77+	Dark gray (10 YR 4/1) when moist, light brownish gray (10YR 6/2) when dry. Silty clay. Weak, fine subangular blocky. Sticky and plastic. Very few and very fine roots. Non-calcareous. pH 6.5

A) Information on soil profile site

Profile ID	**Naiv/2001/Shep-005**
Date of examination	October 3, 2001
Type of observation	Mini-pit
Authors	C. M. Shepande R. Hennemann
Location	211616, 9922443 (UTM, ARC 1960), Delamere farm, 100 m from the main office, in the middle part of the Lacustrine Plain.
Altitude	1893 m above sea level
Geopedological unit	Pl.211, middle part of the Lacustrine Plain
Topography	0% slope, flat
Microtopography	No micro- relief
Parent material	Lacustrine deposits
Vegetation	None
Land use	At the time of investigation, the land was under ploughed fallow

B) General information on soil profile

Classification WRB	Mollic Fluvisol
Diagnostic Criteria WRB	Mollic A, Fluvisoil Material
Human influence	Clearing and disturbance of vegetation (Ploughing)
Drainage class	Well drained
Internal drainage	Saturated for short periods in most years.
External drainage	Neither receiving nor shedding waters.
Effective soil depth	Deep, up to 100 m (Auguring was very difficult)
Ground water depth	Deep, more than 100 m
Surface stones	Nil
Rock outcrops	Nil
Evidence of erosion	None
Sealing/crusting	None
Moisture condition	Soil was dry at the time of investigation

C) Soil profile description

Horizon	Depth (cm)	Description
AP	0-9	Dark brown (10YR3/3) when moist, Dark gray (10YR 4/1) when dry. Silt clay, Very hard consistence when dry and friable when moist; strong, medium size, subangular blocky, Very sticky and very plastic; fine, very few roots. Non-calcareous. pH6.5; clear and wavy boundary
Ah	9-22	Dark grayish brown (10YR 4/2) when moist and brown (10YR 4/3) when dry, Silty clay; strong, medium size subangular blocky. Very sticky and very plastic. Friable when moist and very hard when dry. Very few, fine roots. Non-calcareous. pH 5.5; clear and wavy boundary.
BW	22-35	Very dark grayish brown (10YR 3/2) when moist and grayish brown (10YR5/2) when dry. Silty clay, moderate, medium size subangular blocky, sticky and very plastic when wet; friable when moist and hard when dry, roots are very few and very fine. Non-calcareous. pH 5.5. Horizon boundary is gradual and wavy.
C	35-60	Very dark grayish brown (10YR 3/2) when moist and dark brown (10YR 3/3) when dry. Silty clay (heavy). Moderate, fine to medium sabangular blocky; sticky to very sticky and very plastic when wet. Very few and very fine roots. Non-calcareous. Field pH 5.5.

A. Information on soil profile site

Profile ID	**Naiv/2001/Shep- 00 6**
Date of examination	October 3, 2001
Type of observation	Mini-pit
Authors	C.M. Shepande, R. Hennemann
Location	211058, 9921223 (UTM, ARC 1960), Delamere farm, 150 m Northeast of the airstrip. It is situated in the lowest part of the lacustrine plain.
Altitude	1889 m above sea level
Geopedological unit	Pl.311, lower part of the lacustrine plain.
Topography	2 % slope, almost flat
Microtopography	No micro relief
Parent material	Lacustrine deposits
Vegetation	Mainly woodland, with about 40 % grass cover.
Land use	Extensive grazing for dairy cows.

B) General information on soil profile

Classification WRB	Umbric Fluvisol
Diagnostic Criteria WRB	Umbric A, Fluvic Soil Material.
Human influence	Partial clearing and disturbance of vegetation
Effective soil depth	Very deep, > 150 cm
Drainage class	Well drained
Internal drainage	Saturated for short periods in most years.
External drainage	Neither receiving nor shedding water.
Ground water depth	Very deep, >150 cm.
Surface stones	Nil
Rock outcrops	Nil
Evidence of erosion	None
Sealing/Crusting	None
Moisture condition	The soil was dry at the time of investigation.

C) Soil profile description

Horizon	Depth (cm)	Description
Ah	0-17	Dark gray (5YR4/1) when moist, and gray (10YR 5/1) when dry; sandy clay loam. Moderate, medium size subangular block, slightly sticky and plastic when wet, hard when dry and friable when moist; common, fine roots. pH 7.0; gradual and smooth boundary
2Ah	17-32	Dark reddish gray (5YR 4/2) when moist and gray (10YR5/1) when dry, sandy clay loam, moderate to strong, medium size, subangular blocky. Slightly sticky and plastic when wet, common, fine roots. pH 8.0; gradual and smooth boundary.
BW	32-50	Dark reddish gray (5YR 4/2) when moist and light brownish gray (10YR 7/1) when dry; sandy clay loam, moderate to weak, fine size, subangular blocky. Slightly sticky and plastic when wet. Very few, fine roots. pH 8.5. Diatomite was noticed. Gradual and wavy boundary
C	50-70	Reddish brown (5YR 4/3) when moist; sandy clay loam, weak, fine structure; slightly sticky and plastic when wet; very few, fine roots. Field pH 8.5; smooth and clear boundary

A) Information on soil profile site

Profile ID	**Naiv/2001/Shep-007**
Date of examination	October 3, 2001
Type of observation	Min-pit
Authors	C.M. Shepande, R. Hennemann
Location	Delamere farm,214505, 9923583, about 100 m south of the karati River bridge
Altitude	1956 m above sea level
Geopedological unit	Pf111, deltaic river plain
Topography	10% slope, Convex slope
Microtopography	No micro relief
Parent material	Karati alluvial deposits
Vegetation	Grassland, more than 80% grass cover.
Land use	Extensive grazing for dairy animals.

B) General information on soil profile

Classification WRB	Umbric Fluvisol
Diagnostic Criteria WRB	Umbric A, Fluvic soil Material.
Human influence	Clearing and disturbance of vegetation.
Effective soil depth	Deep, up to 120 cm
Drainage class	Well drained
Internal drainage	Rarely saturated.
External drainage	Neither receiving nor shedding water
Ground water depth	Deeper than 120 cm
Surface stones	Common, mainly coarse gravel
Rock outcrops	Nil
Evidence of erosion	Sheet erosion evident. 5-10% area affected (moderate degree)
Sealing	Sealing of medium thickness, about 2- 5 mm.
Moisture condition	The soil was very dry at the time of investigation.

C) Soil profile description

Horizon	Depth (cm)	Description
Ah	0-20	Dark brown (7.5YR3/2) when moist and light reddish brown (5YR 6/3) when dry. Clay loam, Moderate medium size, subangular blocky structure, slightly sticky and slightly plastic. Very few, fine fine; pH 6.0. Non-calcareous; smooth and clear boundary
AB	20-50	Dark gray when moist (7.5 YR 4/1) and pinkish gray (5YR 7/2) when dry. Sandy clay loam, weak to moderate, fine, subangular blocky structure. Slightly sticky and slightly plastic. Very few, very fine roots. pH 7.0; gradual and wavy boundary
C	50-70+	Dark gray when moist (7.5 YR 4/1) and pink when dry. Sandy clay loam; weak to moderate structure; slightly sticky and slightly plastic. Very few, very fine roots. Slightly calcareous. Field pH 7.0

A. Information on soil profile site

Profile ID	**Naiv/2001/Shep-008**
Date of examination	October 3, 2001
Authors	C.M Shepande, R. Hennemann.
Location	214960, 9925169; Three point farm, about 30 m east of the ridge.
Altitude	1991m above sea level
Geopedological unit	Lf 211, upper foot slope of the step faulted plateau
Topography	4 % slope, gently sloping
Microtopography	No micro relief
Parent material	Kinangop tuff, Eburru Pumice
Vegetation	None
Land use	Irrigated agriculture, (cabbage).

B) General information on soil profile

Classification WRB	Tephric Umbrisol
Diagnostic Criteria WRB	Umbric A, Tephric Soil Material
Human influence	Clearing for cultivation
Effective soil depth	Very deep > 150 cm.
Drainage class	Well drained
Internal drainage	Never saturated
External drainage	Neither receiving nor shedding water
Ground water depth	Very deep, > 150 cm
Surface stones	Few
Rock outcrops	Non
Evidence of erosion	None
Sealing/crusting	None
Moisture condition	Soil was wet at the time of investigation.

C) Soil profile description

Horizon	Depth (cm)	Description
Ah	0-18	Very dark gray (7.5YR 3/1) when moist and Dark gray (7.5YR 4/1) when dry. Silty clay. Strong, medium size subangular blocky structure. Very sticky and very plastic. Friable when moist and hard when dry. Few, coarse roots. Non-calcareous. Field pH 5.0. Clear and wavy boundary.
BW1	18-40	Very dark brown (7.5YR 2.5/2) when moist and brown (7.5 YR5/2) when dry. Silty clay. Moderate, medium to fine size subangular blocky structure. Very sticky and plastic. Friable when moist and soft when dry. Common, medium size roots. Non-calcareous. Field pH 4.5. Clear and smooth boundary
BW2	40-60+	Black (7.5 YR 2.5/1) when moist and gray (7.5 YR 6/1) when dry. Silty clay. Moderate to weak, fine subangular blocky structure. Sticky and plastic. Soft when hard and friable when moist. Common, fine roots. Non-calcareous. Field pH 4.5.

APPENDIX B QUESTIONNAIRES FOR DEFINING LUTs, LURs, LCS, AND DECISION TREES

Questionnaire for the description of LUT-CABBAGE (Three point farm)

Question	Nature of question	Respondent	Response
1.What is the size of the farm?	Management	Mr. Duncan	The total farm area is 297 ha, while the total pivot area is 216 ha.
2.Under what form of tenure is this farm?	Socio-economic	Mr. Duncan (farm manager)	Owned by three points farm
3.Which crops and cultivars are grown on this farm?	Agronomic	-do-	Cabbage (Gloria), rotated with tomatoes and roses
4.During which season is cabbage produced?	Agronomic	Mr. Duncan	Cabbage is produced through out the year under irrigation.
5.How uniform are the production levels through out the year?	Economical	Mr. Duncan	In the months of June and July, most bore holes run out of water resulting in the abandonment of some pivots; hence production is low during this period.
6.Can you give me the major features of the cropping calendar?	Agronomic	Mr. Duncan	Planting/transplantation is done weekly, usually every Monday. Harvesting is done daily.
7.At what stage are seedlings transplanted?	Agronomic	Mr. Onyengo	Seedlings are transplanted when they are 3-4 weeks old.
8. What irrigation method is used?	Management	Mr. Duncan	Pivot irrigation
9.Why do you prefer pivot irrigation to other	Economical /Management	-do-	Water loss is minimal as compared to overhead sprinkler irrigation, while drip irrigation is expensive.
10.Is the water supply seasonal or through out the year?	Management	-do-	Through out the year (from bore holes)
11. Which incentives are	Management	-do-	Seeds, herbicides and fertilizers.

incentives are critical on this farm	nt		
12. When and how do you apply the fertilizers?	Agronomic	Mr. Onyengo	For top dressing NH4 N03 is applied mainly through irrigation water (fertigation) during the folding stage (in the 6th week)
13. How are herbicides applied?	Agronomic	-do-	At folding stage to control grassy weeds (applied together with irrigation water)
14.How much Does ammonium nitrate cost?	Economical	-do-	19200 SH/ ton
15.What is the price for seeds?	Economical	-do-	200 SH/kg
16.What is the cost for the herbicides?	Economical	-do-	112 SH/ Liter
17.Which operations are mechanized and which ones are not?	Manageme nt	-do-	All operations are mechanized except harvesting, cleaning and packaging
18.What is the main type of labor	Manageme nt	-do-	Hired casual labor (80 workers daily), mainly for harvesting, cleaning and packaging
19.How much is a casual worker paid per day?	Socio-economic	Selected casual workers	100 SH/day
19.What is the yield/ha	Agronomic	Igor	30,000 pieces/ha (each piece = 3kg)
20.What is the market for the produce?	Manageme nt	Mr. Igor	European and local markets.
21.When do you have the best market for your produce?	Economical / Manageme nt	Mr. Duncan	The best marketing months are January, February and March. December is the worst marketing month because local farmers also produce rain fed cabbage.
22.What are the prices for the produce?	Manageme nt	Mr. Igor	6.26 KSH/piece

Questionnaire for the selection of LURs for irrigated cabbage (Three point farm)

Question	Nature of question	Respondent	Response
1.Generally speaking, why are you engaged in irrigated cabbage production?	General/manage-ment	Mr. Duncan (Ass. Manager)	There is a conducive environment for cabbage production and we have a readily available market.
2.Are there any variations in the performance of this LUT in different parts of your farm?	General	-do-	Some parts of the farm perform much better than others.
3.Which sections of your farm are best suited for the production of irrigated cabbage?	General	-do-	Different areas perform differently; but the lacustrine sections seem to perform better.
4.What agro-ecological conditions affect the performance of this LUT?	Agronomic	-do-	This LUT performs well in conditions of sufficient moisture in the soil, oxygen, nutrients and optimum conditions for root growth.
5.What management conditions would make this LUT successful or not successful?	Management	-do-	This LUT requires favorable conditions for mechanized operations and favorable soil working conditions.
6.Are there any environmental factors that can influence the performance of this LUT?	Environmental/ Conservation	-do-	The noticeable environmental factors affecting this LUT are sealing and erosion hazard.
7.What socio-economic factors are critical for the successful implementation of this LUT?	Socio-economical	-do-	Availability of market, availability of labor. Labor and markets are readily available.
8. Are there any other factors that seem to affect the performance of this LUT?	General	Mr. Onyengo	It is difficult to say unless you specify a class of factors.

Questionnaire for determining severity levels for the LURs (LUT-Cabbage)

Question	Nature of question	Respondent	Response
1.On the LUR 'moisture Availability' how can you stratify the degrees of the Land quality?	Agronomic	Mr. Duncan, Mr. Onyengo	Moisture availability can be high, moderate Low and very low.
2.On the LUR 'oxygen availability' For the roots, how can you stratify the of the land quality?	Agronomic	-do-	Oxygen availability for the roots can be high, moderate, low and very low.
3.On the LUR'nutrient availability' how can you stratify the degrees of the land quality?	Agronomic	-do-	Nutrient availability can be high, moderate Low, very low
4.Since you apply fertilizers through irrigation, is nutrient availability still a LUR?	Follow-up Question	-do-	Yes, because in areas with high nutrient levels, the fertilizer dosage is lower; so it is more economical.
5.On the LUR'rooting conditions' how can you stratify the degrees of the land quality?	Agronomic	-do	Rooting conditions can be good, moderat Poor and very poor
6.Cabbage isn't deep rooted, so why consider rooting conditions	Follow up question	-do-	Due to surface stones and heavy clays
7.On the LUR 'potential for mechanized operations' how can you stratify the degrees of the land quality?	Management	-do-	Potential for mechani- Zation can be high, moderate, low and
8.On the LUR 'soil workability'	Management	-do-	Soil workability can be good, moderate
9.On the LUR 'erosion hazard'	Environmental		Erosion hazard can be

how can you stratify the degrees of the land quality?		-do-	Completely non existent, noticeable moderate or severe (No history of crop failure due to erosion)
10.On the LUR 'sealing hazard' how can you stratify the degrees of the land quality?	Environmental	-do-	Sealing hazard can be absent, noticeable, moderate or severe.

Questionnaire for selecting land characteristics for LUT Cabbage

Question	Nature of question	Respondent	Response
1.What characteristics of the land do you need to determine the severity levels of the land quality 'moisture supply'?	Agronomic	Duncan, Mr. Onyengo	To determine the land quality of available moisture in an irrigated LUT, one needs to know the water holding capacity, which depends on particle size families.
2.What characteristics of the land do you need to determine the severity levels of the land quality 'oxygen supply'?	Agronomic	-do-	To determine the land quality of available oxygen, we need to know the drainage class of the soil.
3.What characteristics of the land do you need to determine the severity levels of the land quality 'nutrient supply'?	Agronomic	-do-	To determine the land quality of available nutrients, one needs to know the organic matter content, soil reaction and the amount of elements in the soil (K, Ca, Mg).
4.What characteristics of the land do you need to determine the severity levels of the land quality 'rooting conditions'?	Agronomic	-do-	To determine the land quality of rooting conditions, we need to know the soil texture and the incidence of subsurface stones.

5.What characteristics of the land do you need to determine the severity levels of the land quality 'conditions for mechanization'	Management	-do-	To determine the land quality of potential for mechanization, one needs information on surface stones and slope gradient
6. What characteristics of the land do you need to determine the severity level of the land quality 'soil workability'	Management	-do-	To determine the land quality of soil workability, we need to know the consistence of the soil when wet and the soil consistence when dry
7.What characteristics of the land do you need to determine the severity levels of the land quality ' erosion hazard'?	Environmental	-do-	To determine the land quality of erosion hazard, we need to know the slope gradient of the area and the observed incidence of erosion.
8.What land data do you need to determine the severity levels of the land quality 'sealing hazard'?	Environmental	-do-	To determine the land quality of sealing hazard one needs to know the soil textural class and thickness of crusts.

Questionnaire for building a decision tree

Question	Nature of Question	Respondent	Response
1.For the land characteristic 'particle size', what values would mark the critical levels in the decision process?	Agronomic	Mr. Onyengo, Mr. Duncan & The Evaluator	The values for moisture availability are: -Clay, silt Very fine sand (high) -Fine sand (Moderate) -Medium sand (low) -Course sand, Very coarse sand, gravel (Very low)
2.For the land characteristic 'drainage class'	Agronomic		The values for oxygen supply are: Well drained (Good)

what values would mark the critical levels in the decision process?			Moderately well drained (moderate) Imperfectly drained (Poor) Poorly drained (Very poor)
- Is this information enough to determine the severity level?	Follow up question	-do-	Not answered. (No information available). So it will be assumed that the information is enough.
3. For the land quality 'nutrient supply' what is the most important land characteristic (LC)	Agronomic	-do-	The most important LC is organic matter
- What values of this LC (organic matter) mark the critical values in the decision process?	Follow up	-do-	The following values are considered: - High: 4.0 % or more Moderate: 2.5 – 4.0 % Low: 1.5- 2.5 % Very low: 0- 1.5 %
- What is the next most important LC	Follow up question	Do	The next most important LC is soil reaction (pH)
- What values of this LC (pH) mark the critical values?	Follow up question	Do	Good: 5.5- 7.0 Moderate:7.0-7.5; 5.0-5.5 Poor: 7.5 – 8.0; 4.5- 5.0 Very poor: 8.8- 9.5; 3.5- 4.0
-What is the next most important LC	Follow up question	Do	The next most important LC is the amount of soil elements (K, Ca, Mg).
-What values of this LC (soil elements) mark the critical values in the decision process?	Follow up question	Do	The experts could not give the values. But they insist that the severity level of the land quality 'nutrient supply' can be decided using O.M and pH.
4. For the land quality 'rooting conditions' what diagnostic LC most determines the severity level?	Agronomic	Do	The most important LC is soil texture.
-What values of this LC(Texture) mark the critical values in the decision process	Follow up question	Do	The values for the LC are: -S, LS, SL, l, SiL, SCL, CL, SiCL (Good) -Sc. (Moderate) Sic, c (poor)

			Heavy clays (Very poor)
- What is the next most important LC for determining the severity level?	Follow up question	Do	The next most important LC is the incidence of subsurface stones
-What values of this LC mark the critical values in the decision process?	Follow up Question	Do	The values for the LC (incidence subsurface of stones) are: - <5 % (good) 5- 15 % (Moderate)
5. For the land quality 'conditions for mechanization' what LC most determines the	Manageme nt	Do	The most important LC is slope gradient.
-What values of this LC mark the critical values in the decision process?	Follow up question	Do	The values for this LC (slope) are: 0- 9 % (gentle slope) 9- 18 % (moderate slope) 18- 32 % (steep slope) 32- 70 % (very steep slope)
-What is the next most important LC?	Follow up question	Do	The other LC is surface stones
-What values of this LC mark the critical values in the decision process?	Follow up question	Do	The values for this LC are: 0-5 % (Very few) 5- 15 % (Few) 15- 50 % (common) >50 % (many)
6. On the land quality 'soil workability' what LC most determines the severity level?	Manageme nt	Do	The most important LC is soil consistence when wet.
- What values of this LC mark the critical values in the decision making process?	Follow up question	Do	The values for this LC are: Non sticky (Easy) Slightly sticky (Moderate) Sticky (Difficult) Very sticky (Very difficult)
-What is the next most important LC for determining the severity level?	Follow up question	Do	The next most important LC soil consistence when dry.

-What values of this LC mark the critical values in the decision process?	Follow up question	Do	The values for this LC are: Loose/soft (Easy) Slightly hard (Moderate) Hard (Difficult)
7. On the land quality 'erosion hazard' what LC most determines the	Environmental	Do	The most important LC for determining the severity level is slope gradient.
-What values of this LC mark the critical values in the decision process?	Follow up question	Do	The values for this LC are: <3 % (Low Hazard) 3- 8 % (Moderate) 9- 16 % (High) >16 % (Very high)
- What is the next most important LC	Follow up question	Do	The next most important LC is observed erosion.
- What values of this LC mark the critical values in the decision process?	Follow up question	Do	The values for this LC are: Slight Moderate Severe Very severe.
8. On the land quality 'sealing hazard' what LC most determines the severity level?	Management	Do	The most important LC is soil texture.
-What values of this LC mark the critical values in the decision process?	Follow up question	Do	The values for this LC are: S, LS, C, SIC, SC (Low hazard) SL, SCL (Moderate hazard) Si, SIL, L (high hazard)
- What is the next most important LC for determining the severity level?	Follow up question	Do	The next most important LC for determining the severity level is crust thickness.
- What values of this LC mark the critical values in the decision process?	Follow up question	Do	The values for this LC are: <1 mm (Negligible) 1- 2 mm (Slight) 2- 5 mm (Moderate) >5 (Severe)

Questionnaire for the description of LUT Lucerne (Delamere Farm)

Question	Nature of question	Respondent	Response
1.What is the size of the farm?	Managem ent	Mr.Retief	The total pivot area of this farm is about 468 ha, while the area under lucerne production is 88 hectares, with 260 dairy cows
2.Under what form of tenure is this farm?	Socio-economic	-do-	This is a corporately owned farm engaged in dairy farming and fodder production
3.What is the main fodder crop on this farm?	Agronom ic	Mr.W. Rootich (Agriculturis t)	The main crop is lucerne, rotated with oats, sunflower and baby-corn
4.During which season is lucerne produced?	Agronom ic	Mr.Retief	Lucerne is produced through out the year under irrigation.
5.Can you give me the major features of the cropping calendar?	Agronom ic	do	Lucerne has a life span of three years from sowing. Flowering starts after 32- 35 days.
6. What irrigation method is used?	Managem ent	do	Pivot irrigation
7.Why do you prefer pivot irrigation to other methods?	Economic al/Manag ement	do	Water loss is minimal as compared to overhead sprinkler irrigation, while drip irrigation is expensive
8. Is the water supply seasonal or through out the year?	Managem ent	do	Through out the year (from bore holes)
9. Which incentives are critical on this farm?	Managem ent	do	The main incentives required are seeds and herbicides.

10. How about other incentives like fertilizers?	Agronomic	do	Fertilizers are applied 2-3 times during the life span of lucene
11.What are the prices for seeds and herbicides?	Economical	do	Seeds cost about 250 SH/kg, while herbicides cost about 112 SH/Liter
12.Which operations are mechanized and which ones are not?	Management	do	All operations from planting to cutting are mechanized. Only packaging is done manually.
13.What is the main type of labor	Management	do	Hired casual labor (50 workers daily), mainly for packaging
14.How much is a casual worker paid?	Management	Selected casual workers	100 SH/day
15.What is the yield of lucerne/ha?	Agronomic	Mr. Rootich	20 tons/ha
16.What is the cutting interval?	Agronomic	Dr. Ojango	Cutting is done after every 35 to 40 days.
17.What is the main market for the produce?	Management	Dr. Ojango	Some of the lucerne produced is used to feed dairy animals on the farm; some of it is sold to local farmers.
18.During which season do you have the best market for the produce?	Management	Mr. Retief	During the dry season since cultivation of lucerne is entirely dependent on irrigation.
19.What are the prices for the produce?	Economical/ management	do	13150 SH/ton

Questionnaire for selecting land use requirements (LURs) for Lucerne

Question	Nature of question	Respondent	Response
1. Why are you engaged in Lucerne production?	General/Management	Mr. Retief (General Manager) & Dr. Ojango	This farm has about 260 dairy cows. Lucerne is produced for animal feed and for sell to local farmers.
2. Do you observe any variations in the performance of this LUT in the different parts of your farm?	General	Do	Lucerne performs differently in different parts of the farm
3. What agro-ecological conditions affect the performance of this LUT?		Do	For a successful performance of this LUT there should be sufficient soil moisture, oxygen, and good conditions for root growth.
4.What management conditions would make this LUT successful or not successful?	Management	Do	For a successful implementation of this LUT, there should be favorable soil working conditions.
5. Are there any environmental factors that can influence the performance of this LUT?	Management	Do	The most serious environmental factor affecting the performance of this LUT is sealing and soil salinity.
6. What socio-economic factors are critical for the successful implementation of this LUT?	Socio-economical	Do	This LUT requires reliable local markets and labor.
7.Are there any other factors that seem to affect the performance of	General	Do	Climatic conditions are favorable through out the year and positively affect the performance of this LUT.

this LUT

Questionnaire for determining severity levels for the land use requirements (Lucerne)

Question	Nature of question	Respondent	Response
1.On the LUR 'moisture availability' how can you stratify the degrees of the land quality?	Agronomic	Farm horticulturist/ Agronomist	Moisture availability in the soil can be high, moderate, low and very low
2.On the LUR 'oxygen availability' how can you stratify the degrees of the land quality?	Agronomic	Do	Oxygen availability for the roots can be high, moderate, low and very low
3. On the LUR 'rooting conditions' how can you stratify the degrees of the land quality/	Agronomic	Do	Rooting conditions can be good, moderate, poor and very poor.
4. On the LUR 'soil workability' how can you stratify the degrees of the land quality?	Management	Do	Soil workability can be good, moderate, poor and very poor.
5. On the LUR 'sealing hazard' how can you stratify the degrees of the land quality?	Environmental	Do	Sealing hazard can be non-existent, noticeable, moderate or severe.
6. On the LUR 'soil salinity hazard' how can you stratify the degrees of the land quality?	Environmental	Do	Soil salinity can be absent, low, moderate and high.

Questionnaire for selecting land characteristics

Question	Nature of question	Respondent	Response
1. What characteristics of the land do you need to determine the severity levels of the land quality 'moisture supply'?	Agronomic	-do-	To determine the land quality of available moisture, one needs to know the particle size families.
2. What characteristics of the land do you need to determine the severity levels of the land quality 'oxygen supply'?	Agronomic	Do	To determine the land quality of available oxygen, one needs to know the duration of periods when soil is free of saturation (Drainage class)
3. What characteristics of the land do you need to determine the severity levels of the land quality 'rooting conditions'?	Agronomic	Do	To determine the land quality of rooting conditions, one needs to know the minimum rooting depth and soil texture.
4.What characteristics of the land do you need to determine the severity level of the land quality 'soil workability'?	Management	Do	To determine the land quality of soil workability, one needs to know the consistence of the soil when wet and the soil consistence when dry.
5.What characteristics of the land do you need to determine the severity level of the land quality	Environmental	Do	To determine the severity level of the land quality of sealing hazard we need to know the soil texture, the thickness of crusts and the incidence of diatomite.

'sealing hazard'?			
6. What characteristics of the land do you need to determine the severity level of the land quality ' salinity hazard'?	Environmental	Do	To determine the severity level of this land quality, one needs to know the electric conductivity of soil.

Questionnaire for building decision trees

Question	Nature of question	Respondent	Response
1.For the land quality of available moisture, you mentioned that an important LC is soil particle size; what values of this LC would mark the critical levels in the decision process?	Agronomic	Farm agronomist/horticulturist & The evaluator	The values for moisture availability are: Clay, fine clay (high) Loam, fine silt (moderate) Coarse loamy, coarse silt (low) Sand, gravel (very poor)
- Is it possible to determine the severity level from just this information?	Follow up question	Do	As far as the respondents are concerned, Yes.
2.For the land quality of available oxygen, you mentioned that an important LC is drainage class; what values of this LC would mark the critical levels in the decision process?	Agronomic	Do	The values for oxygen supply are: - Well drained (Good) -Moderately well drained (moderate) Imperfectly drained (Poor) Poorly drained (Very poor)
3.For the land quality of rooting conditions, you mentioned two LCs, soil texture and minimum rooting depth; which of these two LCs most determines the severity level	Agronomic	Do	The most important LC is soil texture

- What values of this LC (Texture) mark the critical levels in the decision process?	Follow up question	Do	The values for this LC are: S, LS, L, SiL, CL, SiCL (good) SC (Moderate) SiC, C (Very poor) Heavy clays (Very poor)
- What values of the LC (min. rooting depth) mark the critical levels in the decision process.	Follow up question	Do	The values for this LC are: > 100 cm (Good) 50 – 100 cm (Moderate) 20 – 50 cm (Poor) <20 cm (Very poor)
4. For the land quality 'soil workability' you mentioned two LCs, soil consistence when dry and soil consistence when wet; which of these two LCs most determine the severity level?	Manage ment	Do	It is difficult to pin point one LC, although soil stickiness when wet seems to be more critical. Soil stickiness when wet reduces the efficiency of mechanized operations and increases the expenses on fuel and labor costs.
- What values of this LC (Consist. When wet) mark the critical levels in the decision process?	Follow up question	Do	The values for this LC are: Non sticky (Easy) Slightly sticky (Moderate) Sticky (Difficult) Very sticky (Very difficult)
- What values of the LC (Consist. When dry) mark the critical values in the decision process?	Follow up question	Do	The values for this LC are: Loose/soft (Easy) Slightly hard (Moderate) Hard (Difficult) Very hard (Very difficult)
5. For the land quality of sealing hazard, you mentioned 3 LCs: Texture, diatomite and crust thickness. Which of these most determines the severity level?	Environ mental	Do	The most important LC is Soil texture.
- What values of this LC (Texture) mark the critical values in the decision	Follow up question	Do	The values for this LC are: S, LS, C, SIC, SC (Low hazard)

process?	question		hazard) SL, SCL (Moderate hazard) SI, SIL, L (High hazard)
-What values of the LC ‘Crust thickness’ mark the critical values in the decision process?	Follow up question	Do	The values for this LC are: <1mm (Negligible) 1—2 mm (slight) 2 - 5 mm (Moderate) 5 - 10 mm (severe)
- What values of the LC ‘incidence of diatomite mark the critical values in the decision process?	Environ mental	Do	Experts said they do not have adequate knowledge on this aspect. So no values were given. (To be obtained from literature)
6. For ‘salinity hazard’ an important LC is EC; what values are most critical?	Environ mental	Do	To be obtained from literature. The expert only knows that Lucerne does not tolerate salinity.

Appendix C Laboratory data (chemical and physical analyses)

Factors, Units	***Profile ID Shep 001***	***Profile ID Shep 002***	***Profile ID Shep 003***	
	Horizon Ah	*Horizon Ah*	*Horizon Ah*	*Horizon C1*
PH	6.1	6.6	7.1	6.3
EC, DS/m	1.0	1.5	1.2	1.0
OM, %	3.4	6.8	5.6	1.6
Ca, mg/l	18.3	29.4	29.9	19.0
K, mg/l	34.9	61.1	38.6	48.3
Mg, mg/l	9.2	25.8	18.5	12.8
Na, mg/l	20.6	16.1	39.0	12.1
TEB, cmol/kg	43	73	71	47
C & V.C sand, %	18.2	10.8	6.7	5.0
Medium sand, %	28.9	14.2	11.3	10.6
Fine sand, %	21.4	14.1	18.0	18.5
Very fine sand, %	28.2	30.9	40.7	55.2
Total sand, %	96.9	70	76.7	89.3
Silt, %	2.6	18.8	14.7	7.0
Clay, %	0.4	10.9	8.4	3.4

FAO Tex. class	FS	VFSL	VFSL	VFS
% of total sand				
C & V.C. sand, %	19	15	9	6.0
Medium sand,%	30	20	15	12
Fine & V. F sand	51	64	77	83

Factors, Units	**Profile ID: Shep 4**				
	Horizon Ah	*Horizon AB*	*Horizon C*	*Horizon 2Ah*	*Horizon 2AB*
pH	5.9	6.6	6.7	7.1	6.7
EC, DS/m	1.0	0.8	0.9	0.9	0.9
OM, %	7.8	4.2	1.8	4.8	3.0
Ca, mg/l	19.5	26.3	24.2	53.8	38.3
K, mg/l	48.6	33.7	28.1	31.5	26.2
Mg, mg/l	12.8	9.8	9.8	13.1	9.3
Na, mg/l	12.2	13.6	18.0	28.7	25.5
TEB, cmol/kg	47.5	43.8	43.9	72.7	55.7
C & V.C sand, %	3.6	3.6	3.3	3.4	12
Medium sand, %	6.1	6.2	3.3	6.2	10.8
Fine sand, %	10.1	9.3	7.1	12.2	13.9
Very fine sand, %	23.6	21.2	12.3	26.5	28.2
Total sand, %	43.4	40.3	42.7	48.3	64
Silt, %	37.6	38.0	65.4	32.8	21.8
Clay, %	18.6	21.4	23.9	18.6	13

FAO Tex. class	l	l	10.4	l	vfsl
% of total sand					
C & V.C. sand, %	8	9	5	7	18
Medium sand, %	14	15	11	13	17
Fine & V. F sand, %	78	76	84	80	65

Factors, Units	**Profile ID: Shep 005**			
	Horizon AP	*Horizon Ah*	*Horizon Bw*	*Horizon C*
pH	7.0	7.1	7.5	7.7
EC, DS/m	1.3	1.4	1.3	1.5
OM, %	6.0	3.2	1.2	1.0
Ca, mg/l	27.7	40.9	38.5	38.0
K, mg/l	57.7	66.9	61.3	28.2
Mg, mg/l	26.0	36.6	35.1	10.7
Na, mg/l	38.0	45.1	49.8	53.9
TEB, cmol/kg	83.1	112.2	106.8	73.0
C & V.C sand, %	7.1	2.9	7.4	5.3
Medium sand, %	9.2	4.0	9.4	8.6
Fine sand, %	13.1	8.1	17	18.6
Very fine sand, %	51.8	58.6	57.4	61.0
Total sand, %	81.2	73.6	91.2	93.5
Silt, %	12.1	17.1	7.1	5.8

Clay, %	6.4	9.0	1.4	0.2
FAO Tex. class	VFLS	VFLS	VFS	VFS
% of total sand				
C & V.C. sand, %	9	4.0	8	6
Medium sand, %	11	5.0	10	9
Fine & V. F sand, %	80	91	82	85

Factors, Units	**Profile ID: Shep 006**			
	Horizon Ah	*Horizon 2Ah*	*Horizon BW*	*Horizon C*
pH	7.3	7.6	8.5	8.9
EC, DS/m	1.5	2.3	3.0	3.5
OM, %	8.2	5.0	1.2	0.6
Ca, mg/l	59.0	64.8	48.0	79.7
K, mg/l	84.0	79.5	52.0	100
Mg, mg/l	16.2	14.5	13.0	25.1
Na, mg/l	20.6	44.5	54.0	20.4
TEB, cmol/kg	91.5	104.9	89.3	118.8
C & V.C sand, %	4.4	16.8	8.0	5.5
Medium sand, %	11.0	16.3	10.6	11.4
Fine sand, %	17.0	23.4	16.2	16.7
Very fine sand, %	55.2	22.8	59.5	52.2

Total sand, %	88.2	79.3	94.3	85.8
Silt, %	10.8	19.0	5.1	9.6
Clay, %	0.8	1.4	0.2	4.3
FAO Tex. class	VFS	FLS	VFS	VFLS
% of total sand				
C & V.C. sand	5.0	21.0	8.0	6.0
Medium sand,%	12.0	21.0	11.0	13.0
Fine & V.F sand	83.0	58.0	80.0	80.0

Factors, Units	**Profile ID: Shep 007**		
	Horizon Ah	*Horizon AB*	*Horizon C*
pH	7.2	7.1	6.9
EC, DS/m	0.8	0.8	1.5
OM, %	3.2	2.6	2.3
Ca, mg/l	15.4	19.0	26.2
K, mg/l	32.4	20.9	24.7
Mg, mg/l	13.2	6.1	5.5
Na, mg/l	14.1	24.7	60.1
TEB, cmol/kg	41.2	38.2	62.6
C & V.C sand, %	23.1	24.8	30.5
Medium sand, %	27.5	23.3	20.8
Fine sand, %	21.2	17.8	16.7
Very fine sand,	24.8	26.8	28.0
Total sand, %	96.6	92.7	96.0
Silt, %	2.3	4.4	3.3
Clay, %	0.78	2.7	0.4
FAO Tex. class	ms	ms	ms

Factors, Units	**Profile ID: Shep 008**		
	Horizon Ah	*Horizon BW1*	*Horizon BW1*
pH	7.0	6.8	6.1
EC, DS/m	1.3	0.5	2.2
OM, %	4.2	2.2	1.8
Ca, mg/l	16.2	10.2	10.4
K, mg/l	30.4	21.9	31.7
Mg, mg/l	5.8	6.2	6.4
Na, mg/l	37.8	17.6	32.2
TEB, cmol/kg	46.3	29.4	40.7
C & V.C sand, %	11.8	6.5	14.9
Medium sand, %	14.0	12.5	22.5
Fine sand, %	15.0	15.9	24.6
Very fine sand, %	45.0	54.0	8.0
Total sand, %	85.8	88.9	70.0
Silt, %	9.5	8.9	23.0
Clay, %	4.3	1.9	6.0

FAO Tex. class	MLS	VFS	MSL
% of total sand			
C & V.C. sand, %	14.0	7.0	21.0
Medium sand, %	16.0	14.0	32.0
Fine & V. F sand, %	70.0	79.0	47.0

Appendix D Location of auger hole observation points

Auger hole ID	*X coordinates*	*Y coordinates*
A-2	212813	9924171
A-3	212606	9923821
A-4	212001	9923115
A-6	21451	9922037
B-1	212262	9921037
B-2	212533	9921500
B-3	212834	9922091
B-4	213439	9923313
B-5	213905	9924088
C-1	214106	9922935
C-2	214699	9923308
C-3	214689	9924056
D-1	214913	9924419
D-2	214421	9924464
D-3	213334	9924594
E-1	213302	9925396
E-2	214935	9925356
E-3	215536	9925126
F-2	213616	9926536
F-3	213619	9926534
H-1	214184	9925482
rc1	210070	9924076
ris1	210881	9926160
Tre 1	209063	9923534
LF1	214763	9922356
SC1	215999	9923050
OV1	209904	9922547

Appendix E Photographs

Stoniness in map unit Lf 311

Particle size determination using the pipette method, ITC lab.

Appendix F Decision trees

(Land evaluation for cabbage) Decision Trees

<u>Moisture Availability</u>

(Soil Texture (ST family))
- s (sandy)............... : 4 (Very low)
- cl (coarse-loamy) > Crusts (Thickness of crusts)
  - tn (Thin) [0-1 mm]...... : 3 (Low)
  - m (Medium) [1-2 mm]..... : =1
  - tk (Thick) [2-5 mm]..... : =1
  - vt (Very thick) [5-30 mm : 4 (Very low)
- fl (fine-loamy)......... : 1 (high)
- cs (coarse-silty) > Crusts (Thickness of crusts)
  - tn (Thin) [0-1 mm]...... : 2 (moderate)
  - m (Medium) [1-2 mm]..... : 2 (moderate)
  - tk (Thick) [2-5 mm]..... : 3 (Low)
  - vt (Very thick) [5-30 mm : 4 (Very low)
    - fs (fine-silty)......... : =3
- f (fine)................ : 2 (moderate)
- Vf (very fine).......... : 3 (Low)

<u>Erosion Hazard</u>

Sl-e (Slope)
- Gsl-e (Gentle) [0-3 %]. : 1 (Absent)
- Mod-e (Moderate) [3-8 %] > Crusts (Thickness of crusts)
  - tn (Thin) [0-1 mm] > ST (Soil Texture (ST family))
    - s (sandy)............... : 1 (Absent)
    - cl (coarse-loamy)....... : 2 (Noticeable)
    - fl (fine-loamy)......... : =2
    - cs (coarse-silty)....... : 3 (high)
    - fs (fine-silty)......... : =3
    - f (fine)................ : 2 (Noticeable)
    - Vf (very fine).......... : 1 (Absent)
  - m (Medium) [1-2 mm] > ST (Soil Texture (ST family))
    - s (sandy)............... : 1 (Absent)
    - cl (coarse-loamy)....... : 2 (Noticeable)
    - fl (fine-loamy)......... : =2
    - cs (coarse-silty)....... : 3 (high)
    - fs (fine-silty)......... : =3
    - f (fine)................ : =3
    - Vf (very fine).......... : 1 (Absent)
  - tk (Thick) [2-5 mm]..... : 3 (high)
  - vt (Very thick) [5-30 mm : =3
- Steep-e (Steep s) [8-16 : =2
- Vstee-e (Very) [16-100 : 4 (Very high)

<u>Oxygen availability</u>
SD (Soil drainage)
WD (Well drained)....... : 1 (Optimum)
MWD (Moderately well dra : 2 (needs drainage)
ImpDr (Imperfectly drain : 3 (More drainage)
PoorDr (Poorly drained). : 4 (very low)

<u>Nutrient availability</u>
O.M (Organic matter)
Low (Low) [0-1.5 %]..... : 4 (very large doses)
Mod (Moderatr) [1.5-2.5 %] > SR (Soil reaction)
Vacid (Very acid) [1-4 pH] > T.E.B (Total exchangeable bases)
Vlow (very low) [0-40 cm : 4 (very large doses)
low (low) [40-70 cmol/kg : 4 (very large doses)
moderat (moderate) [70-1 : 3 (even more ferti)
high (high) [100-200 cmo : 2 (more fertilizer)
Acid (Acid) [4-6.5 pH] > T.E.B (Total exchangeable bases)
Vlow (very low) [0-40 cm : 4 (very large doses)
low (low) [40-70 cmol/kg : 3 (even more ferti)
moderat (moderate) [70-1 : 2 (more fertilizer)
high (high) [100-200 cmo : 2 (more fertilizer)
NeuAlk (Neutral to alkal : 2 (more fertilizer)
Valka (Very alkaline) [7 : 2 (more fertilizer)
High (High) [2.5-4 %] > SR (Soil reaction)
Vacid (Very acid) [1-4 p : 2 (more fertilizer)
Acid (Acid) [4-6.5 pH].. : =1
NeuAlk (Neutral to alkal : 1 (optimum)
Valka (Very alkaline) [7 : 3 (even more ferti)
Vhigh (Very high) [4-8.5 : 1 (optimum)

<u>Potential for using agricultural inputs</u>
Sl (Slope)
Gentslop (Gental slope) [0-9 %] > sur-st (Surface stones)
Vfew (Very few) [0-5 %]. : 1 (no limitation)
few (few) [5-15 %]...... : 1 (no limitation)
com (common) [15-50 %].. : 3 (moderate limitation)
many (many) [50-100 %].. : 4 (severe limitation)
Modslop (moderate slope) [9-18 %] > sur-st (Surface stones)
Vfew (Very few) [0-5 %]. : 1 (no limitation)
few (few) [5-15 %]...... : 2 (slight limitation)
com (common) [15-50 %].. : 3 (moderate limitation)
many (many) [50-100 %].. : 4 (severe limitation)

Steeslop (Steep slope) [18-32 %] > sur-st (Surface stones)
Vfew (Very few) [0-5 %]. : 3 (moderate limitation)
few (few) [5-15 %]...... : 3 (moderate limitation)
com (common) [15-50 %].. : 4 (severe limitation)
many (many) [50-100 %].. : 4 (severe limitation)

Vsteep (Very steep) [32- : 4 (severe limitation)

<u>Rooting conditions</u>

(general texture (4 classes))
  Vf (Very fine) > Substons (Subsurface stones)
    Vfew (Very few) [0-5 %]. : 2 (moderate)
    Few (few) [5-15 %]...... : 3 (poor)
    Com (common) [15-30 %].. : 4 (Very poor)
    Many (many) [30-100 %].. : 4 (Very poor)
  F (Fine) > Substons (Subsurface stones)
    Vfew (Very few) [0-5 %]. : 2 (moderate)
    Few (few) [5-15 %]...... : 2 (moderate)
    Com (common) [15-30 %].. : 3 (poor)
    Many (many) [30-100 %].. : 4 (Very poor)
  M (Medium).............. : =2
  C (Coarse) > Substons (Subsurface stones)
    Vfew (Very few) [0-5 %]. : 1 (Good)
    Few (few) [5-15 %]...... : 1 (Good)
    Com (common) [15-30 %].. : 3 (poor)
    Many (many) [30-100 %].. : 4 (Very poor)

<u>Soil workability</u>
Wc (Wet consistence(stickiness))
  Nst (Not stiky)......... : 1 (Good)
  Sl-st (Slightly sticky). : 2 (Moderate)
  sticky (Sticky)......... : 3 (Poor)
  very sti (Very sticky).. : 4 (Very poor)

<u>Sealing hazard</u>
ST (Soil Texture (ST family))
  s (sandy)............... : 1 (Absent)
  cl (coarse-loamy) > diat (Incidence of diatomite)
    Abs (Absent)............ : 1 (Absent)
    Pres (Present).......... : 3 (Moderate)
      fl (fine-loamy) > diat (Incidence of diatomite)
    Abs (Absent)............ : 2 (Slight)
    Pres (Present).......... : 4 (Severe)
  cs (coarse-silty)....... : 4 (Severe)
  fs (fine-silty)......... : =4
  f (fine) > diat (Incidence of diatomite)
    Abs (Absent)............ : 1 (Absent)
    Pres (Present).......... : 3 (Moderate)
  Vf (very fine).......... : 1 (Absent)

<u>Soil Toxicity</u>
SR (Soil reaction)
  Vacid (Very acid) [1-4 p : 3 (++ lime)
  Acid (Acid) [4-6.5 pH].. : 2 (+ lime)

NeuAlk (Neutral to alkal : 1 (No limitation)
Valka (Very alkaline) [7 : 4 (Impossible)

Land evaluation for Lucerne (Decision Trees)

Erosion Hazard

Sl-e (Slope)
Gsl-e (Gentle) [0-3 %]. : 1 (Absent)
Mod-e (Moderate) [3-8 %] > Crusts (Thickness of crusts)
tn (Thin) [0-1 mm] > ST (Soil Texture (ST family))
s (sandy)............... : 1 (Absent)
cl (coarse-loamy)....... : 2 (Noticeable)
fl (fine-loamy)......... : =2
cs (coarse-silty)....... : 3 (high)
fs (fine-silty)......... : =3
f (fine)................ : 2 (Noticeable)
Vf (very fine).......... : 1 (Absent)
m (Medium) [1-2 mm] > ST (Soil Texture (ST family))
s (sandy)............... : 1 (Absent)
cl (coarse-loamy)....... : 2 (Noticeable)
fl (fine-loamy)......... : =2
cs (coarse-silty)....... : 3 (high)
fs (fine-silty)......... : =3
f (fine)................ : =3
Vf (very fine).......... : 1 (Absent)
tk (Thick) [2-5 mm]..... : 3 (high)
vt (Very thick) [5-30 mm : =3
Steep-e (Steep s) [8-16 : =2
Vstee-e (Very) [16-100 : 4 (Very high)
Land evaluation for Lucerne (Decision tree)

Moisture availability

ST (Soil Texture (ST family))
s (sandy)............... : 4 (Very low)
cl (coarse-loamy) > Crusts (Thickness of crusts)
tn (Thin) [0-1 mm]...... : 3 (Low)
m (Medium) [1-2 mm]..... : =1
tk (Thick) [2-5 mm]..... : =1
vt (Very thick) [5-30 mm : 4 (Very low)
fl (fine-loamy)......... : 1 (high)
cs (coarse-silty) > Crusts (Thickness of crusts)
tn (Thin) [0-1 mm]...... : 2 (moderate)
m (Medium) [1-2 mm]..... : 2 (moderate)
tk (Thick) [2-5 mm]..... : 3 (Low)
vt (Very thick) [5-30 mm : 4 (Very low)
fs (fine-silty)......... : =3
f (fine)................ : 2 (moderate)
Vf (very fine).......... : 3 (Low)

Nutirient Availability

O.M (Organic matter)
  Low (Low) [0-1.5 %]..... : 4 (very large doses)
  Mod (Moderatr) [1.5-2.5 %] > SR (Soil reaction)
    Vacid (Very acid) [1-4 pH] > T.E.B (Total exchangeable bases)
      Vlow (very low) [0-40 cm : 4 (very large doses)
      low (low) [40-70 cmol/kg : 4 (very large doses)
      moderat (moderate) [70-1 : 3 (even more ferti)
      high (high) [100-200 cmo : 2 (more fertilizer)
    Acid (Acid) [4-6.5 pH] > T.E.B (Total exchangeable bases)
      Vlow (very low) [0-40 cm : 4 (very large doses)
      low (low) [40-70 cmol/kg : 3 (even more ferti)
      moderat (moderate) [70-1 : 2 (more fertilizer)
      high (high) [100-200 cmo : 2 (more fertilizer)
    NeuAlk (Neutral to alkal : 2 (more fertilizer)
    Valka (Very alkaline) [7 : 2 (more fertilizer)
      High (High) [2.5-4 %] > SR (Soil reaction)
    Vacid (Very acid) [1-4 p : 2 (more fertilizer)
    Acid (Acid) [4-6.5 pH].. : =1
    NeuAlk (Neutral to alkal : 1 (optimum)
    Valka (Very alkaline) [7 : 3 (even more ferti)
  Vhigh (Very high) [4-8.5 : 1 (optimum)

Oxygen Availability

SD (Soil drainage)
  WD (Well drained)....... : 1 (Optimum)
  MWD (Moderately well dra : 2 (needs drainage)
  ImpDr (Imperfectly drain : 3 (More drainage)
  PoorDr (Poorly drained). : 4 (very low)

Potential for using agricultural implements

Sl (Slope)
  Gentslop (Gental slope) [0-9 %] > sur-st (Surface stones)
    Vfew (Very few) [0-5 %]. : 1 (no limitation)
    few (few) [5-15 %]...... : 1 (no limitation)
    com (common) [15-50 %].. : 3 (moderate limitation)
    many (many) [50-100 %].. : 4 (severe limitation)
      Modslop (moderate slope) [9-18 %] > sur-st (Surface stones)
    Vfew (Very few) [0-5 %]. : 1 (no limitation)
    few (few) [5-15 %]...... : 2 (slight limitation)
    com (common) [15-50 %].. : 3 (moderate limitation)
    many (many) [50-100 %].. : 4 (severe limitation)
      Steeslop (Steep slope) [18-32 %] > sur-st (Surface stones)
    Vfew (Very few) [0-5 %]. : 3 (moderate limitati0n)
    few (few) [5-15 %]...... : 3 (moderate limitation)
    com (common) [15-50 %].. : 4 (severe limitation)
    many (many) [50-100 %].. : 4 (severe limitation)
  Vsteep (Very steep) [32- : 4 (severe limitation)

Rooting conditions

- Ps (general texture (4 classes))
  - Vf (Very fine) > Substons (Subsurface stones)
    - Vfew (Very few) [0-5 %] > RD (Rooting depth)
      - Vshal (Very shallow) [0- : 4 (Very poor)
      - Shallow (Shallow) [20-50 : 3 (poor)
      - Mod-Deep (Moderately deep : 2 (moderate)
      - deep (Deep) [100-1000 cm : =3
    - Few (few) [5-15 %]...... : =1
    - Com (common) [15-30 %] > RD (Rooting depth)
      - Vshal (Very shallow) [0- : 4 (Very poor)
      - Shallow (Shallow) [20-50 : =1
      - Mod-Deep (Moderately deep : 3 (poor)
      - deep (Deep) [100-1000 cm : 2 (moderate)
    - Many (many) [30-100 %].. : 4 (Very poor)
  - F (Fine)................ : =1
  - M (Medium) > Substons (Subsurface stones)
    - Vfew (Very few) [0-5 %] > RD (Rooting depth)
      - Vshal (Very shallow) [0- 4 (Very poor)
      - Shallow (Shallow) [20-50: =1
      - Mod-Deep (Moderately deep: 2 (moderate)
      - deep (Deep) [100-1000 cm : 1 (Good)
    - Few (few) [5-15 %]...: =1
    - Com (common) [15-30 %] > RD (Rooting depth)
      - Vshal (Very shallow) [0- : 4 (Very poor)
      - Shallow (Shallow) [20-50 : =1
      - Mod-Deep (Moderately deep: 2 (moderate)
      - deep (Deep) [100-1000 cm : =3
    - Many (many) [30-100 %].. : 4 (Very poor)
  - C (Coarse) > Substons (Subsurface stones)
    - Vfew (Very few) [0-5 %] > RD (Rooting depth)
      - Vshal (Very shallow) [0- : 3 (poor)
      - Shallow (Shallow) [20-50 : =1
      - Mod-Deep (Moderately deep : 2 (moderate)
      - deep (Deep) [100-1000 cm : 1 (Good)
    - Few (few) [5-15 %]...... : =1
    - Com (common) [15-30 %] > RD (Rooting depth)
      - Vshal (Very shallow) [0- : 4 (Very poor)
      - Shallow (Shallow) [20-50 : =1
      - Mod-Deep (Moderately deep : 2 (moderate)
      - deep (Deep) [100-1000 cm : 1 (Good)
    - Many (many) [30-100 %].. : 4 (Very poor)

Sealing hazard

ST (Soil Texture (ST family))
- s (sandy)............... : 1 (Absent)
- cl (coarse-loamy) > diat (Incidence of diatomite)
  - Abs (Absent)............ : 1 (Absent)
  - Pres (Present).......... : 3 (Moderate)

- fl (fine-loamy) > diat (Incidence of diatomite)
  - Abs (Absent)............ : 2 (Slight)
  - Pres (Present).......... : 4 (Severe)
- cs (coarse-silty)....... : 4 (Severe)
- fs (fine-silty)......... : =4
- f (fine) > diat (Incidence of diatomite)
  - Abs (Absent)............ : 1 (Absent)
  - Pres (Present).......... : 3 (Moderate)
- Vf (very fine).......... : 1 (Absent)

Soil Toxicity

SR (Soil reaction)
- Vacid (Very acid) [1-4 p : 3 (++ lime)
- Acid (Acid) [4-6.5 pH].. : 2 (+ lime)
- NeuAlk (Neutral to alkal : 1 (No limitation)
- Valka (Very alkaline) [7 : 4 (Impossible)

Soil workability

Wc (Wet consistence(stickiness))
- Nst (Not stiky)......... : 1 (Good)
- Sl-st (Slightly sticky). : 2 (Moderate)
- sticky (Sticky)......... : 3 (Poor)
- very sti (Very sticky).. : 4 (Very poor)

Salinity hazard

EC (Electric Conductivity)
- l (Low) [0-1.8 ds/m].... : 1 (none)
- m (Moderate) [1.8-3.4 ds/m] > SD (Soil drainage)
  - WD (Well drained)....... : 2 (low)
  - MWD (Moderately well dra : =1
  - ImpDr (Imperfectly drain : 3 (moderate)
  - PoorDr (Poorly drained). : 4 (high)
    - h (High) [3.4-7 ds/m] > SD (Soil drainage)
  - WD (Well drained)....... : 3 (moderate)
  - MWD (Moderately well dra : =1
  - ImpDr (Imperfectly drain : 4 (high)
  - PoorDr (Poorly drained). : =3
  - vh (Very high) [7-12 ds/ : 4 (high)