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SOILS AND THEIR MANGEMENT IN THE PROPOSED KUTUS EAST SMALLHOLDER IRRIGATION SCHEME, CENTRAL DIVISION, KIRINYAGA DISTRICT

BY

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EXECUTIVE SUMMARY

The proposed Kutus East Smallholder Irrigation Scheme (KESIS) is a community based farmers group initiative focusing on economic empowerment of the members through sustainable utilization and management soil and water resources. The bulk of KESIS area is to the south of Kutus township. KESIS is located about 15 km to the south of Kerugoya town. It is bounded between latitudes 00˚ 33'and 00˚ 38' South and longitudes 037˚ 19' and 037˚ 25' East or between or eastings 313 and 317 and northings 9931 and 9939, at an altitude of between 1200 – 1400 m above sea level (asl). The scheme is located in Kamiigua sub-location, Kutus location, Central Division of Kirinyaga District, Central Province of Kenya. It covers about 88 ha of the members' land. CAS Consultants Ltd requested for soil investigations in the project area with a view to providing soils and water information that would ensure the development of sustainable irrigated agriculture through community based management practices. This would ultimately foster the realization of household food self sufficiency/security, wealth creation and a healthy environment.

KESIS is one of the schemes that has been selected for development by the Smallholder Irrigation Program Mt. Kenya (SIPMK) within the Ministry of Water and Irrigation. SIPMK focuses on smallholder irrigation development by providing support for the implementation of new irrigation schemes and related extension work and by offering credit facilities to farmer groups.

The specific purpose of SIPMK is to sustainably increase agriculture production and subsequently farm income of smallholder farmers through the provision of additional irrigation facilities and services. The overall goal of the SIPMK program is to improve the living conditions of the farming population in the program area through increases in net farm income of participating farm households.

KESIS occurs in agro-climatic zone III with high to medium potential for plant growth. The main land use in the project area comprises of rearing of livestock (cattle, goats, sheep and donkeys) and growing rainfed subsistence crops such as maize, beans, pigeon peas and cow peas. The other crops grown mainly for subsistence are sugarcane and bananas. Fruits trees such as paw paw, mangoes and avocadoes are also grown in the area. Irrigated horticultural crops such as french beans, tomatoes, kales, brinjals and water melons are also grown in the lower part of the project area using furrow water en-route to Mwea Irrigation Scheme from River Nyamindi. Diversification by introduction of other horticultural crops such as brinjals, karela, okra, cucumber, dhuhi, water melons, passion fruits and citrus is recommended.

The proposed source of irrigation water for the scheme is River Kiringa, a tributary of River Thiba. The water from this source is suitable for irrigation without causing adverse negative impact to the soils. However results of water from wells indicate that the groundwater has moderate salinization and alkalization hazard and hence the need for efficient application of irrigation water to avoid a potential secondary salinization and sodification of the soils by a rise in the level of the groundwater.

The general physiography of the selected land to be irrigated comprises of uplands. The upper level uplands have soils developed on basalts and basaltic agglomerates. The irrigable upland crests or summits and associated sloping parts are very gently undulating to gently undulating in relief with slopes of between 1 – 5%. The soils are well drained, extremely deep, dusky red to dark reddish brown, friable to very friable, clay loam to clay. The soils are classified as Rhodic Ferralsols and Niti-Rhodic Ferralsols.

The undulating to rolling parts with slopes between 8– 16% have soils which are well drained, extremely deep to very deep, dusky red to dark reddish brown, friable to firm, clay. The soils are classified as Ferric and Ferral -Haplic Lixisols.
The lower level uplands have soils which are developed on trachytic tuffs. The soils are well drained, moderately deep to very deep, dark reddish brown to dark brown, friable to firm, clay. The soils are predominantly Plinthic and Ferric Acrisols.

The flat to very gently undulating valley bottoms with slopes between 0-2% occur at the foot of the uplands. Though not targeted for irrigation as most of them are already under irrigation, they are predominantly occupied by imperfectly drained to poorly drained, moderately deep to very deep, very dark greyish brown to black, firm, cracking clay soils. The soils are classified as Calcic and Eutric Vertisols, sodic phase.

The soils of mapping unit UBr are strongly to moderately acidic (pH 4.7 – 5.6). The soils are deficient in N. P is deficient in some parts of the unit. The unit shows presence of some exchangeable acidity which is detrimental to plant roots and microbial population. Liming the soils of the unit at the rate of 300 kg/acre 3 weeks before planting is recommended. Liming will not only neutralize the excess acidity but will also raise the Ca content and hence enable the uptake of both K and Mg by plants by raising the Ca:K and Ca:Mg to optimal ratios. Application of compound fertilizer N:P:K 23:23:0 at the rate of 250 kg/ha is recommended. Organic matter is low in the unit and application of farmyard manure or compost at the rate of 10 t/ha is recommended.

The soils of mapping unit UPb are moderately acidic (pH 5.6 – 5.9). N is deficient while organic matter is low. N deficiency can be corrected by applying compound fertilizer N:P:K 23:23:0 at the rate of 250 kg/ha while Ca can be improved by topdressing with CAN. The low organic matter content can be improved by applying farmyard manure or compost at the rate of 10 t/ha.

The soils of mapping unit VBd are moderately acidic (pH 5.4 – 5.7). N and K are deficient and can be corrected by applying compound fertilizer N:P:K 17:17:17 at the rate of 250 kg/ha. Ca deficiency in some parts of the unit can be rectified by applying CAN which will not only supply Ca but also N which is deficient in the soils of the unit. Organic matter is moderate and application of farm yard manure or compost at the rate of 5 t/ha is recommended.

As a guide, acidifying fertilizers such as DAP should be applied where soils show a pH >7.0 while non-acidifying compound fertilizers such as N:P:K 17:17:17 or 23:23:0

should be applied in soils with a pH < 6.0. The soils of the project area show a pH range of between 4.7–5.9 and therefore require non-acidifying fertilizers as afore-mentioned.

Application of farmyard manure or compost will improve the structural stability of the topsoil and hence reduce sealing and crusting, moisture and nutrients holding capacity in addition to enhancing soil fauna activity.

Incorporation of agro-forestry practices with emphasis on N-fixing plants in the farming system of the area is necessary. Legumes that would provide wood fuel, forage to livestock and supply N to the soils should be considered.

Deep ploughing or cultivation to loosen the compact subsoil is necessary. For tree crops, pit planting is essential for the plant roots to have more explorable soil volume. Pit planting has also the added advantage of breaking the compact subsoil and any plough pan thus increasing rootable soil depth and improving the internal drainage and the water holding capacity of the soils.

A combination of physical, agronomic and cultural methods of soil and water conservation is necessary. The physical methods suitable in the gently undulating to rolling terrain of the uplands should include construction of well spaced, stabilized, effective and well maintained bench terraces. Agronomic measures would include strip cropping with crops and forage providing plants, timely planting, use of certified seeds, planting adapted cultivars and intercropping. Cultural practices would include contour farming (planting, tilling/ploughing) and crop rotation.

The use of agro-chemicals in an effort to increase crop yields is bound to pollute surface and underground water. Therefore application of the right type and quantity is important. There is need to diversify the irrigated high value horticultural crops in the KESIS area. This could be achieved by introducing crops such as okra, brinjals, cucumber, karela, dudhi, and citrus among others. Advise from the agricultural extension staff should be sought for.

The water from River Kiringa which is the source of the irrigation water is suitable for irrigation. However, groundwater in the project area indicates medium salinity and alkalization hazards. Efficient application of the irrigation water is therefore very crucial to avoid a rise in groundwater level that could result in secondary salinization and sodification of the upland soils.

There is need to consider adoption of irrigation technologies that would use as little water as possible but within the socio-economic acceptability/capability of the farmers.
The adoption of integrated land and pests management in the KESIS area would therefore result in increased food self sufficiency (security), household wealth creation, a healthy community and environment.

Capacity building encompassing but not limited to establishment of Farmer Field Schools (FFS); training on natural resource management, market and marketing of horticultural produce, and farming as a business; visits to other farmer groups in neighbouring regions and involvement of the extension staff, opinion leaders and administrators is important for the success and sustainability of the project.

Table 1 shows the major soil limitations in the project area and the proposed management measures.

Table 1: Summary of soil limitations and management in the KESIS

Land form	Mapping unit / slope class	ACZ	Limitations	Proposed management
Uplands	UBr/AB	III	Low N P& Ca, acidity, low organic matter (OM), compact subsoil, sealing & crusting.	-apply N:P:K 23:23:0 -apply lime -apply farmyard manure -deep ploughing -enhance physical, cultural and biological soil & water conservation measures
	UBr/CD	III	Low NP & Ca, acidity, low organic matter, sealing & crusting, compact subsoil and moderate-high erosion hazard.	-apply N:P:K 23:23:0 -apply lime -apply farmyard manure -deep ploughing -enhance physical, cultural and biological soil & water conservation measures
	UPb/AB	III	N & P deficiency, low organic matter, sealing & crusting, compact subsoil and moderate erosion hazard	-apply N:P:K 23:23:0 -apply farmyard manure -deep ploughing -enhance physical, cultural and biological soil & water conservation measures
Valleys	VBd/A	III	Low NK and Ca, moderate organic matter, compact subsoil, poor workability and waterlogging	-apply N:P:K 17:17:17 -apply farmyard manure -deep ploughing -improve drainage (not for rice)

1 BACKGROUND

KESIS is one of the schemes that has been selected for development by the Smallholder Irrigation Program Mt. Kenya (SIPMK) within the Ministry of Water and Irrigation. SIPMK focuses on smallholder irrigation development by providing support for the implementation of new irrigation schemes and related extension work and by offering credit facilities to farmer groups.

The specific purpose of SIPMK is to sustainably increase agriculture production and subsequently farm income of smallholder farmers through the provision of additional irrigation facilities and services. The overall goal of the SIPMK program is to improve the living conditions of the farming population in the program area through increases in net farm income of participating farm households estimated at 1,500 with a total population of 7,500 persons.

The Ministry of Water and Irrigation (MoWI) is the Program implementing agent and has delegated the execution of the program to executing agents from the private sector: the Program management Unit (PMU) and two financing institutions. A program Steering Committee (PSC) has been established with the function of coordinating and supervising the PMU as well as the executing agent for the credit component of the Program. The PSC has representatives from all Government stakeholders, such as the Ministry of Agriculture, Ministry of Finance and Provincial and District administrators. It approves annual work plans and budgets and finally decides on the selection of schemes proposed by the PMU.

To have sustainable livelihoods in the community calls for rethinking of strategies and management systems, especially of natural resources upon which production system depends. Management systems for the land require that managers have quality and relevant information of the existing resources, a thorough understanding of the socio-economic dynamics of the systems and availability of innovative participatory approaches for profitable and sustainable livelihoods. Information on the natural agricultural resources (soil and water) is needed for present as well as future use and for appropriate management of these two resources.

The CAS Consulting Ltd requested for the assessment of the soils and irrigation water quality in order to provide information that would facilitate sustainable agricultural development through irrigated crops production and environment management. This was made possible by carrying out field soil assessments in February, 2008. The limitations or constraints for irrigated crop production were identified and the possible management remedial measures proposed. The ultimate goal of this work will be the realization of food self sufficiency (security), wealth creation and a clean environment in the project area.

Kutus East Smallholder Irrigation Scheme is located in Kamiigua sub-location, Kutus location, Central Division of Kirinyaga District. The source of irrigation water is Kiringa

River which is a tributary of Thiba river. Soil samples for soil characterization and fertility determinations were collected and delivered to the National Agricultural Research Laboratories (NARL) - Kabete for analysis. In addition, a water sample from the proposed intake was taken for analysis and evaluated for its suitability for irrigation. Two additional water samples were taken from hand dug wells to evaluate possible impacts of the groundwater quality on soils if the level of groundwater rises due to inefficient application of the irrigation water.

In this report, the results of the soils, irrigation water quality assessment, conclusions and recommendations arrived at are hereby presented.

2 INTRODUCTION

Kutus East Smallholder Irrigation Scheme is a community based farmers group initiative focusing on economic empowerment of the members through sustainable utilization and management soil and water resources. The scheme is located to the South of Kutus town. It is bounded between latitudes 00˚ 33’and 00˚ 38’South, and longitudes 037˚ 17’ and 037˚ 23’ East or eastings 313 and 317, and northings 9931 and 9939, at an altitude of between 1200 – 1400 m above sea level.

The scheme is located in Kamiigua sub-location, Kutus location, Central Division of Kirinyaga District, Central Province of Kenya. The scheme is located to the South of Kutus town which is approximately 15 km South from Kerugoya town. It covers about 88 ha of the members’ land. The scheme targets irrigation mainly in upland summits and shoulders which are generally very gently undulating to undulating with slopes of between 1 – 8%. Some sloping parts of the uplands are undulating to rolling with slopes of between 8 – 15%. The valleys are flat to very gently undulating with slopes of between 0 – 2% and are predominantly under irrigated paddy rice. The project area is mainly in agro-climatic zones III with high to medium potential for plant growth.

The cooperative society focuses on economic empowerment of its members through sustainable utilization of the natural land resources, with a focus on appropriate soil and water management practices.
Land use in the project area comprises of rearing of livestock (cattle, goats, sheep and donkeys), poultry keeping, growing mainly rainfed subsistence crops which include maize, beans, cow peas, sugarcane and bananas. Horticultural crops include French beans, tomatoes, water melons, capsicum, carrots, brinjals (egg plants), onions, cabbages, potatoes, spinach and kales.

The proposed source of irrigation water for the scheme is River Kiringa which is a tributary of River Thiba. The water from this source is suitable for irrigation. The local community depends on water from this river for livestock and domestic needs.

The objective of the irrigation scheme is to improve household income of the smallholder farmers through sustainable utilization of land resources, mainly river water and soils in the project area through the provision of additional irrigation facilities and services. This would in addition enhance food security and create a healthy environment.

The purpose of this work was therefore to assess the soils and water resources in order to provide information that would facilitate sustainable agricultural development of the scheme through irrigated crops production and environment management with the ultimate goal of realizing food self sufficiency (security), wealth creation and a clean environment in the project area.

3 THE ENVIRONMENT

3.1 Location, Communication and Population

Kutus East Smallholder Irrigation Scheme (KESIS) is situated in Kamiigua sub-location, Kutus location of Central Division, Kirinyaga District, Central Province of Kenya. It is bounded between latitudes 00˚ 33’and 00˚ 38’South, and longitudes 037˚ 17’ and 037˚ 23’ East or eastings 313 and 317, and northings 9931 and 9939, at an altitude of between 1200 – 1400 m above sea level. The scheme is located in Kamiigua sub-location, Kutus location, Central Division of Kirinyaga District, Central Province of Kenya. Most of the scheme is located to the South of Kutus town approximately 15 km from Kerugoya town. It covers about 88 ha in extent of the members’ land.

The area is accessible through the Nairobi – Sagana – Kagio - Kutus - Embu and the Nairobi-Makutano – Mwea tarmack roads. Other dry weather roads join the area to these two roads. The maintenance of these dry earth roads can play a very important role in raising the socio – economic status of the people.

Kamiigua sub-location has a total population of 4,514. The number of households in the sub-location is 1,332. The population of the sub-location forms about 39% of the location population. The sub-location population and density is posed to almost double by year 2025 to reach 9729 persons and 992 persons/km² (Table 2).

The sub-location population statistics indicate a building population pressure leading to increasing demand, competition and over exploitation of the available land resources leading to land and environmental degradation, if the necessary measures to curb the associated potential problems are not taken seriously. Population pressure is an important land degradation driving force in the KESIS area. The statistics are also reflective of the scenario at both the division and location level.

Table 2. Projected population and population density of Kamiigua sub-location

Year	1999	2000	2005	2010	2015	2020	2025
Population	4,514	4,649	5,389	6,246	7,241	8,393	9,729
Population density(persons/km²)	461	474	550	637	739	856	992

Source:Republic of Kenya, 1999.

3.2 Climate

3.2.1 Rainfall and agro-climatic zonation

The agricultural potential of an area is mainly determined by the prevailing climatic conditions especially the climatic characteristics of rainfall (r), evaporation (E_o) and temperature. KESIS covers agro-climatic zone (ACZ) III with mean annual rainfall to mean annual evaporation ratio of between 0.50 – 0.65. The zone is considered to be semi-humid with a mean annual rainfall of between 800 – 1400 mm and a mean annual potential evaporation of between 1450 – 2200 mm. It has high to medium potential for plant growth, if soil conditions are not limiting and has fairly low risk of crop failure (Sombroek *et al*., 1982).

Rainfall (r) in the area is bimodal with long rains occurring between March and May and short rains from October to December (Table 3). The data for Mwea Tebere camp which is the nearest and representative station for ACVZ III for the area indicates that dry seasons are experienced during January - February and June – September periods.

3.2.2 Evapotranspiration and moisture balance

The potential evapotranspiration (E_t) that is crop water requirement just like temperatures is inversely related to altitude with the low altitude areas having higher evaporation than the higher altitude upland area. The mean annual potential evaporation (E_o) based on Woodhead (1968) altitude equation ranges from 1990 mm at an altitude of 1204 m asl to 2018 mm at an altitude of 1326 m asl in the project area. Potential evapotranspiration is assumed to be 2/3 of Eo and therefore ranges from 1327 mm to 1345 mm in the project area. The rainfall data for Mwea Tebere Camp is considered to be representative of the project area and falls under ACZ III. Monthly Eo values have been calculated according to Braun (1984).

Table 3: Water balance for the project area.

Para meter (mm)	**Mwea Tebere Camp (20 year)**												
	Month												
	J	F	M	A	M	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Year**
r	36	12	54	229	191	9	17	18	22	132	222	56	998
E_o	219	99	99	159	139	119	100	119	179	199	159	199	1992
E_t	146	66	66	106	93	79	67	7 9	119	133	106	132	1328
$r-E_t$	-110	-54	-12	123	98	-70	-50	-61	-97	-1	116	-76	-330

The water balance ($r – E_t$) for the meteorological station indicate that the area experiences water deficit in most of the months except the months of April, May and November. Only in these months does the mean monthly rainfall exceed evapo -transpiration demand.

The periods December – March and Jun – October experience moisture deficits thereby requiring supplementary irrigation. Soil and water conservation measures are necessary in order to reduce amount of runoff and increase amount of water stored in the soil. Also, irrigation technologies that use as little water as possible with minimal loses should be considered so as to avail more water for irrigation and hence increase the area under irrigation. However, this should take into consideration of the socio–economic aspects of the project area.

3.2.3 Temperatures

According to Sombroek *et al*., (1982), the scheme lies in an area that has mean annual temperature of between 20 - 22˚C and a mean maximum of 26 - 28˚C. The mean minimum temperature for the area ranges from 14 - 16˚C.

3.3 Physiography, geology/parent materials and soils

Physiographically, the proposed project area predominantly comprises of uplands and valleys. The upland summits are very gently undulating to gently undulating with slopes of between 1 and 3%. In association with the summits are steeper sloping parts which are generally gently undulating to undulating with slopes of between 2 and 5%. A small portion of the uplands is undulating to rolling with slopes of between 8 – 16%.
The valleys occur at the foot of the uplands and are generally flat to very gently undulating with slopes of between 0 – 2%.

The upper level uplands are covered by basic volcanic rocks which include olivine basalts and basaltic agglomerates. The lower level uplands are covered with trachytic and phonolitic tuffs. The soils of the uplands are well drained, deep to extremely deep, dusky red to very dark brown, friable to firm, clay loam to clay. The soils of the upland summits and upland shoulders are classified as Rhodic Ferralsols and Niti-Rhodic Ferralsols while those on undulating to rolling parts are classified as Ferric and Ferral-Haplic Lixisols. Soils of the lower level uplands developed on trachytic or phonolitic tuffs are classified as Plinthic and Ferric Acrisols (figure 1).

The volcanic plains and valleys are covered by olivine basalts. They are flat to gently undulating with slopes of between 0 – 2%.The soils are predominantly imperfectly to poorly drained, moderately deep to very deep, dark greyish brown to black, friable to firm, cracking clay. The soils are classified as Calcic and Eutric Vertisols, sodic phase.

3.4 Drainage/hydrology

The general drainage direction of rivers in the project area and the surrounding is from North to South East. Kiringa river which is a tributary of River Thiba is the proposed source of irrigation water for the scheme. The water will be distributed by gravity. The river is perennial and has its source of water from the surrounding slopes of the Mt. Kenya. The river provides water for livestock and domestic use. See chapter 5.2 for irrigation water quality.

3.5 Vegetation and Land Use

Vegetation and land use are determined by climate (amount of rainfall and temperatures), topography, soils and due to human activities. Variations are therefore expected in vegetation and land use in the uplands and valleys inspite of the fact that the area falls under ACZ III.

Most of the natural vegetation in the project area consisting of dry forest and moist woodland has been cleared to give way to cultivation. Remnants of the natural vegetation include *Ficus thonningii*, *Warburgia ugandensis* and *Bridelia micrantha.* Within the cultivated land, *Eucalyptus* and *Grevillea* species have been incorporated in agro-forestry for timber, building poles, fencing posts and fuelwood. Selling fuelwood for tea processing takes place in the area by cutting the woody plant species such as mango trees thus causing vegetation depletion.

Rearing of livestock (cattle, goats, sheep and donkeys) is an important land use in the area. Keeping local breeds of poultry also takes place.
Production of rainfed or irrigated subsistence and horticultural crops takes place in the area. Small scale businesses selling basic household goods operate in shopping centres and other established points within the scheme while brick making is an important economic activity in the area.

3.6 Land Tenure

Land ownership in the KESIS is predominantly free hold and is registered and owned privately by farmers. The greatest challenge in undertaking appropriate soil and water management measures lies in availing free hold lands through issuance of title deeds. The registration of land enables the people with title deeds to obtain loans, or establish clear rights to disputed land. Demarcation of land helps establish recognized boundaries for individual land ownership and therefore encourages investment or taking the necessary measures on soil and water management issues. However, farm sizes are bound to decrease due to inheritance and population pressure resulting in more subdivision of land. Though this has not reached an alarming level in the project area, severe soil erosion is taking place in the sloping parts of the uplands which are undulating to rolling indicated by gully erosion along footpaths and livestock tracks. Therefore, there is need to undertake soil and water conservation measures in these areas.

Whereas the land resources are fixed, the population is dynamic showing increases with time. This essentially means more consumption of the agricultural products and increased competition for land with other uses. Since the land on which production is based is not increasing, the challenge to decrease the food deficit and produce some extra for selling while at the same time conserving the land and protecting it from degradation is important. It is therefore imperative to put in place sustainable land use planning, soil and water management measures to meet this challenge.

4 WORKING METHODS

4.1 Field soil characterization, collection of other land resource data and environmental information

All available information on climate, parent materials/geology, soils, drainage/hydrology, vegetation, land use and communication among others was collected and studied. During fieldwork, the project area was traversed with the assistance of selected members of the irrigation scheme. This helped in identifying the scheme boundary.

While traversing the scheme area, participatory discussions were held with the farmers on issues related to the management of the soil and water resources in the scheme and the constraints faced in undertaking rainfed and irrigated agriculture. Possible soil differences due to geology/parent material, physiography and physiographic position, vegetation differences, surface soil characteristics such relief, erosion features such as grass and stone/gravel pedestals, splash erosion, rill erosion and gully erosion, sealing and crusting, stoniness, rockiness, boulderiness etc were noted in a field notebook.

Profile pits, mini pits, erosion and road cut observations were made use of to differentiate the different soil types based on soil drainage, depth, colour, texture, consistency and structure. Profile pits were sited for the major soil types covering the scheme area. All the sited profile pits were dug, examined and described. Selected representative profile pits were in addition sampled for chemical and physical laboratory analysis. Composite soil samples were taken from a depth of 0 – 30 cm around selected profile pits for fertility analysis.

Water samples were also taken from the proposed intake and two wells from the project area. The location (longitude, latitude and altitude) of the intake point, profile pits and wells was recorded using a geographical positioning system (GPS).

The soil characteristics were described and recorded according to FAO Guidelines for Profile Description (FAO, 1977) and Kenya Soil Survey Staff (1987). The soil colour was noted/recorded using Munsel Color Chart (Munsel Color Co., 1975). Soil classification was done according to the FAO/UNESCO/ISRIC (1997) system of classification.

Information on vegetation, land use, visible degradation features/indicators such erosion features, plant nutrient deficiencies, deforestation, waterlogging and siltation/deposition was collected. Information on the type of soil and water conservation measures, their maintenance and effectiveness was also recorded when traversing the area.

4.2 Laboratory analysis

Samples taken from the field were analysed for chemical and physical properties following accepted standard procedures (Hinga *et al.*, 1980). pH-H_2O and electrical conductivity (EC) were measured in a 1:2.5 soil/water suspension. Exchangeable cations (Ca, Mg, K and Na) were determined by a flamephotometer/atomic absorption after leaching the soils with 1 N ammonium acetate at pH 7.0 while cation exchange capacity (CEC) was determined after leaching the samples for exchangeable cations and further leaching the samples with 95% alcohol, sodium acetate (pH 8.2) and 1N ammonium acetate. The CEC was determined with a flamephotometer. Nitrogen was determined by the semi-micro Kjedahl method.

Available nutrients were determined using Mehlich method which involves the extraction of soil by shaking for 1 hour with 1:5 ratio 0.1N HCL/0.025N H_2SO_4. Ca, K and Na were determined by EEL – flamephotometer after anion resin treatment for Ca. Both Mg and Mn were determined colorimetrically. P was determined by Vanodomolydophosphoric yellow colorimetrically.

Electrical conductivity of the extract (EC_e) was estimated to be 3 times EC. Exchangeable sodium per cent (ESP), CEC-clay, sodium adsorption ratio (SAR) and residue sodium carbonate (RSC) were respectively calculated according to the following equations:

ESP = Na/CEC x 100
CEC-clay = (CEC-soil – (4x%C) /%clay)100
SAR = Na/√(Ca+ Mg)/2
RSC = (CO_3^{--} +HCO_3^{--}) – (Ca^{++} x Mg^{++})

4.3 Soil legend construction

Based on the physiography, geology/parent material and soil characteristics in that order, a soils legend/description was made for the different soil units identified in the project area. The physiographic units recognized in the area are uplands and valleys denoted as U and V respectively. For parent material/geology, basalts and basaltic agglomerates are denoted by letter B while trachytic tuffs and tuffs are denoted by letter P. Letters r, b and d represent red, brown and dark subsoil colour. In the soil map (Figure 1), the first, second and third entries are for physiography (U or V), parent material/geology (B or P) and colour (r, b or d) respectively. Below the code is slope class denoted by A, B, C and D which represent slopes of 0-2%, 2-5%, 5-8% and 8-16% respectively. In the legend also, moderately deep, deep, very deep and extremely deep soils have depths of 50 – 80, 80 -120, 120 – 180 and more than 180 cm depth respectively.

5 SOILS AND IRRIGATION WATER QUALITY

5.1 Soils

5.1.1 Soils of the uplands

The general physiography of the selected land to be irrigated comprises of uplands. The uplands are sub-divided into the upper and lower level uplands. The soils of the upper level uplands are developed on basic igneous rocks which are predominantly olivine basalts and basaltic agglomerates while those of the lower level uplands are developed on trachytic or phonolitic tuffs.

5.1.1.1 Soils of the upper level uplands developed on basic igneous rocks (soil mapping unit UBr)

The irrigable summits of the upper level uplands are very gently undulating to gently undulating relief with slopes of between 1 – 5% (slope class AB). The summits have soils that are well drained, extremely deep, dusky red to dark reddish brown, very friable to friable, clay loam to clay (Figure 1).

Colour: Topsoil is dark reddish brown (2.5YR3/4) while subsoil is dusky red (10R3/4) to dark reddish brown (2.5YR3/4).
Structure: Topsoil structure ranges from weak to moderate, fine to medium, subangular blocky. The structure of the subsoil ranges from weak, very fine to medium, subangular blocky in the upper part to porous massive in the deeper subsoil.
Consistency: Topsoil is slightly hard to hard when dry, friable when moist, sticky and plastic when wet while the subsoil is slightly hard when dry, very friable to friable when moist, slightly sticky to sticky and slightly plastic to plastic when wet.
Texture: The texture of the topsoil and subsoil is clay loam to clay.
Silt:clay ratio: 0.07 in the topsoil and 0.05 to 0.1 in the sub-soil.

Chemical properties
Topsoil: pH-H2O: 5.4, organic carbon (OC) 1.74%; electrical conductivity of extract (ECe) 0.27dS/m; cation exchange capacity of soil (CEC-soil) 21.8 cmol/kg and cation exchange capacity of clay fraction (CEC-clay) 18.5 cmol/kg; base saturation percent (BSP) 55 – 73; exchangeable sodium percent (ESP) 5.
Sub-soil: pH-H2O 5.0 – 5.9; OC 1.2 - 1.4%; ECe 0.18 - 0.30 dS/m; CEC-soil 10.3 – 15.7 cmol/kg and CEC-clay 6.2 – 12.5 cmol/kg; BSP 53 – 85; ESP 4 – 5.
Diagnostic properties: ferralic B horizon and hues redder than 5YR.
Soil classification: Rhodic Ferralsols and Niti-Rhodic Ferralsols
For the description of a representative profile pit, see appendix 1, profile description no. 1).

In association with the upland summits are the lower sloping parts which are undulating to rolling in relief with slopes of between 5-15% (slope class CD). The soils in these parts are well drained, extremely deep to deep, dusky red to dark reddish brown, friable to very friable, clay loam to clay.

Colour: Topsoil : dark reddish brown (2.5YR3/3).
Subsoil: dusky red (10R3/4) to dark reddish brown (2.5YR3/4).
Structure: Topsoil: weak, fine to medium, subangular blocky.
Subsoil: weak to moderate, medium to coarse, subangular blocky.
Consistency: slightly hard when dry, friable when moist, slightly sticky to sticky and slightly plastic to plastic when wet in both topsoil and subsoil.
Texture: clay loam to clay in both the topsoil and subsoil
Silt:clay ratio: 0.27 in the topsoil and 0.16 - 0.23 in the subsoil.

Chemical properties
Topsoil: pH-H2O: 6.6, OC 0.75%; ECe 0.42 dS/m; CEC-soil 9.0 cmol/kg and CEC-clay 9.1 cmol/kg; BSP 55; ESP 6.
Sub-soil: pH-H2O 6.4 – 6.7; OC 0.44 – 0.6%; ECe 0.60– 0.84 dS/m; CEC-soil 10.4 – 11.2 cmol/kg and CEC-clay 11.2 – 12.0 cmol/kg; BSP 70 – 85; ESP 2 – 3.
Diagnostic properties: argic B; BS >50%; CEC-clay in B-horizon <24 cmol/kg; ferric properties.
Soil classification: Ferric and Ferral-Haplic Lixisols.

For the description of a representative soil profile pit with analytical data, see appendix 1, profile description no.2.

5.1.1.2 Soils of the lower level uplands developed on trachytic tuffs (soil unit UPb)

The lower level uplands are generally flat to gently undulating with slopes of between 0-4% (slope class AB). The soils are developed on trachytic and phonolitic tuffs. The soils are well drained, deep to very deep, dark red to very dark brown, friable clay.

Colour: Topsoil: dark brown (7.5YR3/4) to very dark greyish brown (7.5YR2.5/2).
Subsoil: dark red (2.5YR3/6) to very dark grayish brown (7.5YR2.5/2)
Structure: Topsoil: weak, fine to medium, subangular blocky
Subsoil: weak, medium, subangular blocky.
Consistency: Topsoil is slightly hard when dry, friable when moist, sticky and plastic when wet while the subsoil is slightly hard to hard when dry, friable when moist, sticky and plastic when wet.
Texture: Clay in both the topsoil and subsoil.
Silt:clay ratio: 0.1 in the topsoil and from 0.1 to 0.3 in the sub-soil.

Chemical properties
Topsoil: pH-H2O 6.4; OC 1.1%; ECe 0.39 dS/m; CEC-soil 13.6 cmol/kg and CEC-clay 18.6 cmol/kg; BSP 68; ESP 5.

Sub-soil: pH-H2O 5.9 – 6.3; OC 0.20 - 0.44%; ECe 0.14 – 0.18 dS/m; CEC-soil 14.4 – 17.2 cmol/kg and CEC-clay 21.8 – 28.4 cmol/kg; BSP 42 – 45; ESP 2.
Diagnostic properties: argic B, BSP < 50; CEC-clay in B-horizon <24 cmol/kg; ferric properties and plinthite within 125 cm from the surface.
Soil classification: Plinthic and Ferric Acrisols.

For the description of a representative soil profile with analytical data, see appendix 1 profile description nos. 3.

5.1.2 Soils of the valleys (soil unit VBd)

The flat to very gently undulating plains with slopes between 0-2% occur at the foot of the uplands. Though not targeted for irrigation as most of them are already under paddy rice irrigation, they are predominantly occupied by imperfectly drained to poorly drained, moderately deep to very deep, very dark greyish brown to black, firm, cracking clay soils. The soils are in places calcareous.

Colour: Topsoil is very dark greyish brown to black (10YR3/2 - 10YR2/1) and subsoil is very dark greyish brown (10YR3/2) to black (2.5Y2/0).
Structure: Topsoil: weak, fine to medium, crumby and subangular blocky.
Subsoil: moderate to strong, medium to coarse prismatic breaking to moderate to strong, fine to medium, angular and subangular blocky structures. The subsoil adjacent to the weathering parent material (C-horizon) tends to be porous massive breaking to weak, medium, subangular blocks. In places it is moderately calcareous.
Consistency: Topsoil is slightly hard to hard when dry, friable to firm when moist, sticky and plastic when wet while the subsoil is hard to very hard when dry, firm to very firm when moist, sticky and plastic when wet.
Texture: clay in the topsoil and subsoil.

Chemical properties
Topsoil: pH-H2O 5.6 - 7.2; OC 1.6 - 2.2%; ECe 0.21 - 1.2 dS/m; CEC-soil ranges from 18.6 - 76.8 and CEC-clay from 15.6 - 87.1 cmol/kg; BSP 59 – 79; ESP 2 - 8.
Subsoil: pH-H2O 5.5 – 8.6; OC 0.4 – 1.7; ECe 0.15 – 1.65 dS/m; CEC-soil 19.5 – 78.8 cmol/kg and CEC-clay 18.7 – 94.5 cmol/kg; BSP 45 – 87; ESP 3 – 13.
Diagnostic properties: 2 – 5 cm wide cracks upto 50 cm deep and clay content >30%.
Soil classification: Calcic and Eutric Vertisols, sodic phase.

For the description of a representative profile pit with analytical data, see appendix 1, profile description nos. 4 and 5.

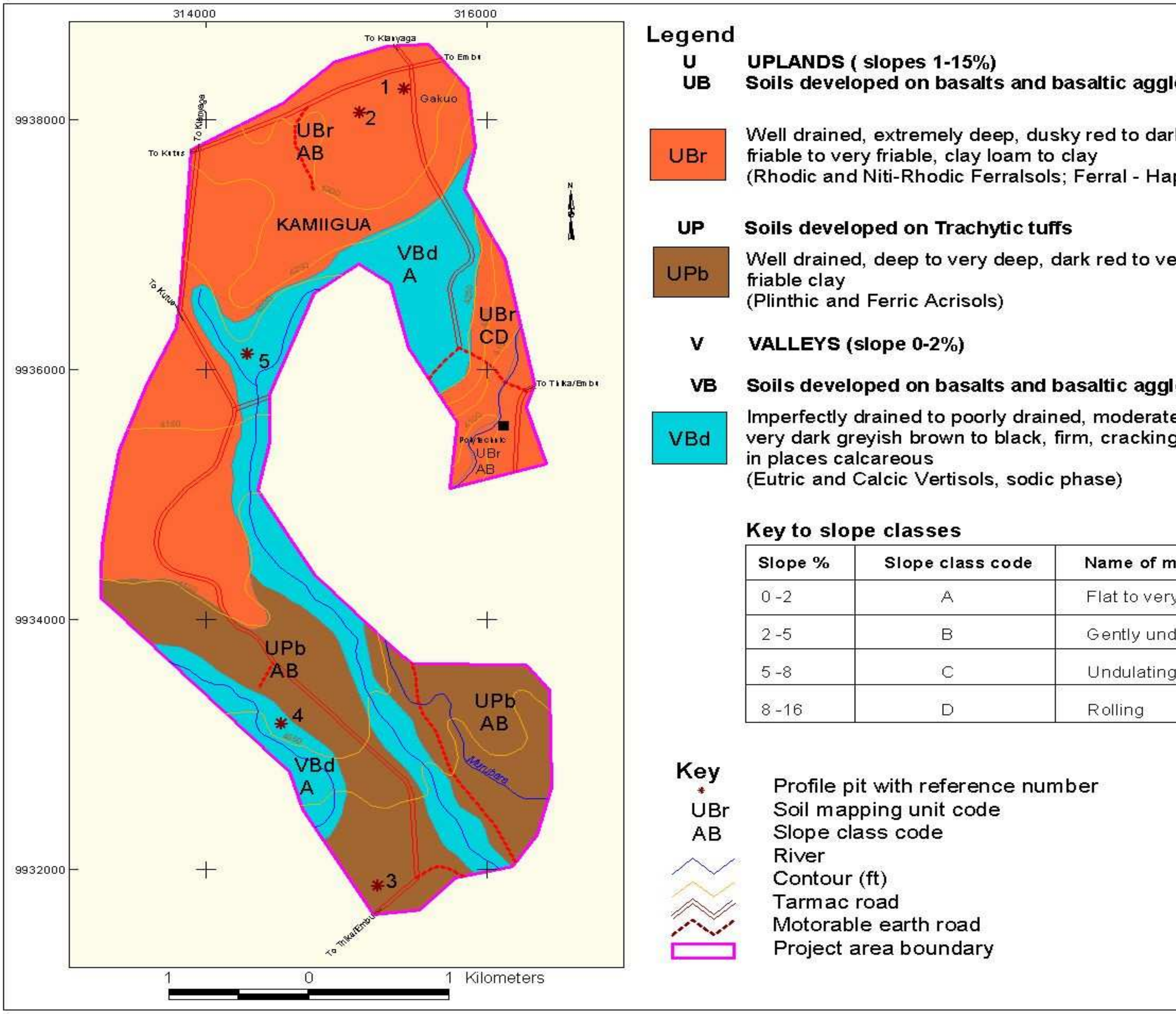

Figure 1. Soil map of Kutus East Smallholder Irrigation Scheme

5.2 Irrigation water quality

Table 4 gives the results of a water sample taken from the proposed River Kiringa intake. The results indicate that the water is of low salinity and low sodicity (Richards, 1954). The water is safe or suitable for irrigation use without causing adverse effects on the soils of the project area such as salinization or sodification. However, there is need for efficient conveyance and application of irrigation water to avoiding wastages through over-irrigation of the soils.

Results of a water samples taken from well no.1 within the project area indicate medium salinity and low sodium content. The water also has high levels of bicarbonates but the residue sodium carbonate (RSC) value however indicates low alkalinization hazard due to high levels of calcium and magnesium. The water from the well can be used for irrigation if a moderate amount of leaching in the soil takes place. The water can be used to grow moderate salt tolerance crops such as vegetables.

Results of the water sample from well no. 2 indicate that the water is of low salinity and low sodicity. The RSC value indicates medium alkalinization hazard due to low Ca and Mg in the water. The water can be used for for irrigation without causing adverse effects on the soils if proper drainage of the soils is maintained.

The results thus indicate that though the surface water from the river intake is suitable for irrigation, the ground water in well no.1 is of medium salinity and can cause soil salinization while ground water from well no. 2 can cause medium alkalinization of the soils due to the presence of residue sodium carbonates. This emphasizes the need for efficient application of irrigation water to prevent a rise in the level of the groundwater which has the potential of causing secondary salinization or sodification of the soils through capillarity.
The results further indicate that the salinity and alkalization hazard of the groundwater is from the weathering of the parent materials.

Table 4. Irrigation water quality from River Kiringa intake and two wells

Parameter	**Intake**	**Well No. 1**	**Well No. 2**
pH	6.9	7.4	6.6
Conductivity (dS/m)	0.08	0.55	0.15
Sodium (me/l)	0.31	2.04	0.87
Potassium (me/l)	0.03	0.02	0.06
Calcium ,,	0.16	2.89	0.33
Magnesium ,,	0.31	3.29	0.46
Carbonates ,,	Trace	Trace	Trace
Bicarbonates ,,	1.30	7.19	1.81
Chlorides ,,	0.63	1.0	1.0
Sulphates ,,	1.03	10.6	1.02
Sodium Adsorption Ratio (SAR)	0.64	1.16	1.38
Residue Sodium Carbonate (RSC)	1.25	-2.32	1.65

6 SOIL FERTILITY AND MANAGEMENT ASPECTS

6.1 Soil fertility aspect

Soil fertility may be defined as the ability of the soil to provide physical conditions favourable to root growth and to supply enough water and nutrients to enable a crop to make the most of other environmental features of a site. The chief factors contributing to soil fertility are organic matter content, availability of major and micro-nutrients, soil reaction and the physical characteristics of texture, structure, depth and nature of the profile. In a broad sense, soil fertility is the natural ability of the soil to provide plants with nutrients, water and oxygen. Chemical soil fertility on the other hand is restricted to the capacity of a soil to provide plants with nutrients. Chemical fertility depends on the degree of chemical weathering and leaching besides being related to the organic matter content and the rate of decomposition. The chemical soil fertility of the soils of the physiographic units within the project area is variable. Soils of the uplands are more weathered than those of the valley bottoms and are thus chemically poorer as indicated by the morphological and physical soil characteristics of red colour, very friable consistency and low silt/clay ratio.

Nutrients are essential for every crop. Without them, arable crop production can neither be developed nor sustained. Therefore, the maintenance or improvement of soil fertility should be an integral part of farm management for both horticultural and subsistence farming.

Soils of mapping unit UBr are strongly to moderately acid (pH 4.7 – 5.6). Organic matter content is low and N is deficient. P is deficient in some pars of the unit. To supplement the deficient N and P in the unit, 250 kg/ha of compound fertilizer N:P:K 23:23:0 should be applied. Application of well decomposed manure at the rate of 10 tonnes/ha to improve the organic matter content is recommended. Sample no. 3, 4, 5 and 6 within the unit show presence of exchangeable acidity in the range 0.2 – 0.7 me%. Liming is therefore necessary to raise the soil pH and supply Ca. Liming at the rate of 300kg/acre is recommended.

For proper plant growth, the optimum ratio of Ca:K and Ca:Mg in the soil solution is 10:1 and 4-2:1 respectively. All the samples in the unit indicate a Ca:K less than 10 while the Ca:Mg ratios are lower than 2. This implies that Ca should be applied to the soils of the unit and hence emphasizing the need of liming the soils to supply the deficient Ca in addition to neutralizing the exchangeable acidity in the soils.

Soils of mapping unit UPb are moderately acid (pH 5.8 – 5.9). Organic matter content is low and N is deficient. P is adequately supplied. To supplement the deficient N and improve P in the soils of the unit, 250 kg/ha of compound fertilizer N:P:K 23:23:0 should be applied. Application of well decomposed manure at the rate of 10 tonnes/ha to improve the organic matter content is recommended.

The ratio of Ca:K and Ca:Mg in the soils of the unit are lower than the optimal values and hence the need to raise Ca level in the soils. Since the soils do not indicate presence of exchangeable acidity, Ca can be supplied by topdressing with calcium ammonium nitrate (CAN) which will not only supply Ca but also N.

Soils of the valley (unit VBd) are moderately acid with a pH range of 5.4 – 5.7. The soils are well supplied with P but they area deficient in N and K. Organic matter content is low to moderate. Ca is deficient in some parts of the unit. N, P and K should be improved by applying 250 kg/ha of compound fertilizer N:P:K 17:17:17. Ca can be improved by topdressing with CAN which would supply the deficient N and Ca. Well decomposed manure should be applied at the rate of 5 tonnes/ha to improve the organic matter content in the soils of the unit.

The soils of the project area thus show low to moderate levels of organic matter as a result of poor management of not incorporating farmyard manures or compost to the soils. This is worsened by high decomposition rates in ACZ III which are accelerated by cultivation.

Discussions and interviews with farmers indicated that crop production is declining in the area due to continuous cultivation without soil nutrient replenishment. This results in nutrient mining through harvested crops. The situation is bound to worsen as population pressure builds up and farms are fragmented into smaller sizes. Therefore use of manures and inorganic fertilizers is important to increase crop production per unit area.

Use of farmyard manure or compost has the importance of improving topsoil structural stability thereby reducing runoff and erosion. It also improves the nutrients and water holding capacity of the soils. Organic matter enhances soil fauna activity thus improving soil physical aspects such as aeration and moisture holding capacity.

As indicated in Table 5, there is considerable variation in the nutrient levels within each landform (uplands and valleys) and each soil mapping unit. The differences are generally due to soil forming (pedogenic) processes as well as anthropogenic effects of differences in soil management aspects from farm to farm. Therefore, the aforementioned comments indicate the possible general soil fertility tendencies within the project area.

Table 5. Available nutrients in the topsoils (0 – 30 cm depth) in the project area

Soil unit	**Ubr**						**Upb**		**VBd**	
Parameter	**Sample no.**						**Sample no.**		**Sample no.**	
	1	2	3	4	5	6	7	8	9	10
pH-H2O	5.5	5.6	4.9	4.8	4.7	5.1	5.9	5.8	5.4	5.7
Hp(me%)	-	-	0.2	0.7	0.4	0.2	-	-	0.1	-
C (%)	0.82	0.96	0.75	1.03	0.85	1.07	0.80	0.95	1.45	1.55
N (%)	0.13	0.13	0.10	0.15	0.11	0.13	0.15	0.12	0.14	0.15
Na (me%)	0.12	0.12	0.08	0.12	0.12	0.10	0.14	0.24	0.16	0.58
K ,,	0.66	0.75	0.50	0.40	0.48	0.42	0.93	1.23	0.20	0.20
Ca ,,	2.0	2.3	1.3	1.5	1.5	2.0	3.10	3.9	1.5	4.5
Mg ,,	2.23	3.72	2.59	1.67	2.24	4.04	5.61	5.62	5.98	6.63
Mn ,,	1.43	1.02	1.52	0.88	0.97	0.60	0.93	0.72	0.61	0.74
P (ppm)	34	31	15	10	11	21	41	115	35	41
Fe ,,	24.9	29.3	21.0	14.9	19.2	24.4	40.0	126	30.8	47.4
Cu ,,	2.15	1.16	1.82	0.92	1.59	4.37	5.20	5.24	4.52	5.19
Zn ,,	9.83	8.12	3.86	5.16	4.0	6.51	7.55	7.29	4.92	4.11
C:N ratio	6.3	7.4	7.5	6.9	7.7	8.2	5.3	7.9	10.3	10.3
Ca:K ratio	3.0	3.1	2.6	3.75	3.12	4.8	3.3	3.2	7.5	2.4
Ca:Mg ratio	0.9	0.62	0.50	0.9	0.68	0.49	0.55	0.69	0.25	0.79

Deficiencies or low levels are underlined

6.2 Soil management aspects

6.2.1 Erosion susceptibility/hazard

The soils of mapping units UBr and UPb indicate moderate susceptibility to erosion due to low organic matter content and high silt to clay ratio in the topsoils in areas with slope class AB defined as very gently undulating to gently undulating with slopes of between 1 - 5%. Soils in UBr which occur in areas which are undulating to rolling (slope class CD) indicate high erosion susceptibility and moderate to severe erosion hazard. There is need to undertake a combination of physical, biological and cultural soil and water conservation measures in the upland areas. Physical conservation measures such as bench terraces should be given priority in areas which are undulating to rolling with slopes between 5 -15%. The valley bottoms (unit VBd) indicate low erosion susceptibility and slight erosion hazard.

6.2.2 Surface sealing and crusting

The soils of the project area indicate high topsoil erodibility due to low organic matter content and sometimes high silt to clay ratio.These parameters make the soils very vulnerable to surface sealing and crusting due to poor structural stability. This is indicated by the occurrence of weak to moderate, 1 – 2 cm thick crusts on the soil surface. Surface sealing and crusting reduce rain or water infiltration and permeability into the soil resulting to increased runoff and erosion. This results to reduced rootable soil depth, decreased water holding capacity of the soils and sedimentation/siltation of water bodies and flash floods in the lower lying areas. Application of farm yard manure or compost to the soils is the best management option to increase the structural stability of the topsoils and hence reduce vulnerability of the topsoils to sealing and crusting.

6.2.3 Plough pan and compact subsoil

A plough pan or compact subsoil occurs in all the soils of the project area at a soil depth of between 15 – 45 cm. The compact subsoil could be due to clay illuviation i.e deposition of clay particles from overlying horizons as a consequence of soil forming (pedogenic) process especially in the upland soils. The plough pan is as a result of continuous shallow ploughing using oxen-plough. The compact subsoil and the plough pan need to be loosened by deep ploughing or double digging to improve on rootability, aeration and hence water holding capacity. The loosening of the subsoil or breaking the plough pan also improves the drainage and thus prevents waterlogging of the soils.

The soils of the valleys (unit VBd) are composed of the type of clay that shrinks when dry and expands when wet. Therefore, workability deteriorates during the dry and wet seasons as the soil consistency is hard to very hard when dry, firm to very firm when moist and sticky to very sticky when wet. The soils are imperfectly to poorly drained thus limiting water movement through the soil leading to waterlogging. Improvement of drainage is necessary for crops that can not withstand waterlogged conditions.

6.2.4 Soil physical aspects

Though no field soil physical determinations were carried out, the dominant soils that occur on the uplands and cover most of the project area are Ferralsols, Lixisols and Acrisols. The soils show a plough pan and /or compact subsoil which is expected to reduce the infiltration and permeability rates of these otherwise well drained soils with expected high infiltration and permeability rates. Results from similar soils indicated infiltration rates of 11.8 – 13.2 cm/hr for the soils of unit UBr and 10.2 – 12.2 cm/hr for soils of unit UPb (Wanjogu *et al.*, 2006). The generally high rates of infiltration and the undulating topography favour the use of sprinkler irrigation method. However low organic matter content and sometimes high silt:clay ratios cause low aggregate stability that make the soils susceptible to surface sealing and crusting. This problem may be excerbated by the drops of irrigation water from the sprinklers, thus causing splash erosion and hence negative environmental impacts in the long-run. Therefore use of organic inputs from the locally available resources is the most appropriate mitigation strategy to enhance topsoil structural stability (see also chapters 6.2.2 and 6.2.3).

Soils of the valley bottoms comprising of mapping unit VBd are mainly Vertisols. These type of soils shrink and crack when dry and swell when wet. Therefore high infiltration rates are expected when the soils are dry and low infiltration rates when they are wet. Thus the permeability or hydraulic conductivity of the Vertisols is expected to be extremely low when under wet conditions and all cracks are closed. Basic infiltration rates under irrigation when all cracks are closed were found to be between 0.1 and 1.5 cm/hr. Data on permeability have shown values of less than 4mm in 24 hr, which in effect indicate a very low permeability on Vertisols (Bie *et a*l., 1966).
This aspect has important implications on the water management of these soils and therefore calls for efficient management of the irrigation water.

Table 6 indicates the relationship between texture, structure and hydraulic conductivity. For soils of unit UBr hydraulic conductivity could be estimated to be within the 2 – 6 cm/hr range. The hydraulic conductivity of soils of unit UPb could be estimated to be within the 0.5 – 2.0 cm/hr range while those of unit VBd could be within the <0.25 – 0.5 cm/hr range.

Table 6. Relationship between texture, structure and hydraulic conductivity

Texture	Structure	Hydraulic conductivity (cm/hr)
Coarse sand and gravel	Single grain	> 50
Medium sand	Single grain	25 – 50
Loamy sand and fine sand	Medium crumbs, single grain	12 – 25
Fine sandy loam, sandy loam	Coarse, subangular blocky and granular, fine crumb	6 – 12
Light clay loam, silt, silt loam, very fine sandy loam, loam	Medium prismatic and subangular blocky	2 – 6
Clay, silty clay, sandy clay, silty clay loam, silt, sandy clay loam	Fine and medium prismatic, angular blocky, platy	0.5 – 2
Clay, clay loam, silty clay, clay, heavy clay	Very fine or fine prismatic, angular blocky, platy	0.25 – 0.5
Clay, heavy clay	Massive, very fine or columnar	< 0.25

Source: Landon (1984)

7 CONCLUSIONS AND RECOMMENDATIONS

Population pressure increases the demand, competition and over exploitation of the available land resources leading to accelerated land degradation. It is a potential land degradation driving and accelerating force. Therefore, there is need to take the necessary remedial measures to control the identified or envisaged degradation processes within Kutus East Smallholder Irrigation Scheme (KESIS). Results of the study show that:

- N is deficient in the soils of mapping unit UBr. P is deficient in some parts of the unit. The unit shows presence of some exchangeable acidity which is detrimental to plant roots and microbial population. Application of compound fertilizer N:P:K 23:23:0 at the rate of 250 kg/ha is recommended. Liming the soils of the unit at the rate of 300 kg/acre is recommended. Liming will not only neutralize the excess acidity and raise the soil pH but will also raise the Ca content to the necessary optimal levels for the uptake of both K and Mg by plants. Organic matter is low in the unit and application of farmyard manure at the rate of 10 t/ha is recommended.

- In soil mapping unit UPb, N is deficient while organic matter is low. N deficiency can be corrected by applying compound fertilizer N:P:K 23:23:0 at the rate of 250 kg/ha while Ca can be improved by topdressing with CAN. The low organic matter content can be improved by applying farmyard manure or compost at the rate of 10 t/ha.

- In mapping unit VBd, N and K deficiencies can be corrected by applying compound fertilizer N:P:K 17:17:17 at the rate of 250 kg/ha. Ca deficiency in some parts of the unit can be rectified by applying CAN which will not only supply Ca but also N which is deficient in the soils of the unit. Organic matter is moderate and application of farm yard manure or compost at the rate of 5 t /ha is necessary.

- Application of farmyard manure or compost in all the mapping units will improve the structural stability of the topsoil and hence reduce sealing and crusting, increase moisture and nutrients holding capacity, enhance soil fauna activity and improve workability.

- Incorporation of agro-forestry practices with emphasis on N-fixing plants in the farming system of the area is necessary. Legumes that would provide wood fuel, forage to livestock and supply N to the soils should be considered.

- Deep ploughing or cultivation to loosen the compact subsoil is necessary. For tree crops, pit planting is essential for the plant roots to have more explorable soil volume. Pit planting has also the added advantage of breaking the compact subsoil and any plough pan thus increasing rootable soil depth and improving the internal drainage and the water holding capacity of the soils.

- A combination of physical, agronomic and cultural methods of soil and water conservation is necessary. The physical methods suitable in the gently undulating to rolling terrain of the uplands should include construction of well spaced, stabilized, effective and well maintained bench terraces. Agronomic measures would include strip cropping with crops and forage providing plants, timely planting, use of certified seeds, planting adapted cultivars and intercropping. Cultural practices would include contour farming (planting, tilling/ploughing) and crop rotation.

- The use of agro-chemicals in an effort to increase crop yields is bound to pollute surface and underground water. Therefore application of the right type and quantity is important.

- There is need to diversify the irrigated high value horticultural crops in the KESIS area. This could be achieved by introducing crops such as okra, brinjals, cucumber, karela, dudhi, and citrus among others. Advise from the agricultural extension staff should be sought for.

- The water from River Kiringa which is the proposed source of the irrigation water is suitable for irrigation. However, groundwater within the project area indicates medium salinity and alkalization hazards. Efficient application of the irrigation water is therefore very crucial to avoid a rise in groundwater level that could result in secondary salinization and sodification of the soils.

- There is need to consider adoption of irrigation technologies that would use as little water as possible so that more farmers benefit from the irrigation water but the technology should be within the socio-economic acceptability and capability of the farmers.

- The adoption of integrated land (water, soils, nutrients) and pests management in the KESIS area would therefore result in increased food self sufficiency (security), household wealth creation, a healthy community and environment.

- Capacity building encompassing but not limited to establishment of Farmer Field Schools (FFS); training on natural resource management, market and marketing of horticultural produce, and farming as a business; visits to other farmer groups in neighbouring regions and involvement of the extension staff, opinion leaders and administrators is important for the success and sustainability of the project.

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APPENDIX 1 - PROFILE DESCRIPTION AND ANALYTICAL DATA

Profile Description No. 1

General site information

Soil map unit code	:UBr
Sheet observation no.	:135/2-1
Location/altitude	:easting 0315566 and northing 9938360; 1346 m asl
Soil parent material	:basalts and basaltic agglomerates
Landform	:uplands
Relief/slopes	:very gently undulating to gently undulating; slopes 1 – 2.5%
Land use	:cultivation of bananas and sweet potatoes; keeping livestock
Erosion type	: slight splash erosion
Surface sealing and crusting	: weak, 1 - 2 mm

Internal drainage : well drained
Plough pan/compactness : 23 - 49 cm depth
Effective soil depth : > 150 cm
Soil classification : Rhodic Ferralsol

Profile description

Horizon Depth

Ap 0 – 23 cm dark reddish brown (2.5YR3/4, moist); clay; weak to moderate, fine to medium, subangular blocky structure; slightly hard to hard when dry, friable when moist, sticky and plastic when wet; many biopores and fine pores; many very fine and fine, common medium roots; clear and smooth transition to:

Bu1 23 – 49 cm dark reddish brown (2.5YR3/4, moist); clay; weak, very fine to medium, subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; many very fine and fine pores; common very fine and fine roots; clear and smooth transition to:

Bu2 49 – 83 cm dark red (2.5YR3/6, moist); clay; weak, very fine to medium, subangular blocky structure; very friable when moist, sticky and slightly plastic when wet; many very fine and fine pores; very few, very fine and fine, few medium roots; gradual and smooth transition to:

Bu3 83 – 150+ cm dark red (2.5YR3/6, moist); clay; weak, very fine to medium, subangular blocky structure; very friable when moist, sticky and slightly plastic when wet; common very fine and fine pores; very few, very fine and fine roots; clear and smooth transition to:

Laboratory data for profile description no. 1

Horizon designation	**Ap**	**Bu1**	**Bu2**	**Bu3**
Depth (cm)	0 – 23	23 – 49	49 – 83	83 – 150+
pH-H2O (1:2.5)	5.4	5.7	5.9	5.0
EC dS/m ,,	0.09	0.06	0.10	0.06
ECe dS/m	0.27	0.18	0.30	0.18
C (%)	1.74	1.36	1.24	1.18
CEC-soil (cmol/kg)	21.8	15.7	10.3	13.9
CEC-clay (cmol/kg)	18.5	12.5	6.2	10.8
Exchangeable Calcium ,,	9.38	7.88	3.75	3.12
Magnesium ,,	4.30	3.97	2.64	3.15
Potassium ,,	0.98	0.72	0.28	0.36
Sodium ,,	1.20	0.85	0.45	0.65
Sum of cations	15.86	13.42	7.12	7.28
Base saturation (%)	73	85	67	53

ESP	5	5	4	5
Sand %	14	10	10	10
Silt %	6	8	4	6
Clay %	80	82	86	84
Texture class	C	C	C	C
Silt:clay ratio	0.07	0.10	0.05	0.07

Profile Description No. 2

General site information

Soil map unit code : UBr
Sheet observation no. : 135/2-2
Location/altitude : easting 0315461 and northing 993804; 1356 m asl
Soil parent material : basalts and basaltic agglomearets
Landform : uplands
Relief/slopes : gently undulating to undulating; slopes 4 – 6%
Land use : strip cropped maize, napier grass, bananas and pasture
Erosion type : moderate splash erosion
Surface sealing and crusting : weak, 1 -2 mm
Internal drainage : well drained
Plough pan/compactness : 15-40 cm depth
Effective soil depth : > 150 cm
Soil classification : Ferric Lixisol

Profile description
Horizon Depth

Ap 0 – 15 cm dark reddish brown (2.5 YR3/6, moist); clay; weak, fine to medium, subangular blocky structure; slightly hard, friable when moist, slightly sticky and slightly plastic when wet; many biopores, many fine pores; many very fine and common fine roots; clear and smooth transition to:

Bt 15 – 40 cm dark reddish brown (2.5 YR3/4, moist); clay; weak, medium, subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many biopores; common very fine and fine roots; gradual and smooth transition to:

Bu1 40 – 82 cm dark red (2.5YR3/6, moist); clay; weak, medium to coarse, subangular blocky structure; slightly hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; many biopores and fine pores; very few very fine and fine roots; gradual and smooth transition to:

Bu2cs 82 – 155+ cm dark red (10R3/6, moist); clay; weak, medium to coarse subangular blocky structure; very friable when moist, slightly sticky and slightly plastic when wet; 1-2mm, 5% Fe and Mn concretions; many very fine pores; very few very fine, fine and few medium roots.

Laboratory data for profile description no. 2

Horizon designation	Ap	Bt	Bu1	Bu2cs
Horizon depth (cm)	0 – 15	15 – 40	40 – 82	82 – 155
pH-H2O (1:2.5)	6.6	6.4	6.7	6.5
EC dS/m ,,	0.12	0.22	0.26	0.28
ECe dS/m ,,	0.42	0.66	0.78	0.84
C (%)	0.75	0.60	0.58	0.55
CEC-soil (cmol/kg)	9.0	11.20	10.40	10.4
CEC-clay (cmol/kg)	9.1	11.9	11.2	12.0
Exchangeable Calcium ,,	2.75	5.16	6.47	5.58
Magnesium ,,	1.17	1.80	1.97	1.59
Potassium ,,	0.48	0.18	0.14	0.14
Sodium ,,	0.55	0.40	0.30	0.25
Sum of cations	4.95	7.84	8.88	7.56
Base saturation (%)	55	70	85	73
ESP	6	3	3	2
Texture – hydrometer				
Sand %	16	14	14	16
Silt %	18	12	14	16
Clay %	66	74	72	68
Texture class	C	C	C	C
Silt:clay ratio	0.27	0.16	0.19	0.23

Profile Description No.3

General site information

Soil map unit code	:UPb
Sheet observation no.	:135/2- 15
Location/altitude	:easting 0315450 and northing 9931934; 1224 m asl
Soil parent material	:tracyhtic tuffs
Landform	:uplands
Relief/slopes	:very gently undulating to gently undulating summit; slopes 1 – 3%
Land use	: growing French beans, bananas, maize, pepper, mangoes and grazing
Erosion	:not observed
Surface sealing and crusting	:not observed due to good surface cover
Internal drainage	:well drained but compact at 23-49 cm depth

Effective soil depth : >150 cm
Soil classification :Ferric Acrisol

Profile description
Horizon Depth

A 0 – 15 cm very dark greyish brown (10YR3/2, moist); clay; weak, fine to medium, subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; many, biopores, very fine and fine pores; many, very fine and fine roots; clear and smooth transition to:

Bt1 15 – 34 cm very dark brown (7.5YR3/4, moist); clay; weak, medium, subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; many, very fine and fine pores; thin, patchy clay cutans; few very fine and fine roots; clear and smooth transition to:

Bt2cs 34 – 103 cm very dark brown (7.5YR3/4, moist); clay; weak, medium, subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; red (2.5YR4/8) oxidation mottles; common coarse, very few very fine and fine roots.

Bt3cs 103 – 150+ cm dark reddish brown (2.5YR3/4, moist); clay; weak, medium, subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; common, very fine and fine pores; red (2.5YR4/8) oxidation mottles; common coarse, very few very fine and fine roots.

Laboratory data for profile description no. 3

Horizon designation	A	Bt1	Bt2cs	Bt3cs
Horizon depth (cm)	0 – 15	15 – 34	34 – 103	103 – 150+
pH-H2O (1:2.5)	6.4	5.9	6.1	6.3
EC dS/m ,,	0.13	0.06	0.07	0.08
ECe dS/m ,,	0.39	0.18	0.14	0.16
C (%)	1.07	0.44	0.3	0.2
CEC-soil (cmol/kg)	13.60	14.4	17.2	17.2
CEC-clay (cmol/kg)	18.6	21.8	28.4	28.4
Exchangeable Calcium ,,	5.98	3.82	4.58	4.50
Magnesium ,,	2.03	2.26	2.16	2.16
Potassium ,,	0.56	0.145	0.20	0.20
Sodium ,,	0.65	0.30	0.35	0.35

Sum of cations	9.22	6.52	7.29	7.21
Base saturation (%)	68	45	42	42
ESP	5	2	2	2
Sand %	46	36	38	38
Silt %	4	6	8	8
Clay %	50	58	54	54
Texture class	C	C	C	C
Silt:clay ratio	0.08	0.10	0.15	0.15

Profile Description No. 4
General site information

Soil map unit code	:VBd
Sheet observation no.	:135/2- 13
Location/altitude	:easting 0314771 and northing 9933392; 1244 m asl
Soil parent material	:basalts and basaltic agglomerates
Landform	:valley
Relief/slopes	:flat to very gently undulating; slopes 0 – 2%
Land use	:grazing of livestock and growing paddy rice
Erosion type	:not observed
Surface sealing and crusting	:not observed
Cracks	:1-3 cm wide and 45 cm deep; most cracks sealed
Groundwater	:struck at 55 cm depth
Internal drainage	:imperfectly to poorly drained
Effective soil depth	:>100 cm
Soil classification	:Eutric Vertisol, sodic phase

Profile description
Horizon Depth

Ap 0 – 18 cm black (10YR2/1, moist); clay; weak, fine to medium, subangular blocky and moderate, fine to medium crumby structure; slightly hard to hard when dry, friable to firm when moist, sticky and plastic when wet; common, biopores and fine pores; many very fine and fine, very many medium roots; clear and smooth transition to:

BU1 18 – 49 cm black (10YR2/1, moist); clay; strong, medium to coarse, prismatic breaking to moderate to strong, fine to medium, angular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; moderate, broken, slickensides; very few fine pores; common very fine and fine roots; gradual and smooth transition to:

BU2 49 – 85 cm black (2.5Y2/0, moist); clay; moderate to strong, medium to coarse, prismatic breaking to strong, medium angular blocky structure; hard when dry, friable to firm when moist, sticky and plastic when wet; thick, continuous slickensides; common, very fine and fine pores; very few, very fine and fine roots; clear and irregular transition to:

Bck 85 – 105+ cm very dark brown (10YR2/2, moist); clay; porous massive breaking to weak, medium, subangular blocky structure; slightly hard to hard when dry, friable when moist, sticky and plastic when wet; slight to moderately calcareous, 50 – 60%, 2 - 50 mm calcium carbonate concretions; few, very fine and fine pores; very few, very fine roots; abrupt and irregular transition to:

Laboratory data for profile description no. 4

Horizon designation	**Ap**	**Bu1**	**Bu2**	**Bck**
Horizon depth (cm)	0 – 18	18 - 49	49 – 85	85 – 105
pH-H2O (1:2.5)	7.2	7.6	8.1	8.6
EC dS/m ,,	0.40	0.40	0.55	0.40
ECe dS/m ,,	1.20	1.20	1.65	1.20
C (%)	2.21	1.75	1.63	0.38
CEC-soil (cmol/kg)	76.8	78.8	53.2	23.6
CEC-clay (cmol/kg)	87.1	94.5	64.8	78.8
Exchangeable Calcium ,,	39.54	38.87	23.85	8.23
Magnesium ,,	19.4	21.67	18.44	5.96
Potassium ,,	0.54	0.34	0.34	0.10
Sodium ,,	1.30	2.45	3.65	3.0
Sum of cations	60.78	63.3	46.28	17.29
Base saturation (%)	79	80	87	73
ESP	2	3	7	13
Texture – hydrometer				
Sand %	20	16	20	58
Silt %	2	8	8	14
Clay %	78	76	72	28
Texture class	C	C	C	SCL
Silt:clay ratio	0.03	0.10	0.11	0.5

Profile Description No. 5
General site information

Soil map unit code	:VBd
Sheet observation no.	:135/2- 17
Location/altitude	:easting 0314360 and northing 9936067; 1283 m asl
Soil parent material	:basalts and basaltic agglomerates
Landform	:valley
Relief/slopes	:very gently undulating to gently undulating; slopes 0 – 2%
Land use	:grazing
Erosion type	:not observed
Surface sealing and crusting	:not observed
Cracking	:1-4cm wide and 55 cm deep
Internal drainage	:imperfectly drained
Effective soil depth	: 110 cm
Soil classification	:Eutric Vertisol, sodic phase

Profile description

Horizon Depth

Ah 0 – 15 cm very dark greyish brown (10YR3/2, moist); clay; weak , fine to coarse subangular blocky and moderate, medium, angular blocky structure; slightly hard to hard when dry, friable when moist, sticky and plastic when wet; very many biopores, very fine and fine pores; common, very fine and fine roots; clear and smooth transition to:

Bu1 15 – 70 cm very dark grey (10YR3/1, moist); clay; strong, medium to coarse prismatic breaking to weak, medium, subangular blocky and moderate fine to medium, angular blocky structure; very hard when dry, friable to firm when moist, sticky and plastic when wet; very many, biopores, very fine and fine pores; common very fine and fine roots; clear and smooth transition to:

Bu2cs 70 – 110 cm very dark grey (10YR3/1, moist); clay; moderate to strong, medium prismatic breaking to weak to moderate, very fine to medium, angular and subangular blocky structure; very hard when dry, friable to firm when moist, sticky and plastic when wet; 2 – 5%, 1 – 5 mm iron and manganese concretions; common, very fine, fine and bio- pores; few, very fine and fine roots; clear and smooth transition to:

110+ Weathering basaltic agglomerates

Laboratory data for profile description no. 5

Horizon designation	**Ah**	**Bu1**	**Bu2cs**
Horizon depth (cm)	0 – 15	15 – 70	70 – 110
pH-H2O (1:2.5)	5.6	5.5	6.1
EC dS/m ,,	0.07	0.05	0.07
ECe dS/m ,,	0.21	0.15	0.21
C (%)	1.63	1.48	1.18
CEC-soil (cmol/kg)	18.6	21.6	19.48
CEC-clay (cmol/kg)	15.1	18.7	26.4
Exchangeable Calcium ,,	5.27	5.09	6.57
Magnesium ,,	2.88	2.85	3.48
Potassium ,,	1.44	0.80	0.68
Sodium ,,	1.45	0.95	0.75
Sum of cations	11.04	9.69	11.48
Base saturation (%)	59	45	59
ESP	8	4	4
Texture – hydrometer			
Sand %	10	10	8
Silt %	10	6	34
Clay %	80	84	56
Texture class	C	C	C
Silt:clay ratio	0.125	0.71	0.61

APPENDIX 2

Climatic, soil and water requirements of the envisaged crops

Crops	**Climate**	**Soil**	**Water requirements in mm over the growing period**
Cabbage	Optimum temperature is 15-20°C; short periods of frost tolerated at –6 to –10°C; optimum relative humidity is 60-90%.	Well drained soils; pH 6.0 to 6.5.	380-500
Tomatoes	Temperature ranging from 18 to 25°C; sensitive to frost and high humidity. Night temperatures falling between 10 and 20°C.	Well drained soils, and is very sensitive to waterlogging with pH ranging from 5 to 7.	400-600
Maize	Temperature between 24 and 30°C, and is sensitive to frost. Night temperature not less than 10°C.	Well drained and aerated soils, with deep water table and without waterlogging; optimum pH range being 5.0 to 7.0.	500-800
Sorghum	Temperature 24-30°C; sensitive to frost.	Relatively tolerant to waterlogging, with pH of at least 6.8.	450-650
Pepper	Optimum temperatures range from 18 to 23°C and sensitive to frost.	Light to medium textured soils with pH varying from 5.5 to 7.0.	600-900
Ground nuts	Temperatures range from 22 to 28°C and sensitive to frost. For good germination, temperature >20°C required.	Well drained, friable and medium textured soils with topsoil pH being 5.5-7.0.	500-700
Rice	Optimum temperatures range from 22 to 30°C and sensitive to frost. Cool temperatures cause head sterility.	Heavy clay soils with low drainability. High tolerance to oxygen deficiency.	350-700
Bananas	Optimum temperatures ranging from 24-26°C and sensitive to frost; temperatures less than 8°C cause serious damage. Requires high relative humidity.	Deep well drained loam without stagnant water.	1200-2200
Water melon	Temperatures range from 22 to 30°C and very sensitive to frost.	Sandy loam is preferred, with pH varying from 5.8 to 7.2.	400-600
Onions	Required temperatures ranging from 15-20 °C and tolerant to frost. Low temperature between 14 and 16°C required for flower initiation. Extreme temperatures or excessive rain not required.	Medium textured without waterlogging. pH range being 6.0 to 7.0.	350-550
Cotton	Optimum temperatures vary between 20 and 30°C and sensitive to frost.	Deep medium to heavy textured soils and free from stagnant water.	700-1300
Beans	Optimum temperatures range from 15-20°C	Sensitive to frost.	300-500

Source: FAO (1986)

The interactions between the crops, soils and management should be understood in planning and designing the irrigation systems.