Kenya Agricultural Research Institute

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Kenya Soil Survey

SUSTAINABLE LAND MANAGEMENT IN KIAMBINDU, KIARUKUNGU, KYEEKOLO AND KISIOKI SMALLHOLDER IRRIGATION SCHEMES
(Mbeere, Kirinyaga, Makueni and Kajiado Districts)

BY

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KENYA SOIL SURVEY ADVISORY SITE EVALUATION REPORT

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EXECUTIVE SUMMARY

Kiambindu, Kiarukungu, Kyeekolo and Kisioki irrigation schemes are community based initiatives started at different dates between 1970's and 2003 focusing on economic empowerment of their members through the utilization of the natural resources. The schemes are located in Mbeere, Kirinyaga, Makueni and Kajiado Districts, respectively. It is in this light that the Ministry of Water and Irrigation, Irrigation and Drainage Department and Japanese International Cooperation Agency (JICA) approached Kenya Soil Survey (KSS) with a request to conduct soil investigations in the four project areas. The purpose of the soil investigations was to provide information that would ensure the development of sustainable community based soils and water management practices which would ultimately support the realization of food self sufficiency/security, wealth creation and a healthy environment. Table 1 gives the summary of land use and other land characteristics in the irrigation schemes. The following are the findings of the soil investigations:

Kiambindu Irrigation Scheme, Mbeere District

The scheme has an area of about 400 ha. The relief of the scheme area ranges from flat to undulating with slopes of between 0 – 8%, surrounded by rolling to hilly relief. It occurs in agro-climatic zone IV with medium potential for plant growth. Land use in the project area comprises of rearing livestock (cattle, goats and sheep), bee keeping, brick making, growing rainfed and irrigated crops. The main rainfed subsistence crops include *Zea mays* (maize), *Phaseolus vulgaris (*beans*)*, *Sorghum bicolor* (sorghum), *Bulrush millet* (millet), *Cajanus cajan* (pigeon peas), *Lablab purpureus* (dolichos beans), *Vigna unguiculata* (cow peas), *Ipomea batatas* (sweet potatoes), *Saccharum officinarum* (sugarcane) and *Musa sapientum* (bananas) while the main irrigated horticultural crops include vegetables such as *Lycopersicum esculentum* (tomatoes), *Brassica oleracea* var. *capitata* (cabbages), *Brassica oleracea* var. *acephala* (kales), spinach, *Capsicum frutescens* and *C. annum* (chilies), *Allium ampeloprassum* (leafy onions), *Allium cepa* var. *cepa* (onions), *Monordica foetida* (karela), *Lageneria siceraria* (bottle gourd or dudhi)**,** *Solanum melongena* (egg-plant or brinjals) and fruits such as *Carica papaya* (paw paw), *Mangifera indica* (mangoes) and *Persea americana* (avocadoes). The proposed source of irrigation water for the scheme is River Thuci and water from this source is suitable for irrigation.

The major soil limitations for crop production in this scheme include nutrients availability (soil fertility), susceptibility to sealing and crusting, susceptibility to erosion and workability during cultivation. The soils indicate deficiency in nitrogen (N), phosphorus (P), and low organic matter. This can be rectified by use of NP supplying fertilizers while organic matter can be improved by application of farmyard manure (FYM). The soils of the scheme area are very susceptible to sealing and crusting due to unstable soil aggregates as a result of high silt/clay ratio and low organic matter content. This triggers runoff causing water erosion. Low organic matter content and high silt/clay ratio also make the soils susceptible to erosion due to increased topsoil erodibility.

Application of FYM which is easily available in the area is essential to improve the structural stability of the topsoil and therefore reduce erosion. Soil and water management practices should be enhanced together with N-fixing plants and agro-forestry. Other important agronomic practices in the area should include intercropping with good cover crops, crop rotation and use of organic pesticides. Efficient use of the available irrigation water should be emphasized.
Due to the presence of stones, boulders and rocks, workability could be improved by constructing terraces using these materials for soil and water conservation in addition to creating more space for agricultural activities.

Kiarukungu Irrigation Scheme, Kirinyaga District
The scheme is located in Mwea Division and has an area of 300 ha. The project area is flat to undulating in relief with slopes of 0 – 8%. The scheme is located in agro-climatic zones III and IV which are semi-humid to semi-arid with high to medium potential for plant growth. The major land use in the area is growing of *Oryza sativa* (paddy rice). Other crops grown in the area include horticultural crops such as French beans, tomatoes, sunflower and mangoes while subsistence crops include maize, beans, cow pea, *Vigna radiate* (green grams) and sorghum. *Gossypium* spp (cotton) is also grown as a cash crop. Other horticultural crops grown in the scheme in the past but have been abandoned due to lack of market include cucumber, courghetts, water melons, dudhi and capsicum. Livestock and bee keeping are also important land uses in the area. The source of irrigation water for Kiarukungu irrigation scheme is River Thiba whose water quality is suitable for irrigation.

The general physiography of the area consists of a plain which is flat to very gently undulating with slopes of 0 – 2% and the uplands which are gently undulating to undulating with slopes of between 2 – 8%. The flat to very gently undulating plains have soils that are imperfectly drained, very deep, dark grey to black, firm to very firm, cracking clay; in places calcareous and sodic in deeper subsoil. The soils are classified as Calcic and Eutric Vertisols, sodic phase. The uplands have soils that are well drained, very deep, dark reddish brown to dark brown, friable to firm, clay loam to clay; in places with a humic topsoil. The soils are classified as Haplic Ferralsols.

The major soils limitations for crop production include nutrients availability, workability, compact subsoil, plough pan, surface sealing and crusting. Therefore use of the right fertilizers, timely ploughing and planting, deep ploughing and use of farmyard manure or compost are necessary. To avoid salinization or sodification of the soil, efficient use of the irrigation water is very important. In addition, agrochemicals should be carefully applied to avoid pollution of surface and groundwater.

Kyeekolo Irrigation Scheme, Makueni District
The scheme is located in Kilungu Division, and has an area of 150 ha. The project area is generally undulating to hilly in relief. It occurs in agro-climatic zone III which has high to medium potential for plant growth. Land use in the project area comprises a few natural and planted forests, cultivation of annual and perennial crops, and keeping livestock. The irrigation scheme has its source of water from Kyeekolo stream and the water is suitable for irrigating crops.

The soils of the hills are excessively drained to well drained, red to dark yellowish brown; rocky, bouldery and stony, gravelly sandy clay loam to clay. The footslopes which constitute the project area occur at the foot of the hilly areas and are gently undulating to rolling with slopes between 3% and 14%. The soils are well drained, moderately deep to very deep, dark reddish brown to very dark greyish brown, very friable to friable, sandy loam to clay; in places shallow, rocky, stony and gravelly. The valleys occur in the incised hills and footslopes, along the stream. The valleys show differences in relief along the stream channel. They are flat to undulating where they are well formed and steeply dissected at the foot of the hills with slopes of between 16% and 30% forming V-shaped valleys. The soils found in the lesser steep valleys are moderately well drained, moderately deep to very deep, greyish, sandy clay loam to clay soils. The flat to gently undulating areas with slopes of 0 – 2% have soils that are imperfectly drained to very poorly drained, greyish brown to very dark grey, friable to firm, micaceous, stratified, sandy loam to clay.

The hills show high to very high susceptibility to erosion due to the slope steepness and length. Erosion hazard is moderate to severe mainly due to presence of bench terraces which are not stabilized, maintained and properly spaced thus rendering them ineffective in soil erosion control. All these factors were found to cause overflow of collected runoff leading to breaking of the terrace banks. Other causal factors include up-slope tillage and planting, mono-cropping, non-application of organic and inorganic fertilizers and dominant cultivation of annuals. It was also observed that the unit is very prone to soil slumping/mass wasting in areas with slopes greater than 35% where forestry has been replaced with cultivation of subsistence annual crops leading to enormous soil losses during the rainy seasons. The effectiveness of indigenous trees such as *Bridelia micrantha, Croton macrostachyus and Ficus thonningii* was noted in the control of this phenomenon. Therefore, reforestation preferably with the indigenous tree species and enhancement of agro-forestry with multipurpose trees and shrubs with N-fixing ability, catchment conservation, and fuel wood and timber species are crucial in these steep and hilly areas.

Soil slumping was noted at the edges of bench terraces, road sides and pasture fields. Therefore planting deep rooting plants/trees to hold the soil firmly is necessary. In the hilly areas, a combination of physical, agronomic and cultural soil conservation measures need to be enhanced as the soils have high susceptibility to erosion. The footslopes indicate high susceptibility to erosion and the main contributing factor is slope steepness and length. The high susceptibility to erosion is reflected by the occurrence of strong splash and rill erosion on bare soils leading to decapitated soils without the topsoil thus exposing the compact and less fertile subsoil. The footslopes indicate moderate erosion hazard and hence the need for increased combinations of soil conservation measures such as stabilizing *fanya juu* terraces, planting of woodlots, strip cropping with good cover crops (e.g. pastures, sweet potatoes), inter-cropping, agro-forestry and use of FYM. Use of the locally available stones and boulders in the construction of terraces is necessary especially in the hills and footslopes.

The valleys indicate low to moderate susceptibility to erosion varying with slope within the valleys. Susceptibility to erosion is low in flat to very gently undulating parts of the valleys with slopes of 0 – 2% and moderate in areas which are gently undulating with slopes of 2 – 5%. They indicate non to slight erosion hazard in the flat to very gently undulating and slight to moderate in the gently to rolling parts of the valleys/lower parts of the hills due to the good cover provided by natural vegetation and the cultivation of crops which provide fairly good cover such as sugarcane, vegetables, arrowroots and sweet potatoes. The soils are susceptible to sealing and crusting and hence the need to maintain good protective soil cover to protect the topsoil against impacting raindrops and applied irrigation water by planting crops such as bananas, sweet potatoes, *Colocasia antiquorum* (arrow roots) and vegetables. Since the valleys occur on lower parts of the incised hills and footslopes, their protection is very much dependent on the types and effectiveness of the conservation measures adopted in the steeper adjacent higher lying areas.

The soils of the project area are generally moderately acidic to strongly acidic (pH-H_2O 4.7 – 5.8) and have low organic matter content, and are deficient in N, P and K. Application of FYM or compost is recommended to improve structural stability of the topsoil and hence prevent sealing, crusting and runoff while compound fertilizers containing NPK should be applied to supply the deficient nutrients. This should also go hand in hand with incorporating N-fixing leguminous trees or shrubs such as *Tephrosia vogelii* in the farming systems to enhance N supply in the soils. The shrub can be used as grains preservative, and pesticide against stem borers, repellant against mosquitoes, cockroaches and rodents such as moles.

The proposed strategies are focused on provision of reliable information to the extension staff about technologies that optimize use of rainfall in soil and water conservation, soil fertility improvement by use of FYM or compost with application of inorganic fertilizers, timely planting, weeding, contour ploughing/tillage, crop rotation and use of certified seeds. This will ultimately result in higher productivity of rainfed agriculture with increased crop yields per unit area and livestock products especially milk. Increased soil water storage capacity would result in long duration groundwater recharge thus making the streams to have flowing water in the better part of the year or permanently. This would make it possible to grow high value horticultural crops such as tomatoes, egg plants/brinjals, onions, karela, okra, French beans, soya beans, dudhi, citrus and avocadoes thus creating alternative and diversified sources of income (wealth) and food self sufficiency (security).

Kisioki Irrigation Scheme, Kajiado District

The scheme is located in Loitokitok Division and has an area of 30 ha. The project area is very gently undulating to gently undulating in relief, and occurs in agro-climatic zone V which has medium to low potential for plant growth. Land use in the project area comprises natural riverine vegetation, livestock (cattle, goats, sheep and donkeys) keeping and bee keeping, cultivation of subsistence crops which include maize, beans, cassava, bananas, sweet potatoes, arrowroots, pigeon peas, sugar cane, sorghum, dolichos beans, *Amaranthus hybridus*, cow peas and green grams. The major horticultural crops grown in the area include tomatoes, onions, capsicum, brinjals, okra, karela, kales, sunflower, citrus, *Artocarpus integrifolia* (jack fruit or fenas) and avocadoes. Timely planting of these horticultural crops on seasonal basis is important in order to fetch maximum profits and avoid flooding the market with some crops.

The source of irrigation water for the irrigation scheme is River Rombo A and B. The water quality for irrigation from the proposed intake point which is near the confluence of these two streams/springs is marginally suitable for irrigation purposes due to the medium salinity and low sodium content in the water. Bicarbonates content are at high level requiring moderate amount of soil leaching. Plants with moderate salt tolerance such as vegetables can be grown using the water, only when accompanied by other soil and water management amendments that improve soil drainage and avoid water logging. Such strategies among others include use of livestock manure which is locally available to improve topsoil structure stability which in turn will improve drainage of the soils and prevent sealing and crusting. The area is inherently prone to environmental degradation hence it is very crucial to adhere to sustainable management strategies to avoid salinization and sodification of the soils. Maintenance of the indigenous riverine vegetation is very important to control stream bank erosion.

Table 1: Summary of land use and land limitations in the irrigation schemes

Scheme	Extent (Ha)	Relief	Agro zone	Livestock	Subsistence crop	Horticultural crop	Water source	Soil/limitations
Kiambindu	400 ha	Flat to undulating relief, slopes 0-8%	Zone IV	Cattle, Goats, Sheep, Bee keeping	Maize, Beans, Sorghum, Millet, Pigeon Peas, Dolichos Beans, Cowpeas, Sweet Potatoes, Sugar Cane, Bananas	Tomatoes, Cabbages, Kales, Spinach, Chillies, Leafy Onions, Onions, Karela, Egg-Plant, Pawpaw, Mangoes, Avocadoes	River Thuchi	Soil fertility, sealing & crusting, erosion & workability during cultivation, deficiency in N, P & low organic matter
Kiarukungu	300 ha	Flat to very gently undulating relief slopes 0-2%	Zone III & IV	Bee keeping, Cattle, Goats	Maize, Beans, Cow Peas, Green Grams, Sorghum, Cotton	French Beans, Tomatoes, Sunflower, Mangoes	River Thiba	Nutrients availability, workability, compact subsoil, plough pan surface sealing and crusting
Kyeekolo	150 ha	Undulating to hilly relief, slopes 5% to > 16%	Zone 111	Cattle, poultry, Goats and bee keeping	Sugarcane, Vegetables, Arrowroots, Sweet potatoes, Bananas	Tomatoes, Brinjals, Onions, Karela, Okra, French Beans, Soya Beans, Dudhi, Citrus & Avocados	Kyeekolo stream	Soil slumping, sealing & crusting, acidic, low organic matter, deficiency in N, P & K
Kisioki	30 ha	Very gently to gently undulating relief, slope 0.5 – 5 %	Zone V	Cattle, Goats, Sheep, Donkeys, Bee keeping	Maize, Beans, Cassava, Bananas, Sweet Potatoes, Arrowroots, Pigeon Peas, Sugarcane, Sorghum, Dolichos Beans, Cowpeas, Green Grams	Tomatoes, Onions, Capsicum, Brinjals, Okra, Karela, Kales, Sunflower, Citrus, Jack Fruit, Avocadoes	River Rombo A & B	Sealing & crusting, salinization & sodification, high level of bicarbonates in irrigation water

BACKGROUND

The Japanese International Cooperation Agency (JICA) through the Technical Coordinator, Dr. Yasuhiro Doi requested for the assessment of the soils, water and other closely related land resources in order to provide information that would facilitate sustainable agricultural development through production of irrigated crops and environmental management in four irrigation schemes. The field soil assessments were carried out in July, 2006 which assisted in the identification of soil limitations/constraints for irrigated crop production. Some possible management and remedial measures have been proposed. The ultimate goal of this work will be the realization of food self sufficiency (security), wealth creation and a clean environment in the four project areas.

The irrigation schemes are Kiambindu, Kiarukungu, Kyeekolo and Kisioki. The Kiambindu irrigation scheme is located in Ishiara area of Mbeere District and the intended source of irrigation water is River Thuci. The Kiarukungu irrigation scheme is in Mwea Division of Kirinyaga District and the source of water is River Thiba. Kyeekolo irrigation scheme is in Kilungu Division, Makueni District and its source of water is Kyeekolo stream. Kisioki irrigation scheme is in Oloitokitok Division of Kajiado District and its irrigation water is from river Rombo. Soil samples for soil characterization and fertility determinations in the four schemes were collected and analyzed at the National Agricultural Research Laboratories (NARL) – Kabete. In addition, water samples from the proposed intakes were taken for analysis and evaluated for their suitability for irrigation.

In this report, the results of the soils and water assessment, recommendations and possible remedial measures are presented scheme by scheme. Part 1 of the report discusses Kiambindu Irrigation Scheme; Part 2 discusses Kiarukungu Irrigation Scheme; Part 3 discusses the Kyeekolo Irrigation Scheme, while Part 4 discusses the Kisioki Irrigation Scheme.

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1.1 INTRODUCTION

Kiambindu Irrigation Scheme is a community based initiative which focuses on economic empowerment of its members through the utilization of natural land resources especially soils and water. The scheme area is gently undulating to rolling adjacent to a hilly terrain. The scheme occurs at an altitude between 920 m and 950 m above sea level. It occurs in agro-climatic zone IV which is classified as having medium potential for plant growth.

The land use in the scheme comprises of rearing of livestock (cattle, goats and sheep), bee keeping, growing subsistence and horticultural crops. The main rainfed subsistence crops include maize, beans, sorghum, millet, pigeon peas, dolichos beans, cow peas, sweet potatoes, sugarcane and bananas while the main irrigated horticultural crops include vegetables such as tomatoes, kales, spinach, chilies, onions, karela, dhuthi, brinjals, and fruits such as paw paws, mangoes and avocadoes. The proposed source of irrigation water for the scheme is the permanently flowing River Thuci. The water from this source is suitable for irrigation. The local community depends on water from this river for livestock, domestic needs and some irrigated agriculture. However, inappropriate utilization and mismanagement of the land resources has led to land degradation in the form of soil erosion, surface sealing and crusting, fertility decline, sedimentation/siltation and deforestation, leading to declining crop yields.

The irrigation project was initiated with the objective of improving household incomes through sustainable utilization of natural resources, mainly spring/stream water and soils in the project area. This would in addition enhance food security and create a healthy environment. However, the project did not pick up well due to limited capacity on project development and management, inadequate community participation, lack of technical support and know-how, and inadequate resources among other reasons. Consequently, the project stalled in 1991 but was revived in 2000.

The need to implement appropriate natural land resource management and conservation strategies is crucial in enhancing food security and economic development in the area. Land use planning in the project area is essential for identification of the changes required in land use practices which will increase productivity and opportunities, making decisions on where the changes should be and to avoid misuse of the land resources.

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

1.2 THE ENVIRONMENT

1.2.1 Location, Communication and Population

Kiambindu Irrigation Scheme (KIAMIS) is situated in Evurore Division, Mbeere District, Eastern Province of Kenya. It is bounded by latitudes 00˚ 20‘and 00˚ 30‘south, and longitudes 37˚ 55‘and 37˚ 58‘east, at an altitude of between 820 – 920 m above sea level (asl). It covers an area of about 400 ha in extent.

The area is accessible through the Ishiara-Kanyuambora-Siakago murram road which joins the Embu-Kitui road and the Ishiara-Kanyuambora-Karurumo murram road which joins the Embu-Meru tarmack road. The indigenous people in the area are the Mbeere who are engaged in farming, livestock rearing and carrying out businesses. Table 2 below shows the population of Evurore Division as per the population census of 1999 and the projected population to the year 2020.

Table 2: Present and projected population of Evurore Division (1999 – 2020)

Year	**1999**	**2000**	**2005**	**2010**	**2015**	**2020**
Population	44,476	45,810	53,106	61,564	71,369	85,217
Population density(persons/km²)	64	66	76	89	103	123

Source: GoK, 1999.

The high concentration of the population is attributed mainly to the high potential of soils for agriculture. Other factors are poor family planning facilities and low literacy levels. High population densities in the area are also expected in up-coming market centers such as Ishiara which is adjacent to the KIAMIS due to business expansion and increase in public institutions such as schools and dispensaries. According to the above projections, the division population density of 64 persons/km² in 1999 is projected to almost double to 123 persons/km² by the year 2020. The population statistics indicates a build-up of population pressure which will ultimately lead to increased demand, competition and over exploitation of the available natural resources. This may eventually lead to land degradation, if the necessary mitigation measures are not put in place.

1.2.2 Climate

1.2.2.1 Rainfall, agro-climatic zonation, temperatures and potential evaporation

The rainfall data used is for Ishiara meteorological station which is within the project area recorded for 11 years. Rainfall in the area is bimodal with long rains occurring between March and May and short rains from October to December. However, the short rains are more reliable than the long rains. The scheme falls under agro-climatic zone (ACZ) IV which has a mean annual evaporation and mean annual rainfall ratio of 0.4 - 0.5. Zone IV is classified as semi-humid to semi-arid with a mean annual rainfall of 600-1100 mm and a mean annual evaporation of 1550-2200 mm. The mean annual temperatures are 24˚C–30˚C which is fairly hot to very hot. It has medium potential for plant growth, if soils are not limiting and has low risk of crop failure.

1.2.2.2 Evapotranspiration and Moisture balance

The potential evapotranspiration (Et) i.e. crop water requirements, is inversely related to altitude with low altitude areas having higher evapotranspiration than the higher altitude areas. The mean annual potential evaporation (Eo) based on Wood head (1968), altitude equation ranges from 2067 mm in the hilly areas to 2117 mm in the low lying areas as shown in Table 3. The potential evapotranspiration is assumed to be 2/3 of Eo and therefore ranges from 1378 mm to 1411 mm in the project area. Monthly Eo values have been calculated according to Braun (1984).

Table 3: The soil water balance for the project area.

Parameter	**Month**												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Yr**
Rainfall (r)	31	31	87	268	45	8	3	3	11	81	221	68	857
Evapo (Eo)	212	190	212	169	148	148	148	148	190	190	169	190	2117
Evapotr(Et)	14 1	127	141	113	99	99	99	99	127	127	113	127	1411
r-Et	-110	-96	-54	155	-54	-91	-96	-96	-116	-46	108	-59	-554

Table 3 shows the water balance (r - Et) exceeds the mean monthly and annual rainfall evapotranspiration demand in the months of April and November. Table 3 further shows that the periods between January to March, May to October and the month of December experiences moisture deficits thereby requiring irrigation supplementation. Due to scarcity of water in the area, water harvesting technologies such as rock and roof catchments, and 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 little water with little losses should be promoted.

1.2.3 Physiography, geology/parent materials and soils

The physiography of the scheme is predominantly uplands which are very gently undulating to rolling with slopes of 1-10 %. The valleys occur at the area surrounding the water intake. The hills are very steep with slopes of more than 16%. The hills and the accompanying valleys are covered by granitoid gneisses which are somewhat resistant to weathering and erosion due to predominance of quartzitic material. However, variations in the composition do occur resulting in some areas being richer in muscovite, feldspars or biotite. The soils of the hills are excessively drained to well drained, shallow to very deep, dark reddish brown to yellowish brown and are classified as Ferralic and Chromic Cambisols; Ferric and Ferralic Lixisols and Haplic Acrisols.

The footslopes occur at the foot of the hilly areas and are gently undulating to rolling with slopes of 3-16 %. They are underlain by undifferentiated various banded gneisses which indicate mineralogical composition differences at short distances. The soils are well drained, moderately deep to very deep, red to dark brown, very friable to friable, sandy loam to clay; in places shallow, rocky, stony and gravelly. The soils are classified as Ferral-Ferric, Ferric and Haplic Acrisols with Chromic Cambisols (FAO-UNESCO, 1997).

The soils of the uplands are developed on a mixture of ferromagnesian rich gneisses, Pleistocene alluvial and colluvial sediments and pyroclastic rocks (tuffs) overlying Basement System rocks. The soils developed on ferromagnesian rich rocks are dark red to strong brown, gravelly sandy clay loam to clay soils of varying depth, surface stoninnes and rockiness. They are classified as Ferric Lixisols with a sodic phase. The soils developed on mixed alluvial, colluvial and pyroclastic materials occupy most of the central part of the project area. They are well drained, moderately deep to deep, red to dark reddish brown, slightly gravelly, sandy clay loam to clay. The soils are classified as Ferralic Cambisols with a sodic phase. The soils of the upper part of the scheme near the water intake are developed on a mixture of colluvial, alluvial and volcanic rocks including tuffs and basalts and are well drained, dark reddish brown, friable clay soils of varying depth, stoninnes, rockiness and boulderiness. These soils are classified as Eutric Cambisols and Ferric Lixisols, rudic phase.

1.2.4 Drainage

The general drainage pattern in the area is from West to East with River Thuci as the main source of water. There are seasonal streams which pass through the scheme. The proposed source of water in the scheme is River Thuci which originates from the volcanic footridges of Mt. Kenya. The river provides water for livestock, domestic use and some ongoing smallholder irrigated agriculture in the area. Table 4 shows analytical results of a water sample taken from the proposed intake. The table also gives the safe level / allowable limits for parameters mostly used to classify water quality hazards according to Richards (1954). They include pH, electrical conductivity (EC) which indicates total dissolved salts, residue sodium carbonate (RSC) indicating carbonate and bicarbonate concentration hence alkalinization hazard of the water, and the sodium adsorption ratio (SAR) which indicates sodicity hazard. The results indicate indicates that the water is suitable for irrigation use without causing salinization or sodification of the soils.

Table 4: Irrigation water quality classification from River Thuci Intake

Parameter	Intake Value	Allowable limit/Safe level
pH	6.8	6.0 – 8.0
EC (dS/m)	0.07	0.0 – 0.75
Sodium (me/l)	0.39	
Potassium (me/l)	0.05	
Calcium ,,	0.03	
Magnesium ,,	0.08	
Carbonates ,,	Trace	0.0 – 1.25
Bicarbonates ,,	1.19	0.0 – 1.25
Chlorides ,,	0.63	
Sulphates ,,	1.54	
SAR	1.70	0 – 13
RSC	1.08	0.0 – 1.25

1.2.5 Vegetation and Land Use

Vegetation and land use are determined by climate (amount of rainfall and temperatures), altitude, soils and partly due to human activities. Variations are therefore expected in vegetation and land use in the hills, valleys and uplands. Rainfed cultivation of crops such as cassava, pigeon peas, cow peas and sorghum which are more drought resistant is dominant in the uplands. Production of kales, tomatoes, onions, paw paws, mangoes, avocadoes, spinach, pepper, sweet potatoes, sugarcane, and bananas takes place in the valleys and some parts of the uplands mainly through irrigation. Within the cultivated areas, *Eucalyptus* and *Grevillea* species have been planted for timber, building poles, fencing posts and fuelwood while *Mangifera indica, Carica papaya, Psidium guajava* and citrus are planted for fruits. Growing of *Azandiracta indica* (Neem tree) for use in malaria treatment is common within the scheme. The natural vegetation consists of thorny dry woodland and bushland with major species being *Commiphora, Combretum* and *Acacia* spp, *Terminalia brownii,* and *Lantana camara*. Farmers have gradually cleared woodland and bushland for cultivation of crops such as maize, beans, bananas, vegetables, cow peas, pigeon peas, sorghum, sweet potatoes, cassava, avocado, citrus and mangoes in the farms. Charcoal production, bee keeping and grazing of livestock (goats and cattle) also takes place.

1.2.6 Land Tenure

Land ownership in the scheme is predominantly free hold (registered and privately owned by farmers). Some land near Ishiara town is held under trust by the County Council. The greatest challenge in undertaking soil and water conservation measures lies in the free hold lands. Demarcation of land helps establish recognized boundaries for individual land ownership and therefore encourages land investments related to soil and water conservation. However, farm sizes are decreasing due to subdivision during inheritance and population pressure. It is therefore imperative to put in place sustainable land use planning, soil and water management measures to meet this challenge.
Though this has not reached serious levels, overgrazing by livestock has caused serious soil erosion in the area.

1.3 WORKING METHODS

1.3.1 Field soil characterization and collection of other land and environmental data

Differentiation of soil types was based on soil drainage, depth, colour, texture, consistency and structure. Representative soil profile pits for the major soil types were then sited, dug, described and sampled for laboratory chemical and physical analysis. From five sites/locations within a radius of 10 m around each profile pit, soil samples were taken and mixed into a composite sample for fertility evaluations. Additional composite fertility samples were taken from other sites in the scheme. Table 5 shows the location of the soil profile pits.

Table 5: Location of the soil profile pits

No. of observation /type	Easting	Northing
1 –profile pit	037˚ 47.031’	00˚ 27.478’
2 – profile pit	037˚ 46.787’	00˚ 27.622’
3 – profile pit	037˚ 47.339’	00˚ 28.306’

The soil characteristics were described and recorded on standard forms according to FAO Guidelines for Profile Description (FAO, 1977). The soil colour was determined through use of the Munsel Color Chart (Munsel Color Co., 1975). The FAO/UNESCO/ISRIC (1997) was used for soil classification. Information on vegetation, land use, land 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.

1.3.2 Field soil physical determinations

The infiltration rates were determined using double ring infiltrometers. Saturated hydraulic conductivity for each identified soil horizon in every profile pit was determined using augered holes of known diameter. Disturbed soil samples were taken for moisture determination. Undisturbed soil samples were taken using core rings for bulk density determination. Soil samples were also taken from the topsoil and subsoil from each of the described profile pit for laboratory determination of specific gravity, sieve analysis (soil texture classification) and consistency. These determinations were done following the procedures described by Hinga *et al*.(1980).

1.3.3 Laboratory analysis

Samples taken from the field were analysed for chemical and physical properties following procedures described by Hinga *et al*. (1980). The soil pH-H2O 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, organic carbon by the Walkley and Black method.

Soil fertility (available nutrients) was determined by the Mehlich method which involves the extraction of soil by shaking for 1 hour with 1:5 ratio 0.1N HCL/0.025N H2SO4. 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 (ECe) was estimated to be 3 times EC. Exchangeable sodium per cent (ESP), sodium adsorption ratio (SAR), residue sodium carbonate (RSC) and CEC-clay were respectively calculated according to the following equations:

ESP = Na/CEC x 100
SAR = Na/√(Ca+ Mg)/2
RSC = (CO3 +HCO3) – (Ca xMg)
CEC-clay = (CEC-soil – (4x%C) /%clay)100

The soil texture was determined by the hydrometer method. Bulk density and moisture content for disturbed and undisturbed samples were determined as described by Hinga et al., (1980). The particle density was determined using air pyknometer. The moisture content was determined for each soil horizon at pF 2.0 and 4.2. The total water holding capacity was determined for each horizon as the difference between the water content (in volume basis) at pF 2.0 and 4.2. The total water holding capacity of each profile was determined by the summation of the total water holding capacity of the individual soil horizons. The soil Atterberg limits (liquid and plastic limits) were determined using the Casagrande apparatus.

The aggregate stability was determined by dry sieving. The soil samples were air-dried and put on top of a set of sieves of 2.0, 1.0, 0.5, 0.25 and 0.15 mm, fixed on the vibrax with a unit timer. After shaking for 5 minutes, the weight fractions of the sample retained on the sieves were weighed and the size fraction on each sieve determined. The mean weight diameter (MWD) i.e. the sum of each fraction times the corresponding mean mesh size of the two sieves passing and retaining the fraction was determined and the following formula used to calculate MWD:

MWD=∑xiwi, where xi is the mean diameter of each size fraction and w is the proportion of the total sample weight occurring in the corresponding size fraction.

1.3.4 Legend construction

Based on the physiography, geology/parent material and soil characteristics in that order, a soils legend was made for the different soil units identified in the scheme. The physiographic units in the area are hills, footslopes, uplands and valleys denoted as H, F, U and V respectively. However, the scheme covers mostly the uplands and a small part of the V-shaped valley near the water intake. For geology/parent material, granitoid gneisses are denoted by letter Q while undifferentiated banded gneisses are indicated by letter U. Various undifferentiated parent materials including metamorphic, volcanic, alluvial and colluvial materials are denoted by letters X. Letters r, b represent red and brown soil colour respectively. Letter P indicates occurrence of very shallow (0-25 cm) soil depth and letter p moderately deep soils (50–80 cm), in some parts of the soil unit.

1.4 SOILS

1.4.1 Soils of the hills

The hills do not cover the scheme but occur around it. The soils of the hills are developed on granitoid gneisses and undifferentiated mixture of volcanic origin and gneisses. They occur on a hilly relief with slopes greater than 16%. The soils developed on granitoid gneisses are somewhat excessively drained, shallow to moderately deep, dark yellowish brown to strong brown, very stony, gravelly, loose, and sand to loamy sand. The soils are classified as Lithic Leptosols and Eutric Cambisols, rudic phase.

1.4.2 Soils of the footslopes

The unit is undulating to rolling with slopes of 8-14 %.The soils are developed on granitoid gneisses and colluvial material derived from these gneisses. The soils are in places gravelly and stony. They are somewhat excessively drained, shallow to deep, dark yellowish brown to dark reddish brown, gravelly, friable, loamy sand to sandy loam friable clay. The soils are classified as Ferral-Ferric Acrisols and Lithic Leptosols. In some places, the topsoil has been eroded exposing the compact subsoil.

1.4.3 Soils of the uplands

Soils of unit UQr

The soils are developed on undifferentiated banded gneisses. The soils occur on gently undulating relief with slopes of 2-5%. The soils are somewhat excessively drained to well drained, deep to very deep, dark reddish brown to dark red, fairly gravelly, friable clay. Moderate rill and severe gully erosion occur on these soils. The colour of the topsoil is dark red (2.5YR3/6), while that of the subsoil is red to dark red (10R4/8 – 2.5YR3/6). The soil structure of the A-horizon is weak, fine to medium, subangular blocky while that of the subsoil is moderate, medium subangular blocky. The soil consistency is friable when moist, slightly sticky to sticky and slightly plastic to plastic when wet in both topsoil and subsoil. The soil texture ranges from sandy clay loam to clay in the topsoil and subsoil. The silt:clay ratio ranges from 0.08 – 0.25 in the topsoil and from 0.1 to 0.5 in the sub-soil.

Soil chemical properties

Topsoil:	pH-H2O: 6.4 – 6.6, organic carbon (OC) 0.75%; EC 0.12 – 0.13 and ECe 0.39 – 0.42 dS/m; CEC-soil 9.0 – 13.6 cmol/kg and CEC-clay 18.6 – 18.75 cmol/kg; base saturation (BS) 55 – 68%; ESP 5 - 6
Sub-soil:	pH-H2O 5.9 – 6.7; OC 0.44 – 0.6%; EC 0.04 - 0.28 and ECe 0.12 – 0.84 dS/m; CEC-soil 10.4 – 17.2 cmol/kg and CEC-clay 21.8 – 28.4 cmol/kg; BS 42 – 85%; ESP 2
Diagnostic properties:	argic B; BS >50%; CEC-clay in B-horizon <24 cmol/kg; ferric properties
Soil classification:	Ferric Lixisols

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

Soils of unit UUp

The soils are developed on undifferentiated banded gneisses on undulating to rolling relief with slopes of between 5-14 %. The soils are somewhat excessively drained to well drained, shallow to deep, red to dark reddish brown, friable, sandy clay to clay. The soils are generally rocky, stony and gravelly. Moderate splash, rill and gully erosion occur on these soils. The colour of the topsoil is dark red

(2.5YR3/6) while that of the subsoil is red to dark reddish brown (10R4/8 – 2.5YR3/4). The soil structure of the topsoil is weak, fine to medium, subangular blocky while that of the subsoil is weak, medium, subangular blocky. The consistency of the A-horizon is slightly hard to hard when dry, friable when moist, sticky and plastic when wet. The texture ranges from sandy clay loam to clay in the topsoil and from sandy clay to clay in the subsoil. The silt:clay ratio is 0.1 in the topsoil and from 0.1 to 0.3 in the sub-soil.

Soil chemical properties

Topsoil:	pH-H2O: 6.4; organic carbon (OC) 1.1%; EC 0.13 and ECe 0.39 dS/m; CEC-soil 13.6 cmol/kg and CEC-clay 18.6 cmol/kg; base saturation (BS) 68%; ESP 5 - 6
Sub-soil:	pH-H2O 6.4 – 6.8; OC 0.44 – 0.83%; EC 0.04 - 0.08 and ECe 0.12 – 0.24 dS/m; CEC-soil 10.6 – 17.2 cmol/kg and CEC-clay 20.2 – 28.4 cmol/kg; BS 42 – 79%; ESP 2 - 4
Diagnostic properties:	argic B, cambic B; BS < 50%; CEC-clay in B-horizon <24 cmol/kg; ferric and ferralic properties
Soil classification:	Ferric Acrisols and Ferralic Cambisols

For the description of a representative soil profile with analytical data, see Appendix 1 profile description nos. 3 and 4.

Soils of mapping unit UXr

The soils are developed on mixed alluvial, colluvial and pyroclastic materials. They occur on gently undulating to undulating topography with slopes of 1-5 %. The soils are well drained, moderately deep to deep, red to dark reddish brown, friable, sandy clay loam to clay. The colour of the topsoilis dark red (2.5YR3/6) while that of the subsoil is red to dark reddish brown (10R4/8 – 2.5YR3/4) The structure of the topsoil is weak, fine to medium, subangular blocky, while that of the subsoilis weak to moderate, fine to medium, subangular blocky. The consistency of the 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 to slightly sticky and plastic to slightly plastic when wet. The texture ranges from sandy clay loam to clay in the topsoil and from sandy clay to clay in the subsoil. The silt:clay ratio is 0.2 in the topsoil and from 0.2 to 0.4 in the sub-soil.

Soil chemical properties

Topsoil:	pH-H2O: 5.0; organic carbon (OC) 0.66 %; EC 0.12 and ECe 0.36 dS/m; CEC-soil 13.1 cmol/kg and CEC-clay 15.8 cmol/kg; base saturation (BS) 60%; ESP 8
Sub-soil:	pH-H2O 5.1 – 6.4; OC 0.44 – 0.56%; EC 0.17 - 0.23 and ECe 0.51 – 0.69 dS/m; CEC-soil 6.5 – 11.6 cmol/kg and CEC-clay 6.4 – 16.7 cmol/kg; BS 60 – 100%; ESP 10 - 15
Diagnostic properties:	cambic B, ferralic properties and ESP > 6
Soil classification:	Ferralic Cambisols, sodic phase

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

Soils of the valleys

The soils are developed on various parent materials mainly pyroclastic rocks, granitoid gneisses, colluvial and alluvial materials from different sources. They occur in the area surrounding the intake. The soils are well drained, dark reddish brown, friable, clay soils of varying depth and rockiness. The soils are classified as Chromic Luvisols; Chromic Cambisols with Lithic Leptosols, rudic phase.
Land use in this soil unit consists of growing irrigated bananas, paw paw, avocadoes, guavas, mangoes, maize, pigeon peas, dolichos beans, sweet potatoes, cassava, sugarcane, arrow roots, pumpkins and vegetables (tomatoes, spinach, onions, pepper, kales, cabbages, Amaranthus).

1.5 SOIL HYDRAULIC PROPERTIES AND CROPPING SYSTEMS

1.5.1 Hydraulic conductivity and infiltration

Infiltration rate is a very important hydraulic property of the soil in partitioning the rain and irrigation water into run-off and water entering the soil profile. It is also the principle determinant of the water supply duration per irrigation setting. Hydraulic conductivity is a measure of the internal drainage, deep water percolation and hence the irrigation efficiency and it is expressed in the following equation:

K = (1.15R (log ho + R/2) – Log ht + R/2))/t

Where:

K = Hydraulic conductivity in cm/hour
ho = Initial head in cm
R = Radius of the augerhole in cm
ht = The final head in cm
t = Time for the drop of hydraulic head from ho to ht in hours

The results of the field measurements of infiltration rates and hydraulic conductivity as determined for the three soil profiles in the scheme are presented in Tables 6 and 7.

Table 6: Infiltration rates for different soil profiles in Kiambindu irrigation scheme

Profile number	Infiltration rate (cm/hour)
1	3.6
2	7.2
3	4.8

Table 7: Hydraulic conductivity at different soil depths

Profile No.	Depth (cm)	K (cm/hour)
1	0-28	7.8
	28-53	12.4
	53-84	2.0
2	0-32	15.1
	32-48	7.7
	48-53	1.3
	90-103	6.1

The soils in the project area are dominantly Lixisols, Ferralsols and Cambisols which are generally well drained and highly porous, hence high water permeability. However, the values obtained for the area are relatively lower than the values for typical Lixisols and Ferralsols. This could be attributed to higher degree of compactness, surface sealing and crusting due to low organic matter content and high exchangeable sodium percentage. The differences in infiltration rates and hydraulic conductivity between the three soil profiles (Tables 6 and 7) indicate that each soil profile represents a soil unit with a different soil water regime, thus requiring different irrigation schedules. Ignoring these differences through uniform water application may lead to an inefficient irrigation practice.

The generally high infiltration rates and undulating topography favour the use of sprinkler irrigation method. However, low organic matter content and high ESP may cause low aggregate stability that make the soils susceptible to surface sealing and crusting. This problem may be exacerbated by the drops of water from the sprinklers, thus causing splash erosion hence negative environmental impacts in the long-run. Therefore, detailed analysis of soil aggregate stability against the impacts of forces with the magnitude comparable to that of sprinkler water drops is required for predicting the impacts of the irrigation development on environment. However, use of organic inputs from locally available resources is the most appropriate mitigation strategy.

1.5.2 Bulk density and water retention capacity of the soils

The total water retention capacity of the soils is expressed in volume basis as a product of bulk density and the difference between soil moisture content at pF 2.0 and pF 4.2 (Table 8). As a rule, the readily available soil water is taken as 50 % of the total available water for irrigation purposes. For the design of irrigation systems, the proportion of the total available soil water that can be depleted without causing the actual evapotranspiration (ETa) to become less than the maximum evapotranspiration (ETm) has to be defined to determine when soil water has to be replenished. This means that when soil water is replenished before it becomes less than this fraction, the irrigated crops will not experience moisture stress.

Table 8: Bulk density and soil moisture retention characteristics

Profile	Soil Depth (cm)	Bulk Density (g/cc)	% Soil moisture at pF 2.0	% Soil moisture at pF 4.2	Total soil moisture (mm)	Total water holding capacity (mm/m)	Available water holding capacity (mm/m)
1	0-28	1.35	36.6	21.1	43.5	185.6	92.8
	28-53	1.49	34.3	17.5	42.0		
	53-84	1.61	35.0	12.3	70.4		
2	0-32	1.50	43.5	12.1	100.8	328.4	164.2
	32-90	1.24	45.3	11.7	194.9		
	90-95	1.40	45.6	13.7	16.0		
3	0-25	1.30	30.0	13.7	40.8	98.6	49.3
	25-30	1.25	32.6	11.7	10.5		
	30-53	1.57	31.9	11.9	46.0		
	53-58	1.58	23.8	12.0	5.9		

Some crops, such as most vegetables, continually need relatively wet soils to maintain ETa=Etm. Others such as cotton and sorghum can deplete soil water further before ETa falls below ETm. According to FAO (1986), crops can be grouped according to the fraction (p) to which available soil water (Sa) can be depleted while maintaining ETa equal to ETm (Tables 9 and 10).

Table 9: Crop groups according to soil water depletion

Group	Crops
1	Onion, Pepper, potato
2	Banana, cabbage, cow pea, tomato
3	Alfalfa, bean, citrus, ground nut, pineapple, sunflower, water melon
4	Cotton, maize, safflower, sorghum, soybean, sugar cane

Table 10. Soil water depletion fraction (p) for crop groups and ETm

Crop group	ETm mm/day								
	2	3	4	5	6	7	8	9	10
1	0.50	0.425	0.350	0.300	0.250	0.225	0.200	0.200	0.175
2	0.675	0.575	0.475	0.400	0.350	0.325	0.275	0.250	0.225
3	0.80	0.700	0.600	0.500	0.450	0.425	0.375	0.350	0.300
4	0.875	0.800	0.700	0.600	0.550	0.500	0.450	0.425	0.400

1.5.3 Engineering properties of the soil

The engineering aspects of the soil examined were aggregate stability, consistence (Atterberg's limits) and particle density. The three Atterberg's limits (% water contents) are liquid limits (LL), plastic limit (PL) and Sticky limit (SL) as shown in Table 11.

Table 11: The engineering properties of the soil

Profile No.	Depth (cm)	Particle density (g/cm³)	Aggregate stability					Atterberg's limits		
			xi_1wi_1 Dia 2.0 mm	xi_2wi_2 Dia 1.0 mm	xi_3wi_3 Dia 0.5 mm	X_4iwi_4 Dia 0.25 mm	∑xiwi Dia 0.15 mm	LL	SL	PL
1	0-30	2.58	0.795	0.215	0.086	0.005	1.101	24.5	22.9	12.6
	30-60	2.98	1.145	0.195	0.0538	0.004	1.398	25.0	22.1	14.6
2	0-30	2.56	0.902	0.195	0.097	0.006	1.201	35.0	31.8	22.7
	30-60	2.60	0.731	0.223	0.090	0.004	1.049	37.3	32.7	22.4
3	0-30	2.24	0.558	0.250	0.089	0.005	0.902	27.0	21.5	17.3
	30-60	2.35	0.850	0.211	0.750	0.004	1.140	25.0	26.9	18.3

Generally, the aggregate stability index is high in soil profile no. 1 at the depth of 30-60 cm, followed by soil profile no. 2 at the depth of 0-30 cm. The lowest index is soil profile no. 3 at the depth of 0-30 cm. Very low index (0.004-0.006) in the sieve of the smallest diameter as compared to that of larger sieves could be an explanation of the existence of soil aggregates with very high resistance to disruptive forces. However, relatively high proportion of the aggregates in the largest sieve indicates poor size distribution due to poorly formed aggregates. The particle density of profile nos. 1 and 2, fall within the normal range for most soils, except for profile no.1 at the depth of 30-60 cm, where the value is rather high. Values for the profile number are too low. This could be explained by incomplete expulsion of air, creating more volume, thereby decreasing the density. The moisture content generally decreases from liquid limit through sticky to plastic limit. As the moisture content decreases, the ability of the soil to maintain its shape without rupture also decreases. The higher the moisture content at each limit, the better the workability of the soil.

1.6 LAND DEGRADATION AND MANAGEMENT

Land degradation is defined as the decline in the productive capacity of an ecosystem due to processes induced by human activities which lead to a significant reduction of the productive capacity of land. Human activities that contribute to land degradation include unsustainable agricultural land use, poor soil and water management practices, deforestation, removal of natural vegetation, frequent use of heavy machinery, overgrazing, improper crop rotation and poor irrigation practices. Natural disasters including drought, floods and landslides contribute to land degradation (UNEP/GEF, 2005).
Within the scheme, land degradation is caused by several processes including soil erosion, nutrient depletion and fertility decline, soil surface sealing and crusting and vegetation depletion.

1.6.1 Erosion susceptibility, sealing and crusting

Considering the increasingly serious threat of soil erosion to sustainable agricultural production, the evaluation of susceptibility or resistance to erosion was regarded of particular importance. Soil susceptibility to erosion was determined according to (Weeda, 1987) by evaluating climate, rainfall erosivity, topography (slope steepness and length), and soil erodibility. The soils of the uplands (dominant) indicate high susceptibility to erosion with the main contributing factor being high soil erodibility due to low organic matter content and high silt content relative to clay content in the surface horizons. The high susceptibility to erosion is reflected by the occurrence of strong splash and rill erosion on bare soils leading to decapitation of the topsoil thus exposing the compact and less fertile subsoil. The occurrence of gravelly or stony soil surface indicates selective removal of the fine soil particles by splash erosion from the topsoil leaving the coarse soil components.

Gully erosion occurs along cattle tracks and footpaths, sometimes exposing the underlying bedrock or weathering rock. The impact of erosion was indicated by exposed stones and gravel pedestals which reflected the amount of soil lost by the impacting raindrops. The pedestals measured 5-20 cm high thus indicating a past soil loss of 5.6-22.4 tonnes taking an area measuring 10 x 10 m, assuming 80 % bare surface and soil density of 1.4g/cm^3. This is quite a substantial amount of soil lost during previous rainfall events and therefore calls for concerted efforts in enhancing soil and water conservation measures in the control of the erosion processes and to halt further soil loss. The prescence of pedestals shows that once vegetation cover is removed the soils of the KIAMIS may be very prone to erosion and can be eroded very fast thus exposing the underlying bedrock. Once erosion has been triggered, slope steepness and length determine the rate at which it proceeds. Therefore, it is recommended that improved soil cover and in addition soil and water conservation practices should be enhanced in areas earmarked for cultivation. Also, overstocking should be checked to avoid overgrazing.

To reduce erosion on the steep slopes, physical soil conservation measures should be put in place. These include bench, fanya juu and stone terraces. In addition, the terraces would also require stabilizion by planting grasses that would also provide fodder for livestock and preferably N-fixing trees or shrubs that would help in fixing nitrogen. Further it was noted that indigenous trees, stone and boulders are very effective in stabilizing terraces. Adoption of agro-forestry practices particularly the inclusion of N-fixing trees and shrubs, adaptable to the environment should be enhanced.

The soils indicate moderate to high susceptibility to surface sealing and crusting. This is indicated by the occurrence of moderately strong to strong 1-5 mm thick surface crusts on bare soils. Sealing and crusting hinders water from infiltrating into the soil thus generating runoff leading to strong splash, rill and gully erosion noted on bare compacted soils. In addition, the crusts hinder seedling emergence thus causing non-uniform seedling emergence which affects yields. As surface sealing and crusting is due to unstable topsoil aggregates as a result of low organic matter content in the topsoil, there is need to incorporate farmyard manure in the soils to improve the structural stability of the topsoils. This results in improving the water holding capacity of the soils and supply of soil nutrients upon decomposition. The valleys (unit VXg) indicate moderate susceptibility to erosion. The soils in addition are susceptible to sealing and crusting and hence the need to maintain soil cover to protect the topsoil against raindrop impacts. As the valleys occur on lower parts of the incised hills, the protection of the soils against erosion is very much dependent on the type of land use and conservation measures adopted in the valleys and the adjacent upper lying hills and footslopes.

1.6.2 Erosion hazard

Erosion hazard is a measure of the degree of soil erosion that is likely to occur in the near future. When erosion is already clearly evident, the erosion hazard expresses the intensity of the erosion process or the degree of soil loss which is expected from a specific form of land use, management and conservation practices. It combines the effects of the influence of the more permanent factors such as climate, relief/topography and soil, and the alterable factors of land use management and conservation practices. Similarly, 'actual erosion risk' is referred to as the risk of erosion under current land use and vegetation conditions and is determined by adjusting the potential soil erosion risk which is the inherent susceptibility to erosion, to take account of the protection afforded by the present land cover. In arriving at the erosion hazard classes given in Table 12, consideration was given to the erosion susceptibility classes , visible erosion features, land use, type of vegetation, presence of surface gravels, stones, rocks and boulders, type of conservation measure(s) i.e. physical, biological/agronomic or cultural and their state and effectiveness.

Table 12: Erosion susceptibility and Erosion hazard in the project area

Mapping Unit	Erosion Susceptibility	Vegetation/land use/conservation measures/ management	Erosion Hazard
FQP	High	Grazing; cultivation of annuals	Moderate to Severe
UXr	High	Cultivation of annuals; unmaintained or lack of terraces conservation measures; grazing; bushland	Severe
UQr	High	Grazing; growing annuals; lack of or unmaintained terraces/conservation measdures; bushland	Moderate to Severe
UUp	High	Grazing; growing annuals; bushland; lack of or unmaintained terraces/conservation measures	Moderate to Severe
VXb	Low –Moderate	Cultivation of sugarcanes, vegetables, bananas, arrow roots, sweet potatoes	Slight

The scheme indicates severe erosion hazard due to the occurrence of strong splash, rills, plants, stones and gravel pedestals. The conservation measures adopted such as terraces were not stabilized with vegetation, lacked maintenance and most of them were neglected and not properly spaced thus rendering them ineffective in soil erosion control. All these factors were found to cause overflow of collected runoff leading to breaking of the terrace banks. Other causal factors include up-slope tillage, non-application of organic and inorganic fertilizers and cultivation of annuals crops (in some cases as monocrops). However, a combination of physical, agronomic and cultural soil conservation measures need to be enhanced as the soils have high susceptibility and severe hazard to erosion. There is need for increased combinations of soil conservation measures such as properly spaced and stabilized terraces (bench, fanya juu and stone); strip cropping with good cover crops such as fodder crops, sweet potatoes and intercropping. Other measures include agro-forestry; mulching and use of farm yard manure or compost. The valleys (unit VXb) indicate slight erosion hazard.

1.6.3 Soil fertility decline

Soil fertility may be defined as the ability of the soil to provide enough water, oxygen and nutrients for crop growth. The main factors contributing to soil fertility are organic matter content, availability of major and micro-nutrients, soil reaction and physical characteristics (texture, structure, depth and nature of the profile). The soils of the scheme show low organic carbon and hence low organic matter content. The low organic matter content in the soil is due to non-application of manures. Therefore, the maintenance or improvement of soil fertility should be an integral part of farm management for both cash and subsistence cropping. In the scheme, continous cultivation results in nutrient mining through harvested crops resulting in a decline in yields. The situation is bound to worsen with time 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. Table 13 shows analytical results of the nutrient levels of the soil samples collected from the scheme.

Table 13: Available nutrients (0-20 cm depth) in the soils of the project area

Parameter	Footslopes (Unit FQr)	Uplands (unit UQr)	Uplands (unit UUP)	Uplands (unit UXr)	Valleys (unit VXp)
pH-H2O	4.7	7.0	6.0	4.7	6.6
Hp	0.5	-	-	0.4	-
C (%)	0.4	0.72	0.63	0.06	0.85
N (%)	0.04	0.05	0.04	0.57	0.08
Na (me%)	-	0.06	0.08	0.16	0.20
K ,,	0.8	0.63	0.51	0.61	0.85
Ca ,,	2.6	1.6	1.6	2.2	3.0
Mg ,,	2.1	2.28	1.27	2.92	3.83
Mn ,,	0.2	0.53	0.43	0.72	1.21
P (ppm)	11	162	12	11	20
Fe	-	63.7	28.3	34.5	51.7
Cu	-	1.25	1.14	0.66	1.87
Zn	-	2.63	1.63	1.15	3.06
EC	-	0.27	-	-	

The footslopes occur on the western part of the scheme and comprise of the soil unit FQr where the soils are strongly acid with a pH of 4.7 (see appendix 3). The soils show low levels of nitrogen (N), organic matter (OM) as reflected by percent organic carbon (OC) and phosphorus (P). The uplands are comprised of soil units UQr, UUp and UXr. The soils of mapping unit UQr are slightly alkaline with a pH of 7.1. and are deficient in N and Ca, and low in OM. The soils of mapping unit UUP are moderately acidic with a pH of 6.0 and they show a deficiency of N, P, K and Ca and low OM. The soils of unit UXr are strongly acidic with a pH of 4.7 and show deficiency in N and P. They are also low in OM. The soils of the valleys (unit VXp) are slightly acid with a pH of 6.6) and indicate N and P deficiency. Organic organic matter is low.

Generally, nitrogen, phosphorus and potassium are deficient in the soils of the scheme while organic matter is low. In the management of soil fertility in the area, use of well decomposed farm yard manure or compost is recommended which will improve the topsoil structural stability thereby reducing runoff and erosion. It also improves the nutrients and water holding capacity of the soils. Organic matter enhances the activity of soil fauna thus improving soil physical aspects such as aeration, moisture content and nutrients holding and exchange capacity of the soils.

The pH of the soils ranges from 4.7 to 6.2 while the optimal performance of most crops ranges between 6.0 and7.0. Therefore, compound N, P and K fertilizers should be applied in which CAN should be applied as a top-dress to supply both Ca and N where they are deficient. The soils show low CEC which indicate that the soils have undergone high degree of weathering while the base saturations are indicative of a non-leaching environment. Therefore, the management of nutrients and organic matter is important in the productivity of the soils of the project area.

1.6.4 Salinisation and sodification

Salinisation in the scheme is not serious but there are indications that the process is taking place as indicated by higher EC of the topsoils than the underlying horizons as indicated in profile nos. 2 and 3 (Table 14 and appendix 3). This indicates accumulation of salts in the topsoil by cappilarity. Similarly, higher ESP in the topsoil than underlying horizons is a good indication of the sodification process as shown in profile nos. 1, 2 and 3. High ESP in profile no. 4 relative to the other profiles indicates that sodification process is taking place.

Table 14: EC and ESP of topsoils and underlying horizons

Parameter	Horizon	Profile 1	Profile 2	Profile 3	Profile 4
ECe	Topsoil	0.42	0.39	0.39	0.36
	Subsoil	0.66	0.12	0.33	0.51
ESP	Topsoil	6	5	5	8
	Subsoil	3	2	4	13

Since the quality of the underground water is not known, application of the irrigation water should be done with caution avoiding over-irrigating the soils. This is very important in controlling a rise in groundwater level.

1.6.5 Soil Compaction

Soil compaction is mainly caused by trampling of livestock while grazing and browsing, especially in overgrazed areas. The impact of trampling on the soils is shown by higher bulk densities than the underlying soil horizons. This reduces infiltration rate of rainfall hence faster generation of runoff resulting in erosion. Compaction increases topsoil bulk density thus causing a decrease in infiltration rate (Infil Rate), saturated hydraulic conductivity (Ksat) and moisture content of the soil. The management of compaction would require keeping the right number of livestock per unit area. Also in cultivated areas, it is important to do deep ploughing to loosen the soils. Use of farmyard manure to maintain good topsoil structure is important in the management of compaction. Also, when planting deep rooted crops, it is important to dig deep planting holes which will not only loosen the soils but also increase the water holding capacity of the soils. Loosening the topsoil improves the infiltration of water thereby reducing runoff and improving the moisture held by the soil.

1.6.6 Sedimentation/siltation

Alluvial deposition along River Thuci indicates sedimentation and siltation processes taking place along the river and the streams. The high susceptibility of the soils to erosion indicates the need for taking seriously the management practices mentioned in Chapter 1.5.2 and 1.5.3. Further, there is need to control stream bank erosion by maintaining a protective vegetation cover along the stream.

1.6.7 Vegetation depletion

In the scheme, degradation of forests and vegetation is attributed to cutting of trees, overgrazing and clearing for cultivation. With the fast growing population, a change and intensification of the land-use system is expected, with an increased pressure in clear vegetation. The woodlands and bushlands have been cleared for cultivation, building purposes, furniture, fencing and production of charcoal. The water balance studies show that the forest zone is the largest contributor to river/stream flow and groundwater recharge through infiltration. Farmers are intensively using the land for cultivation, grazing and browsing without taking the necessary management measures. Indications of biological degradation are reflected by the distribution of organic carbon and observed clearing/cutting of forests and woody species in the different landform units. Soil organic matter, temperature and moisture determine the type and population of microbial organisms. Though the determination of micro-organisms was not done, the factors mentioned above within the different land uses and management practices are reflective of the possible microbial variations within the project area.

1.7 POTENTIAL IMPACTS

The proposed strategies on optimization of supplied irrigation water for soil and water conservation, soil fertility improvement by use of FYM or compost, application of inorganic fertilizers, timely planting, weeding, contour ploughing/tillage, crop rotation, use of certified seeds will ultimately result in higher productivity of rainfed and irrigated agriculture thus increasing crop yields per unit area and livestock products especially milk and manure. The resultant impact would be food self sufficiency (security) and income generation/wealth creation at household level. However, use of inorganic fertilizers and pesticides should be used carefully to avoid pollution of the surface and underground water.

Increased soil water storage capacity would result in long duration groundwater recharge thus making the streams in the area to have more flowing water for longer periods. Growing of high value horticultural crops such as tomatoes, egg plants/brinjals, onions, karela, okra, french beans, soy beans, dudhi, citrus and avocadoes would create alternative sources of income with more people venturing into this investment thus creating more job opportunities resulting thus reducing idleness, dependency, consumption of illicit brews, drugs and crimes etc. Wealth creation and food security would result in improved livelihoods and access to medical and education facilities.

Effective physical, agronomic and cultural soil and water conservation measures would lead to reduced run-off and hence more clean stream/river water due to reduced siltation/sedimentation. Increased infiltration and more soil water storage capacity would lead to reduced flooding hazard in the lower parts of River Thuci. In addition, incorporation of agro-forestry in the farming systems, and increased planting of woodlots would create more carbon sinks because plants use carbon dioxide and release oxygen in their metabolism leading to a healthy environment. Good soil and efficient water management practices would result in an enhanced conservation of biodiversity, filtering and buffering capacity of the soil resource resulting in more clean and safe water downstream.

1.8 CONCLUSIONS AND RECOMMENDATIONS

Population pressure increases the demand, competition and over exploitation of the available natural resources leading to accelerated land degradation. There is therefore the need to take the necessary measures to control the degradation processes in the KIAMIS. Such measures would include:

1. Leaving the hilly areas to the west of the scheme under vegetation cover (particularly indigenous species) and planting a strip of vegetation adjacent to the stream channels to check stream bank erosion. Selective vegetation clearing especially of trees and shrubs should be adopted, when opening new areas for cultivation to avoid leaving soil surface bare and therefore more prone to erosion. Agro-forestry practices should be incorporated into the farming systems of the area, more so with N-fixing legumes since the soils are deficient in nutrient N.
2. A combination of physical, agronomic and cultural methods of soil conservation is necessary. The physical methods suitable in the undulating to rolling terrain consisting mainly uplands, include construction of well spaced, stabilized, maintained and effective bench, fanya juu and stone terraces. Agronomic measures would include strip cropping with crop and pasture/forage vegetation combinations, timely planting, planting adapted cultivars and intercropping. Cultural practices would include contour farming (planting, tilling/ploughing) and crop rotation.

3. The soils show low levels of organic matter and hence the need to apply farm yard manure or compost. Application of manure will improve the structural stability of the topsoil, water/moisture and nutrients holding capacity in addition to enhancing soil fauna activity.
4. N, P and K are deficient and need to be improved in the soils by applying the right NPK containing fertilizers. Differences in the parent materials within the scheme indicate that application should be farm specific but as a guide acidifying fertilizers such as DAP should be applied where soils show a pH >7.0 and non-acidifying fertilizers such as the N:P:K 17:17:17 or 23:23:0 for soils with a pH <6.0. CAN need to be applied to supply calcium and N if they are deficient.
5. The use of agro-chemicals to control crop pests and diseases is bound to pollute surface and underground water. Therefore application of the right type and quantity is important.
6. Roof and rock catchments should be used for harvesting the scarce water resource from rainfall.
7. There is need to introduce irrigated high value horticultural crops in the KIAMIS area. Such crops would include soy beans, french beans, okra, brinjals, karela, dudhi, onions, bananas, avocadoes and citrus. The growing of such crops requires deep ploughing to loosen the compact, crusted and sealed topsoil. 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 weathering parent rock thus increasing rootable soil depth which in some cases is limited due to the process of erosion.
8. Population and livestock pressure, when considered in the light of land tenure are the driving forces of land degradation. Therefore there is need to sensitize the local community on the benefits of keeping few but beneficial livestock and investing in soil and water conservation opportunities.
9. Though water from River Thuci is suitable for growing irrigated subsistence and high value horticultural crops, the amount of water applied within a specified duration of time is important to avoid triggering degradative processes emanating from mismanagemet of irrigation water such as salinization, sodification, water pollution and erosion, processes which are very costly to reverse
10. Monitoring soil fertility, ESP and EC levels is important in order to take the necessary remedial measures at the appropriate time. This should be done preferably after every 2-3 years.

REFERENCES

Braun, H.M.H. 1984. Evaporation in Kenya. Miscellaneous Paper, Kenya Soil Survey, Nairobi.

FAO, 1977. Guidelines for Soil Profile Description, Rome.

FAO, 1986. Guidelines: Land evaluation for rainfed agriculture. FAO Soils Bull, 52, FAO, Rome.

FAO-UNESCO, 1997. Soil Map of the World. Revised Legend with corrections and updates. Technical Paper 20, ISRIC, Wageningen.

Gachathi, F. N. 1989. Kikuyu Botanical Dictionary. Publication supported by gtz and printed by AMREF, Printing Dept., Nairobi.

Government of Kenya, 1999. Population Census, Central Bureau of Statistics, Ministry of National Development, Nairobi.

Hinga, G., Muchena, F.N. and Njihia, C.M. 1980. Physical and Chemical Methods of Soil Analysis. National Agric. Res. Labs, Nairobi.

Jaetzold, and Schmidt, 1983. Farm Management Handbook of Kenya, Vol.II/C East Kenya, Ministry of Agriculture, Nairobi.

Kenya Soil Survey Staff, 1987. Manual for soil survey and land evaluation. Vol. 1. Miscellaneous paper no. M24, Kenya Soil Survey, Nairobi.

Munsell Color Charts, 1975. Munsell soil color charts, Munsell Color Co., Baltimore, Maryland.

Richards, L. A. (ed). 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook No.60, Washington DC.

Sombroek, W.G., Braun, H.M.H. and Van Der Pouw, B.J.A. 1982. Exploratory Soil Map and Agro-Climatic Zone Map of Kenya. Exploratory Soil Survey Report No.E1, Kenya Soil Survey, Nairobi.

UNEP/GEF, 2005. Protecting the Environment from Land Degradation. UNEP's Action in the Framework of the Global Environment Facility.
Woodhead, T. 1968. Potential evaporation in Kenya, E.A.A.F.R.O., Nairobi.

APPENDIX 1 - PROFILE DESCRIPTION AND ANALYTICAL DATA

Profile Description No. 1

General site information

Soil map unit code	:UQr
Sheet observation no.	:122/4-1
Location/elevation	:037˚ 47.031'E and 00˚ 27.478'S; 878 m asl
Soil parent material	:granitoid gneisses
Landform	:uplands
Relief/slopes	:flat to gently undulating; slopes 0 - 4%
Land use	:livestock grazing and browsing; cultivation of maize, pigeon peas and millet
Erosion type	: strong splash and rill erosion on bare soil leaving quartzitic stones and gravels on the surface
Surface sealing and crusting	: moderate to strong, 1 -5 mm
Internal drainage	: well drained
Effective soil depth	: > 120 cm
Soil classification	: Ferric Lixisols

Profile description

Horizon Depth

Ap 0 – 28 cm dark red (2.5 YR3/6, moist);clay; weak, fine to medium, subangular blocky structure; slightly hard to hard when dry, friable when moist, sticky and plastic when wet; many biopores, many fine pores; many very fine and common fine roots; clear and smooth transition to:

Bt 28 – 53 cm dark red (2.5 YR3/6, moist); clay; weak, medium, subangular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; many biopores; muscovite micas; common very fine roots; gradual and smooth transition to:

Bu 53 – 84 cm dark red (2.5YR3/6, moist); gravelly clay; weak, medium, subangular blocky structure; slightly hard when dry, friable when moist, sticky and slightly plastic when wet; few very fine pores; muscovite micas; few very fine and fine roots; clear and irregular transition to:

BC 84 – 124+ cm red (10R4/8, moist); gravelly clay; porous massive; friable when moist, slightly sticky and plastic when wet; few very fine pores; many muscovite micas; very few very fine and fine roots.

Laboratory data for profile description no. 1

Horizon designation	Ap	Bt	Bu	BC
Horizon depth (cm)	0 – 28	28 – 53	53 – 84	84 – 124
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)	18.75	23.16	25.25	127.3
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
Exchangeable sodium percent (ESP)	6	3	3	2
Texture – hydrometer				
Sand %	60	48	54	54
Silt %	8	14	14	16
Clay %	32	38	32	30
Texture class	SCL	SCL	SCL	SCL
Silt:clay ratio	0.25	0.4	0.4	0.5

Profile Description No. 2

General site information

Soil map unit code : UUp
Sheet observation no. : 122/4- 3
Location/elevation : 037˚ 47.339’E and 00˚ 28.306’S; 848 m asl
Soil parent material : undifferentiated banded gneisses
Landform : uplands
Relief/slopes : very gently undulating to undulating; slopes 1 – 6%
Land use : grazing with indications of overgrazing
Erosion : strong rill and gully erosion; 10 – 30 cm high plants pedestals
Surface sealing and crusting : moderate, 1 – 10 mm thick surface crusts
Internal drainage : well drained
Effective soil depth : >105 cm
Soil classification : Ferric Acrisol

Profile description
Horizon Depth

A 0-30 cm dark red (2.5YR3/6, moist); clay; weak, fine to medium, subangular blocky structure; slightly hard to 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 30-68 cm dark red (2.5YR3/6, moist); clay; weak, medium, subangular blocky structure; 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:

Bt2 68-105+ cm dark red (2.5YR3/6, 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. 2

Horizon designation	A	Bu1	Bu2
Horizon depth (cm)	0 – 30	30 – 68	68 – 105
pH-H2O (1:2.5)	6.4	5.9	6.1
EC dS/m ,,	0.13	0.06	0.04
ECe dS/m ,,	0.39	0.18	0.12
C (%)	1.07	0.44	0.47
CEC-soil (cmol/kg)	13.60	14.4	17.2
CEC-clay (cmol/kg)	18.6	21.8	28.4
Exchangeable Calcium ,,	5.98	3.82	4.58
Magnesium ,,	2.03	2.26	2.16
Potassium ,,	0.56	0.145	0.20
Sodium ,,	0.65	0.30	0.35
Sum of cations	9.22	6.52	7.29
Base saturation (%)	68	45	42
Exchangeable sodium percent (ESP)	5	2	2
Sand %	46	36	38
Silt %	4	6	8
Clay %	50	58	54
Texture class	C	C	C
Silt:clay ratio	0.08	0.10	0.15

Profile Description No.3
General site information

Soil map unit code	: UUp
Sheet observation no.	: 122/4- 4
Location/elevation	: 037˚ 47.339’E and 00˚ 28.306’S; 848 m asl
Soil parent material	: various undifferentiated rocks (gneisses and pyroclastics)
Landform	: uplands
Relief/slopes	: very gently undulating to gently undulating; slopes 1 – 4%
Land use	: grazing/browsing of livestock; cultivation of maize, pigeon peas and bananas
Erosion type	: strong splash, rill and gully erosion
Surface sealing/crusting	: weak to moderate, 1 – 10 mm surface crusts
Internal drainage	: well drained
Effective soil depth	:> 120 cm
Soil classification	:Ferralic Cambisol

Profile description
Horizon Depth

A 0 – 30 cm dark reddish brown (2.5YR3/4, moist); very gravelly sandy clay; weak, fine, subangular blocky structure; slightly hard when dry, friable when moist, sticky and slightly plastic when wet; many, very fine, common, fine pores; muscovite micas; common, very fine and fine, roots; clear and smooth transition to:

Bw 30 – 63 cm dark red (2.5YR 3/6, moist); sandy clay; weak, fine to medium, subangular blocky structure; hard when dry, friable when moist, sticky and slightly plastic when wet; many fine pores; very few very fine and few medium fine roots; abrupt and smooth transition to:

C 63+ cm Weathering gneisses

Laboratory data for profile description no. 3

Horizon designation	A	Bw
Horizon depth (cm)	0 – 30	30 – 63
pH-H2O (1:2.5)	6.4	6.8
EC dS/m ,,	0.13	0.10
ECe dS/m ,,	0.39	0.33
C (%)	1.1	0.83
CEC-soil (cmol/kg)	13.6	10.6
CEC-clay (cmol/kg)	18.6	20.2
Exchangeable Calcium ,,	6.0	5.68
Magnesium ,,	2.0	1.87
Potassium ,,	0.56	0.42
Sodium ,,	0.65	0.45
Sum of cations	9.21	8.42
Base saturation (%)	68	79
Exchangeable sodium percent (ESP)	5	4
Sand %	46	52
Silt %	4	12
Clay %	50	36
Texture class	SC	SC
Silt:clay ratio	0.08	0.3

Profile Description No. 4
General site information

Soil map unit code	:UXr
Sheet observation no.	: 122/4- 2
Location/elevation	: 037˚ 46.787’E and 00˚ 27.622’S; 859 m asl
Soil parent material	: various undifferentiated rocks (gneisses and pyroclastics)
Landform	: uplands
Relief/slopes	: very gently undulating to gently undulating; slopes 1 – 4%
Land use	: grazing and browsing of livestock; cultivation of maize, pigeon peas and bananas
Erosion type	: strong splash, rill and gully erosion
Surface sealing and crusting	: weak to moderate, 1 – 10 mm surface crusts
Internal drainage	: well drained
Effective soil depth	:> 120 cm
Soil classification	: Ferralic Cambisol, sodic phase

Profile description
Horizon Depth

A 0-30 cm dark red (2.5YR3/6, moist); silty clay; weak, fine to medium, subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; many, very fine, common, fine pores; muscovite micas; few, very fine and very few, medium roots; clear and smooth transition to:

Bu1 30-58 cm red (2.5YR4/8, moist); silty clay; weak, medium, subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; many fine pores; very few very fine and fine roots; gradual and smooth transition to:

Bu2 58-100 cm red (2.5YR4/8, moist); clay; weak, medium, subangular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; many, very fine and fine pore; moderate, broken clay cutans; muscovite micas; very few, very fine roots; gradual and smooth transition to:

Bcs 100-130 cm yellowish red (5YR4/8, moist); clay; moderate, fine to medium, angular blocky and moderate, medium, subangular blocky structure; slightly hard to hard when dry, friable to firm when moist, sticky and plastic when wet; few, very fine and fine pores; moderate, broken clay cutans; very few, very fine and fine roots; abrupt and wavy transition to:

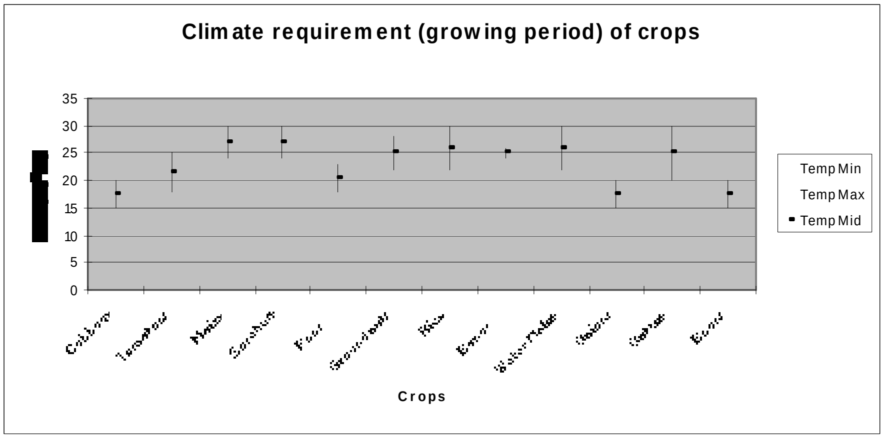
Ccsk 130-150+ cm yellowish red (5YR4/6, moist); gravelly clay; porous massive; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many very fine pores; 60% iron and manganese concretions, 1-5 cm; very few very fine root.

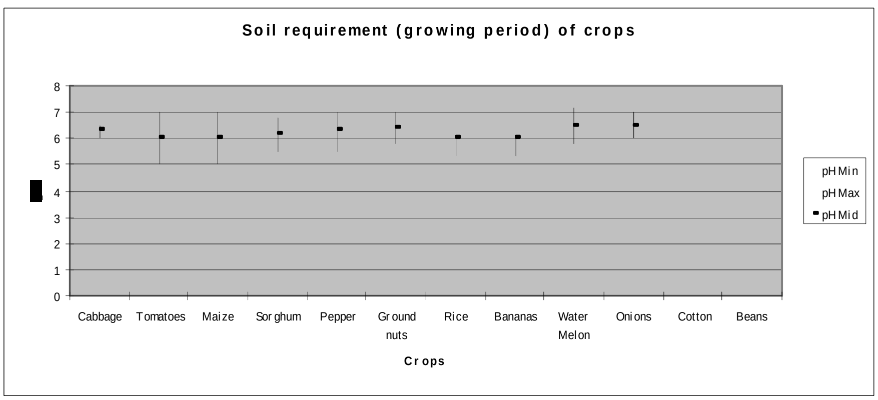
Laboratory data for profile description no. 4

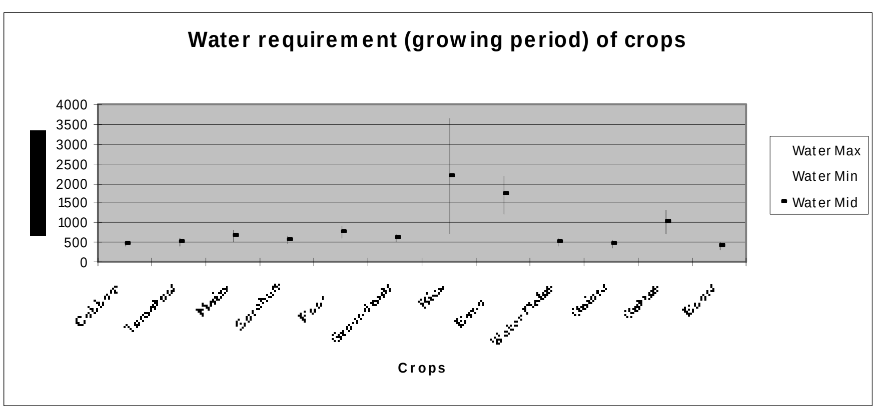
Horizon designation	A	Bu1	Bu2	Bcs
Horizon depth (cm)	0 – 30	30 – 58	58 – 100	100 - 130
pH-H2O (1:2.5)	5.0	5.1	5.2	6.4
EC dS/m ,,	0.12	0.17	0.18	0.23
ECe dS/m ,,	0.36	0.51	0.54	0.69
C (%)	0.75	0.60	0.58	0.55
CEC-soil (cmol/kg)	13.13	6.50	7.96	11.60
CEC-clay (cmol/kg)	15.8	6.4	8.8	16.7
Exchangeable Calcium ,,	3.68	2.52	4.14	3.97
Magnesium ,,	2.27	1.91	2.17	1.51
Potassium ,,	0.92	0.50	0.44	0.36
Sodium ,,	1.05	0.85	1.20	1.15
Sum of cations	7.92	5.78	7.95	6.99
Base saturation (%)	60	89	100	60
Exchangeable sodium percent (ESP)	8	13	15	10
Texture – hydrometer				
Sand %	22	16	16	22
Silt %	12	14	14	24
Clay %	66	70	70	56
Texture class	C	C	C	C
Silt:clay ratio	0.2	0.2	0.2	0.4

APPENDIX 2

Climatic, soil and water requirements (for a growing period) of the envisaged crops







APPENDIX 3. CLASSIFICATION OF SOME SOIL PROPERTIES

Soil reaction (pH) classification

pH	Class name
<4.5	Extremely acid
4.5 – 5.0	Very strongly acid
5.1 – 5.5	Strongly acid
5.6 – 6.0	Medium acid
6.1 – 6.5	Slightly acid
6.6 – 7.3	Neutral
7.4 – 7.8	Mildly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9.0	Strongly alkaline
>9.0	Very strongly alkaline

Classification of EC

EC2.5 (dS/m)	Derived ECe (dS/m)	Class name
0 – 1.2	0 – 4	Non saline
1.2 – 2.5	4 – 8	Slightly saline
2.5 – 5.0	8 – 15	Moderately saline
5.0 – 10.0	15 – 30	Strongly saline
>10.0	>30	Excessively saline

Classification of ESP

ESP	Class name
0 – 6	Non sodic
6 – 10	Slightly sodic
10 – 15	Moderately sodic
15 – 40	Strongly sodic
>40	Excessively sodic

Classification of % C, CEC and % BS

Class name	%C	CEC-soil (cmol/kg)	BS%	Silt/clay
Very low	<4.0	<5	<10	<0.2
Low	0.5 – 0.9	5 – 15	10 – 29	0.20 – 0.59
Medium	1.0 – 1.9	15 – 25	30 – 49	0.60 – 1.00
High	2.0 – 5.0	25 – 40	50 – 79	>1.00
Very high	>5.0	>40	>80	

Kenya Agricultural Research Institute

National Agricultural Research Laboratories

Kenya Soil Survey

SUSTAINABLE LAND MANAGEMENT IN KIARUKUNGU SMALLHOLDER IRRIGATION SCHEME, KIRINYAGA DISTRICT

BY

S. N. WANJOGU, E. M. MUYA, P. N. MACHARIA AND P. T. KAMONI

KENYA SOIL SURVEY ADVISORY SITE EVALUATION REPORT NO. P 122

DECEMBER, 2006

2.1 INTRODUCTION

Kiarukungu Irrigation Scheme (KIARIS) is a community based initiative which focuses on economic empowerment of its members through the utilization of natural land resources especially soils and water. The proposed source of irrigation water for the scheme is River Thiba and the water from this source is suitable for irrigation. The local community depends on water from this river for livestock, domestic needs and some irrigated agriculture. However, inappropriate utilization and mismanagement of the land resources has led to land degradation in the form of soil erosion, surface sealing and crusting and soil fertility decline leading to decline in crop yields.

The scheme was initiated in 1996 with the main objective being to improve household income through sustainable utilization of natural resources, mainly spring/stream water and soils in the scheme through irrigated agriculture. This would in addition enhance food security, wealth creation and a healthy environment. However, the project did not pick up well due to limited capacity on project development and management, inadequate community participation, lack of technical support and know-how, and inadequate resources among others. Consequently, the project stalled and was revived in 2003.
The need to implement appropriate natural resource management and conservation strategies is crucial in enhancing food security and economic development in the area. Land use planning in the scheme is essential for identification of the changes required in land use practices which will increase productivity and opportunities, making decisions on where the changes should be and to avoid misuse of the land resources.

The objective of the soil survey was to provide information on soils and other natural resources to facilitate the development of sustainable community based irrigated agriculture.

2.2 THE ENVIRONMENT

2.2.1 Location, Communication and Population

The scheme is situated in Kiarukungu Location, Mwea Division, Kirinyaga District. It is situated between latitudes 00˚ 45‘and 00˚ 50‘south, and longitudes 37˚ 45‘and 37˚ 50‘east, at an altitude of between 820-920 m above sea level (asl). It covers an area of about 300 ha in extent. The area is accessible through the Nairobi-Embu tarmack road while other motorable roads pass through the scheme and join the tarmack road. Accessibility is excellent in the project area. Most of the people here originated from Eastern and other areas in Central Provinces and comprises the Embu, Mbeere, Kikuyu and Akamba people. The people engage in farming, livestock rearing and carrying out businesses. Table 1 below shows the population of Mwea Division as per the population census of 1999 and the projected population to the year 2020.

Table 1: Present and projected population of Mwea Division (1999 – 2020)

Year	1999	2000	2005	2010	2015	2020
Population	125,962	129,741	150,405	174,361	202,132	234,326
Population density(persons/km²)	246	253	293	340	394	457

Source: GoK, 1999

High concentration of the population is mainly in the high potential soils for agriculture purposes. High population densities in the area are also expected in up-coming market centers such as Ngurubani and Kimbimbi which are within or adjacent to the scheme business purposes and increase in public institutions such as schools, dispensaries and KARI-Mwea Regional Research Center. According to the above projections, the division population density of 246 persons/km² in 1999 is poised to almost double to 457 persons/km² in 2020. The population statistics indicate a building population pressure which will lead to increasing demand of the available natural resources thus culminating to land and environmental degradation, if necessary measures are not put in place.

2.2.2 Climate

2.2.2.1 Rainfall, agro-climatic zonation, temperatures and evaporation

The agricultural potential of an area is mainly determined by the prevailing climatic conditions especially rainfall, evaporation and temperature. Rainfall in the area is bimodal with long rains occurring between March and May and short rains from October to December. The scheme occurs in agro-climatic zones (ACZ) III and IV which have mean annual evaporation to mean annual rainfall ratio of 0.5-0.65 and 0.4-0.5, respectively (Sombroek et al., 1982). ACZ III and IV are considered to be semi-humid and semi-humid to semi-arid with mean annual rainfall of 800-1400 mm and 600-1100 mm, and mean annual evaporation of 1450-2200 mm and 1550-2200 mm, respectively. The mean annual temperatures for the area are in the range 22˚C – 24˚C, considered to be warm. The area has therefore high to medium potential for plant growth.

2.2.2.2 Evapotranspiration and Moisture balance

The potential evapotranspiration (Et), i.e. crop water requirement is related to altitude with the low altitude areas having higher evapotranspiration than higher altitude areas. The mean annual potential evaporation (Eo) based on Wood head (1968) altitude equation at an altitude of 1250 m asl is 1980 mm. Potential evapotranspiration is assumed to be 2/3 Eo and is therefore 1320 mm in in the scheme. Rainfall data used is for Mwea Tebere meteorological station with 16 years record. Mean monthly Eo values have been calculated according to Braun (1984).

Table 2: Water balance for the project area.

Parameter	**Month**												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Yr**
Rainfall (r)	41	34	64	218	139	21	28	11	17	86	189	45	993
Evapo (Eo)	218	198	198	158	139	119	99	119	178	198	158	198	1980
Evapotr(Et)	146	133	133	106	93	80	66	80	119	133	106	133	1320
r-Et	-105	-99	-69	112	46	-59	-38	-69	-102	-47	83	-88	-327

From Table 2, the water balance (r – Et) for the area shows that the mean monthly and annual rainfall exceed evapotranspiration demand in the months of April, May and November. The periods January-March and June-October and the month of December experience moisture deficits thereby requiring irrigation. Irrigation technologies that use little water with minimal loses should be considered within the prevailing socio-economic set up.

2.2.3 Physiography and geology/parent materials

The area covered by the scheme is predominantly comprised of plains and associated uplands. The plains are flat to very gently undulating with slopes of 0-2 % while the uplands are very gently undulating to gently undulating with slopes of 2-5 % which are very gently undulating to rolling with slopes of between 1 and 10 %. The plains form the major part of the scheme.

2.2.4 Drainage, salinization and sodification

The general drainage pattern in the area is from North to South with River Thiba being the main permanent river and partly forms the eastern boundary of the scheme. The river has its source of water from the slopes of Mt Kenya. The river provides water for some ongoing smallholder irrigation within the scheme whereby, individual farmers pump the river water to their farms for irrigation. The river water is also used for livestock and domestic use. Table 3 shows analytical results of a water sample taken from the proposed intake and the allowable limits for parameters mostly used to classify water quality hazards according to Richards (1954). They include pH, electrical conductivity (EC) which indicates total dissolved salts, residue sodium carbonate (RSC) indicating carbonate and bicarbonate concentration hence alkalinization hazard of the water, and the sodium adsorption ratio (SAR) which indicates sodicity hazard.

The results of the water sample from the proposed intake on River Thiba indicate that the water is suitable for irrigation and can be used without causing salinization and sodification of the soils. However, a water sample taken from a shallow well indicates high salinity, very high sodicity and high content of bicarbonates and is not suitable for irrigation. This indicates that though the surface water from the river is suitable for irrigation, the underground water is not suitable for irrigation thus emphasizing the need to maintain good drainage to allow adequate leaching of salts.

Table 3: Irrigation water quality classification from River Thiba intake and well

Parameter	**Water source**		**Suitability class**		
	Intake	**Well**	**Safe**	**Marginal**	**Unsuitable**
pH	6.7	8.9	6.0 – 8.0	≤6.0 – >8.0	<6.0 & > 8.0
EC (dS/m)	0.15	1.70	0.0 – 0.75	0.25 – 0.75	>0.75
Sodium (me/l)	0.87	17.4			
Potassium (me/l)	0.03	0.03			
Calcium ,,	0.11	0.08			
Magnesium ,,	0.51	0.39			
Carbonates ,,	Trace	2.09	0.0 – 1.25	1.25 – 2.5	>2.5
Bicarbonates ,,	2.06	12.1	0.0 – 1.25	1.25 – 2.5	>2.5
Chlorides ,,	0.63	2.63			
Sulphates ,,	1.48	10.4			
SAR	1.56	35.7	0 – 13	7 – 13	>13
RSC	0.44	13.72	0.0 – 1.25	1.25 – 2.5	>2.5

The results further indicate that the salinity and sodicity of the groundwater is from the weathering of the basic parent materials and hence naturally occurring. Therefore, the chances of anthropogenically induced secondary salinisation and sodification due to inefficient use of the irrigation water are very high if proper soil and water management practices are not emphasized since the soils are alsready imperfectly drained.

2.2.5 Vegetation and Land Use

Vegetation and land use are determined by climate (amount of rainfall and temperatures), altitude, soils and partly due to human influences. The area has been cleared for cultivation and therefore the original natural vegetation is not there. However some remnants of the original vegetation are could be observed in places where selective clearing of the vegetation was done. The original vegetation is considered to have been a dry woodland and bushland. Relics of this vegetation are noted in the form of indigenous trees such as *Croton megalocarpus, Ficus thonningii* and *Lantana camara*. Agro-forestry are practiced through incorporation of *Grevillea robusta, Eucalyptus* species, *Azandirachta indica* (Neem), *Mangifera indica* (mangoes), *Psidium guajava* (guavas) and *Carica papaya* (paw paws) into the farms. Rainfed cultivation of subsistence crops such as maize, cassava, pigeon peas, dolichos, cow peas, pumpkins and sorghum takes place in in the scheme. Irrigation is mainly used on income generating crops such as tomatoes, French beans, passion fruits, bananas, kales, mangoes, paw paws, capsicum, and maize. In some cases cotton is also irrigated. Irrigation is determined by a farmer's ability to buy a water pump, water pipes, meet operational costs and maintenance. Livestock rearing (cattle, goats and sheep), bee keeping are also important land uses in KIARIS.

2.2.6 Land Tenure

Land ownership in the scheme is predominantly free hold where the land is registered and owned privately by farmers or other individuals. Some land near the Ngurubani town center is held under trust by the County Council. The type of land ownership determines investments in soil and water conservation measures. The registration of land and acquisition of title deeds within the freehold ownership enables the people to use title deeds to obtain loans. Demarcation of land helps establish recognized boundaries for individual land ownership and encourages investments on soil and water conservation practices and use of farminputs farmyard manure (FYM).

Farm sizes are decreasing due to inheritance and population pressure resulting in more subdivision of land. Though this has not reached serious levels in the area, proper use of the available soil and water resources is crucial for the long term sustainability of the production systems in KIARIS. The land resource is fixed while the population is increasing meaning more consumption of the agricultural products and increased competition for land with other uses. It is therefore imperative to put in place sustainable land use planning and soil and water management strategies to meet this envisaged demand.

2.3 WORKING METHODS

2.3.1 Field soil characterization and collection of land resources and environmental data

Soil characteristics were studied from augerhole and mini pit and through digging of representative profile pits for the major soil types. The profile pits wer described according to FAO (1977) methodology and sampled for chemical and physical analysis. The soil colour was determined through use of the Munsel Color Chart (1975). The FAO/UNESCO/ISRIC (1997) was used for soil classification. Three soil profile pits were located to represent zones A, B and C of the scheme (Table 4). From five sites/locations around each profile pit within a radius of 10 m, composite soil samples were taken by augering to a depth of 20 cm fertility analysis. Information on vegetation, land use, visible degradation features/indicators such erosion features, plant nutrient deficiencies, deforestation, waterlogging and siltation/deposition was collected. Also, information on the type of soil and water conservation measures, their maintenance and effectiveness was recorded when traversing the area.

Table 4: Location of the soil profile pits

No. profile pit	Easting	Northing
1	037˚ 21.245’	00˚ 39.583’
2	037˚ 21.240’ (esitimated)	00˚ 39.590’ (esitimated)
3	037˚ 21.450’ (esitimated)	00˚ 39.750’ (esitimated)

2.3.2 Field soil physical determinations

The infiltration rates were determined using double ring infiltrometers. Saturated hydraulic conductivity for each identified soil horizon in every profile pit was determined using augered holes of known diameter. Disturbed soil samples were taken for moisture determination. Undisturbed soil samples were taken using core rings for bulk density and moisture content determination.
Soil samples were also taken from the topsoil and subsoil from each of the described profile pit for laboratory determination of specific gravity, sieve analysis (soil texture classification) and consistency. These determinations were done following the procedures described by Hinga et al., (1980).

2.3.3 Laboratory analysis

Samples taken from the field were analysed for chemical and physical properties following procedures described by Hinga *et al.* (1980). pH-H2O and Electrical Conductivity (EC) were measured in a 1:2.5 soil/water suspension. Exchangeable cations were determined by a flamephotometer/atomic absorption after leaching the soils with 1 N ammonium acetate at pH 7.0 while cation exchange capacity was determined after leaching the samples for exchangeable cations (CEC) 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 and organic carbon by the Walkley and Black method.

Soil fertility (available nutrients) was determined by the Mehlich method which involves the extraction of soil by shaking for 1 hour with 1:5 ratio 0.1N HCL/0.025N H2SO4. 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 (ECe) was estimated to be 3 times EC. Exchangeable sodium per cent (ESP), sodium adsorption ratio (SAR), residue sodium carbonate (RSC) and CEC-clay were respectively calculated according to the following equations:

$$ESP = Na/CEC \times 100$$
$$SAR = Na/\sqrt{(Ca+ Mg)/2}$$
$$RSC = (CO3 + HCO3) – (Ca \times Mg)$$
$$CEC\text{-}clay = (CEC\text{-}soil – (4x\%C)/\%clay)100$$

The soil texture was determined by the hydrometer method. Bulk density and moisture content for disturbed and undisturbed samples were determined as described by Hinga *et al*. (1980). The particle density was determined using air pyknometer. The moisture content was determined for each soil horizon at pF 2.0 and 4.2. The total water holding capacity was determined for each horizon as the difference between the water content (in volume basis) at pF 2.0 and 4.2. The total water holding capacity of each profile was determined by the summation of the total water holding capacity of the individual soil horizon. The soil Atterberg limits (liquid and plastic limits) were determined using the Casagrande apparatus. The aggregate stability was determined by dry sieving. The soil samples were air-dried and put on top of a set of sieves of 2.0, 1.0, 0.5, 0.25 and 0.15 mm, fixed on the vibrax with a unit timer. After shaking for 5 minutes, the weight fractions of the sample retained on the sieves were weighed and the size fraction on each sieve determined. The mean weight diameter (MWD) i.e. the sum of each fraction times the corresponding mean mesh size of the two sieves passing and retaining the fraction was determined and the following formula used to calculate MWD, thus:

$MWD=\sum x_i w_i$, where xi is the mean diameter of each size fraction and w is the proportion of the total sample weight occurring in the corresponding size fraction.

2.3.4 Legend construction

Based on the physiography, a geology/parent material and soil characteristic in that order, a soils legend was made for the different soils represented by the profile pits. The physiographic units recognized in the area are uplands and plains denoted as U and P respectively. The scheme is mainly in the plains which occur in association with the uplands. For geology/parent material, basalts and basaltic agglomerates are denoted by letter B, intermediate parent materials such as phonolites and trachytic phonolites are denoted by letter I. Pyroclastic rocks which include welded tuffs are denoted by letter P. Letters d, r and b represent dark, red and brown soil colour respectively.

2.4 SOILS

2.4.1 Soils of the uplands

The soils of the uplands are developed on intermediate igneous rocks which include phonolites and trachytic or rhyolitic phonolites. Uplands have a very gently to gently undulating relief with slopes between 1 and 5%.The soils are well drained, very deep, dark reddish brown to dark brown, very friable to friable, gravelly clay loam to clay. The colour of the topsoil is very dark greyish brown (10YR3/2) while that of the subsoil is dark reddish brown (5YR3/4) to dark brown (7.5YR3/4). Topsoil structure ranges from weak to moderate, fine to medium, crumby to weak, medium, subangular blocky. The structure of the subsoil ranges from weak, very fine to medium, subangular blocky in the upper part to porous massive near the weathering parent material. The consistency of the topsoil is slightly hard to hard when dry, friable when moist, sticky and plastic when wet while that of the subsoil is slightly hard when dry, very friable to friable when moist, slightly sticky to sticky and slightly plastic to plastic when wet. The texture of the topsoil is clay loam to clay and that of the subsoil is gravelly clay loam to clay. The soils are highly weathered. The soils indicate high erodibility and are thus susceptible to surface sealing and crusting due to occurrence of weak to moderate, 1-2 cm thick crusts on the soil surface. A compact plough pan occurs between 15-45 cm depth as a result of continuous ploughing using a tractor or oxen-plough. The soils are classified as Haplic Ferralsols. For description of a representative profile pit, see appendix 1, profile description No. 2.

2.4.2 Soils of the plains

Soils of Block A

The soils are developed on basic igneous rocks which include nepheline basalts and basaltic agglomerates. The soils occur on a flat to very gently undulating topography with slopes of 0-2 %. Land use consists of cultivation of paddy rice, maize, tomatoes, French beans and grazing of livestock. The soils are imperfectly drained to poorly drained, deep, very dark greyish brown to black, firm to very firm, cracking clay. In places calcareous. The colour of the topsoil is black (10YR2/1) while that of the subsoil is very dark greyish brown (10YR3/2) to black (2.5Y2/0). The soil structure in the topsoil is moderate, fine to medium, crumby and weak, fine to medium subangular blocky while that of the subsoil is moderate to strong, medium to coarse prisms breaking to moderate to strong, fine to medium, angular blocks. The subsoil adjacent to the weathering parent material (C-horizon) tends to be porous massive breaking to weak, medium, subangular blocks. It is moderately to strongly calcareous with 50-60 %, 2 mm to 50 mm calcium carbonate concretions. The consistency of the topsoil is slightly hard to hard when dry, friable to firm when moist, sticky and plastic when wet while the subsoil is slightly hard to hard when dry, firm to very firm when moist, sticky and plastic when wet. The texture is clay in both the topsoil and subsoil.

Chemical properties

Topsoil:	pH-H2O 7.2; organic carbon 2.21%; CEC-soil and CEC-clay 76.8 and 87.1 cmol/kg respectively; ECe 1.2 dS/m; ESP 2; %Base Saturation (%BS) 79.
Subsoil:	pH-H2O 7.6-8.6; % organic carbon 0.38-1.75; CEC-soil 23.6-78.8 cmol/kg and CEC-clay 64.8-94.5 cmol/kg; ECe 1.2-1.65 dS/m; ESP 2-13; %BS 73-87.
Diagnostic properties:	2-5 cm wide cracks upto 50 cm deep and clay content >30 %.
Soil classification:	Calcic Vertisols, sodic phase.

For the description of a representative profile pit with analytical data, see Appendix 1, profile description No. 2.

Lower part- Block C

The soils occurring in the lower part of the scheme are developed on pyroclastic rocks. The soils are imperfectly drained, deep, dark brown to very dark greyish brown, friable to firm, clay. The soils occur on a flat to very gently undulating topography with slopes of 0-2 %. The colour of the topsoil is very dark greyish brown (10YR3/2). The structure consists of moderate, medium, angular blocky and weak, fine to coarse, subangular blocky structure. The consistency is slightly hard to hard when dry, friable when moist, sticky and plastic when wet. The colour of the subsoil is very dark brown (7.5YR3/2) to very dark greyish brown (10YR3/2) while the structure is weak to moderate, fine to medium, angular blocky and weak, fine to medium, subangular blocky. The consistency of the subsoil is slightly hard to hard when dry, friable to firm when moist, sticky and plastic when wet. The texture ranges from gravelly clay to clay. The subsoil horizon adjacent to the weathering parent material (C-horizon) tends to be porous massive breaking to weak, medium, subangular blocks. Murram occurs at 100 to 150 cm depth. The soils are classified as Calcic and Eutric Vertisols. For the description of a representative soil profile pit with nanalytical data, see Appendix 1, profile description No. 3).

The soils are very susceptible to sealing and crusting as evidenced by the occurrence of weak to moderate, 1-2 cm crusts. The topsoil is much pulverized due to ploughing. A plough pan occurs at 20-30 cm depth. Up-down slope cultivation was noted in the area. Use of farmyard manure would improve the structural stability of the pulverized, sealing and crusting topsoils thus making them more resistant to the degradative processes. Deep ploughing is recommended to break the plough pan and thus improve the drainage of the soils in addition to improving aeration/oxygen availability of the soils. Cultivation or ploughing up/down slope accelerates soil erosion. Therefore contour ploughing and cropping is very important and should be emphasized.

2.5 SOIL HYDRAULIC PROPERTIES AND CROPPING SYSTEMS

2.5.1 Hydraulic conductivity and water retention characteristics

Infiltration rate is a very important hydraulic property of soils in partitioning the rain and irrigation water into run-off and water entering the soil profile. It is also the principle determinant of the water supply duration per irrigation setting. Hydraulic conductivity is a measure of the internal drainage, deep water percolation and hence the irrigation efficiency and it is expressed in the following equation:

$$K = (1.15R (\log ho + R/2) – \text{Log } ht + R/2))/t$$

Where:

K = Hydraulic conductivity in cm/hour
ho = Initial head in cm
R = Radius of the augerhole in cm
ht = The final head in cm
t = Time for the drop of hydraulic head from ho to ht in hours

The results of the field measurements of infiltration rates and hydraulic conductivity for the three soil profiles in the scheme are shown in Table 5. Appropriate design of an irrigation system requires a careful consideration of the differences in soil water uptake and subsurface movement in planning the irrigation schedule.

Table 5: Infiltration rates in different soil profiles

Profile number	Block	Infiltration rate (cm/hour)
1	A	7.2
2	B	13.2
3	C	10.8

In Kiarukungu irrigation scheme, there are three main soil types, classified by the farmers as black, red and brown which occur in block A, B and C respectively. Farmers seem to plan their cropping in regards to soil types as shown in Table 6.

Table 6: Dominant crops around the three soil profile pits

Profile pit	Block	Soil classification	Dominant crops
1	A	Black cracking soils(Calcic Vertisol, sodic phase)	Rice, maize
2	B	Red soils (Haplic Ferralsol)	Tomatoes, French beans, bananas and maize
3	C	Brown soils (Eutric Vertisols, sodic phase)	Sorghum, cotton, cowpea, pepper, amaranthus

The hydraulic properties of the three soils vary considerably. The initial infiltration rate is highest in black soil due to cracks, which gradually close up as the soil is wetted. The final infiltration rate is lowest in the black soil, followed by the red soil. The highest infiltration rate was recorded in the red soil as shown in Figure 1. For the black soil, the final rate of infiltration, measured at 7.2 cm/hour, does not seem to be the basic infiltration, which is expected to be far much lower. This could be due to closing up of the cracks within three hours at which the final infiltration rate was determined.

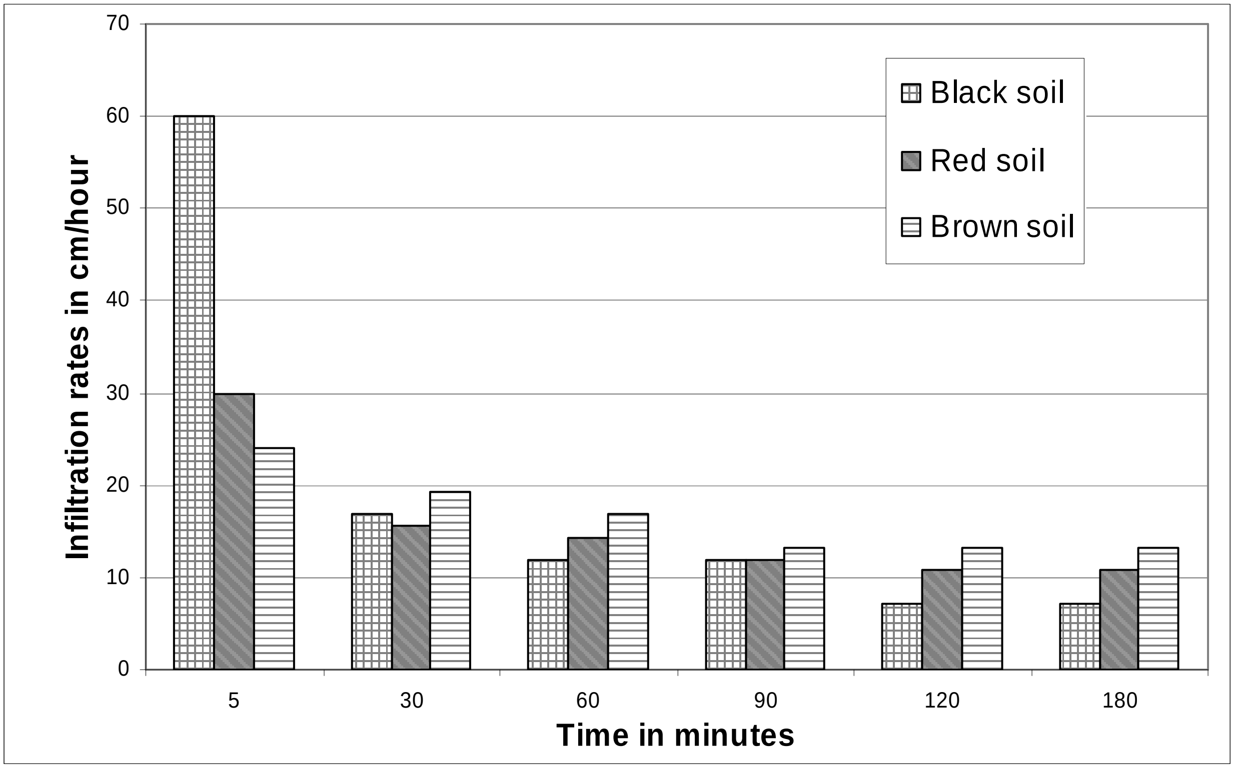


Figure 1: Infiltration rates at different times for different soils

The hydraulic conductivity is highest in the red soil, followed by the brown soil. It is lowest in the black soil. However, the effective hydraulic conductivity is highest in brown soil. This is attributed to the highest value of 18.01, measured at the depth of between 110 and 141 cm (Table 7). This means each soil profile represents a soil unit with different soil water uptake, retention and movement characteristics, thus requiring different irrigation schedules.

Table 7: Infiltration rate and hydraulic conductivity in the different Blocks in the scheme

Profile No/Block	Depth (cm)	K (cm/hour)
1	0-18	1.89
Block A	18-49	0.39
	49-85	0.14
2	0-20	5.47
Block B	20-73	3.40
	73-107	1.24
	107-150	1.21
3	0-26	2.30
Block C	26-64	1.14
	64-110	3.46
	110-141	18.01

A spatial extent of each soil unit, cropping systems and management strategies intended to optimize the use of water within the unit are the basis of defining the production unit, production objectives and appropriate irrigation unit within the scheme. Therefore, the marked differences in the hydraulic properties between the three soil types show that appropriate management approaches can be identified for sustained water use efficiency if the extent, distribution and potentials of these soils for different crops are known. Management requirements of each soil can then be determined with respect to the envisaged crops. This is required to ensure an efficient production system.

In the scheme, only 60l/sec. of water supply is available for over 300 farmers, each growing different crops on at least 0.25 ha, mainly for commercial purposes. In this case, efficient production means, not only improved water use efficiency, but also reasonable economic return in shillings per millimeter of irrigation water. This can be attained by deciding on the irrigation practices, based on the hydraulic properties of soil, topographic characteristics of the area and optimum cropping patterns. The current irrigation practices which are not based on these parameters may have negative environmental impacts in the long-run.

The irrigation methods practiced are basins (mainly in block A) and furrow (mainly in red and brown soils). The red and brown soils have convex slopes, and furrows constructed along the slopes may cause erosion through excess irrigation and rain water. This being a commercially irrigated agriculture, considerable quantity of agricultural inputs and water are applied by the farmers with an aim of maximizing the production for maximum profits. Relatively low water permeability of the subsoil may cause topsoil saturation, causing the flow of water, nutrients and chemicals along the furrows into the river, hence increased degradation of water quality in the long-run. This concern needs to be verified by conducting an environmental impact analysis and monitoring.

2.5.2 Bulk density and water retention capacity of the soils

The total water retention capacity of the soils is expressed in volume basis as a product of bulk density and the difference between soil moisture content at pF 2.0 and pF 4.2 (Table 8). The readily available soil water is taken as 50 % of the total available water for irrigation purposes. For the design of irrigation system, the proportion of the total available soil water (p) that can be depleted without causing the actual evapotranspiration (ETa) to become less than the maximum evapotranspiration (ETm) has to be defined, as it determines when soil water has to be replenished. This means that when soil water is replenished before it becomes less than this fraction, the irrigated crops will not experience moisture stress. Therefore, the value of the fraction (p) depends on the crop, the magnitude of ETm and the soil.

Table 8: Bulk density and soil moisture retention characteristics along the profiles

Profile number and Block	Soil depth (cm)	Bulk density (g/cc)	% soil moisture at pF 2.0	% Soil moisture at pF 4.2	Total soil moisture (mm)	Total water holding capacity (mm/m)	Available water holding capacity (mm/m)
1 (A)	0-18	1.64	65.3	28.2	66.8	159.5	79.8
	18-49	1.66	60.5	32.5	86.8		
	49-85	1.60	60.5	36.7	85.7		
2 (B)	0-20	1.11	54.3	8.7	91.2	162.1	81.0
	20-45	1.15	50.0	9.7	100.8		
	45-73	1.18	52.2	12.8	110.3		
	73-150	1.22	37.8	18.9	51.1		

3 (C)	0-26	1.00	50.2	20.3	77.7	157.9	78.9
	26-64	1.11	48.5	21.9	101.1		
	64-110	1.10	50.5	21.1	135.2		
	110-141	1.31	39.8	21.1	58.0		

Some crops such as most vegetables, continually need relatively wet soils to maintain ETa=Etm. Other such as cotton and sorghum, can deplete soil water further before ETa falls below ETm. According to FAO (1986), crops can be grouped according to the fraction (p) to which available soil water (Sa) can be depleted while maintaining ETa equal to ETm as shown in Table 9 and 10.

Table 9: Crop groups according to soil water depletion

Group	**Crops**
1	Onion, Pepper, potato
2	Banana, cabbage, cow pea, tomato
3	Alfalfa, bean, citrus, ground nut, pineapple, sunflower, water melon
4	Cotton, maize, safflower, sorghum, soybean, sugar cane

Table 10: Soil water depletion fraction (p) for crop groups and maximum evapotranspiration (ETm)

Crop group	**ETm mm/day**								
	2	3	4	5	6	7	8	9	10
1	0.50	0.425	0.350	0.300	0.250	0.225	0.200	0.200	0.175
2	0.675	0.575	0.475	0.400	0.350	0.325	0.275	0.250	0.225
3	0.80	0.700	0.600	0.500	0.450	0.425	0.375	0.350	0.300
4	0.875	0.800	0.700	0.600	0.550	0.500	0.450	0.425	0.400

2.5.3 The engineering properties of the soil

The engineering properties of the soils were particle density, aggregate stability and consistence (Atterberg's limits). The three Atterbergs limits (moisture contents in %) are liquid limit (LL), sticky limit (SL) and plastic limit (PL) as shown in Table 11.

Table 11: The engineering properties of the soil

Profile No.	**Depth cm**	**Particle density g/cc**	**Aggregate stability**					**Atterberg's limits**		
			xi_1wi_1	**xi_2wi_2**	**xi_3wi_3**	**x_4iwi_4**	**$\sum xiwi$**	**LL**	**SL**	**PL**
1	0-30	3.74	1.704	0.090	0.009	0.001	1.804	53.8	53.8	29.8
	30-60	3.00	1.897	0.036	0.004	0.001	1.937	53.0	45.0	25.1
2	0-30	2.39	0.903	0.196	0.0978	0.006	1.202	45.9	40.5	26.7
	30-60	2.40	0.816	0.177	0.150	0.006	1.149	45.5	43.5	29.3
3	0-30	2.38	0.950	0.177	0.078	0.002	1.206	44.1	38.4	25.3
	30-60	2.42	0.876	0.134	0.006	0.003	1.420	41.9	35.2	24.7

The particle density is abnormally high for the profile number 1, while profile numbers 2 and 3 have very low values. This marks distinct differences between profile number 1 and the other two in terms of soil characteristics such as texture, clay mineralogy as well as changes which take place upon drying or contact with water. These changes include cracking, shrinking and swelling. These differences are also reflected in size distribution and stability of the soil aggregates. Profile number 1 has much more soil aggregates held in the larger sieves than profiles numbers 2 and 3 which have better size distribution. The fact that there are generally more aggregates held in the smallest sieves by profiles 2 and 3 than number 1, shows that profile number 1 has stronger cohesive forces within the aggregates than the other two profiles. From these data, it can be concluded that profile number 1 is very different from numbers 2 and 3 which have comparable characteristics.

2.6 LAND DEGRADATION AND MANAGEMENT

The productive capacity of an ecosystem declines due to processes induced by human activities, processes which lead to land degradation. Human activities that contribute to land degradation include unsustainable agricultural land use, poor soil and water management practices, deforestation, removal of natural vegetation, frequent use of heavy machinery, overgrazing, improper crop rotation and poor irrigation practices. Within the scheme, land degradation is caused by several processes including fertility decline, soil erosion, soil compaction and pulverization, soil surface sealing and crusting.

2.6.1 Erosion susceptibility, sealing and crusting

Soil erosion is a serious threat to sustainable agricultural production. As such therefore, the evaluation of susceptibility or resistance to erosion was regarded of particular importance. Soil susceptibility to erosion was determined by assessing climate (rainfall erosivity), topography (slope steepness and length), and soil erodibility (Weeda, 1987). The soils of the uplands indicate low susceptibility to erosion while those of the plains indicate very low susceptibility to erosion. Very low to low classes are mainly due to the flat to very gently undulating topography in the plains with slopes of 0-2 % and the very gently undulating to gently undulating topography of the uplands with slopes between 1-5 %. Topsoil erodibility in the soils of the uplands and plains is moderate due to low organic matter content and/or high silt content relative to clay content.

The soils indicate moderate to high susceptibility to surface sealing and crusting. This is indicated by the occurrence of weak to strong, 1-5 mm thick surface crusts on bare soils. Sealing and crusting hinders water from infiltrating into the soil thus generating runoff which leads to rill and gully erosion. In addition, the crusts hinder seedling emergence thus causing non-uniform seedling emergence which affects yields. As surface sealing and crusting is due to unstable topsoil aggregates mainly as a result of low organic matter content in the topsoil, there is need to incorporate farmyard manure in the soils to improve the structural stability of the topsoil which will result in improved water holding capacity of the soils. Surface sealing and crusting takes place where the topsoils are exposed to raindrop impacts or drops of applied irrigation water, for example by sprinkler irrigation. This therefore calls for provision of protective cover crops and farm management practices that improve the protection of the topsoil.

2.6.2 Erosion hazard

Erosion hazard is a measure of the degree of soil erosion that is likely to occur in the future. When erosion is already clearly evident, the erosion hazard expresses the intensity of the erosion process or the degree of soil loss which is expected from a specific form of land use, management and conservation practices. It combines the effects of the influence of the more permanent factors such as climate, relief/topography and soil, and the alterable factors of land use management and conservation practices. The erosion hazard classes shown in Table 12 were arrived at after consideration of the erosion susceptibility classes , visible erosion features, land use, type of vegetation, type of conservation measure(s) (physical, biological/agronomic or cultural), their state and effectiveness. The uplands (mapping unit UPr) indicate slight to moderate erosion hazard. There is need therefore for increased combinations of soil conservation measures such as properly spaced fanya juu terraces, contour ploughing/cultivation, strip cropping with cover crops such as pastures, sweet potatoes and intercroppings, agro-forestry; mulching, and use of farm yard manure or compost.

Table 12: Erosion susceptibility and hazard in the Kiarukungu irrigation scheme

Mapping Unit	Erosion Susceptibility	Vegetation/land use/conservation measures/ management	Erosion Hazard
UPr	Low	Growing annuals, grazing, lack of conservation measures	Slight - moderate
PBb	Very low	Growing annuals, vegetables; agro-forestry; upslope ploughing and cropping	Slight
PBd	Very low	Cultivation of annuals and vegetables; grazing	Slight

The plains (soil units PBd and PBb) indicate slight erosion hazard. Maintenance of a topsoil protective cover from water/raindrops impactings is important. Incorporating agro-forestry trees in the farms or planting trees along farm boundaries should be encouraged as they act as windbreaks. Agronomic and cultural practices that control physical soil degradation such as surface sealing, crusting, compaction and pulverization should be enhanced.

2.6.3 Soil fertility decline

Soil fertility may be defined as the ability of the soil to provide favourable conditions for crop growth by supplying enough water, nutrients and oxygen. The main 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. Chemical soil fertility refers to the capacity of a soil to provide plants with nutrients which depends on the degree of chemical weathering and leaching in addition to the organic matter content and its rate of decomposition. The soils of the uplands are more weathered than those of the plains and are thus chemically poorer than those of the plains as indicated by the morphological characteristics such as the red soil colour and very friable consistency. Soils of the upland are expected to have lower pH, CEC, exchangeable cations and ESP than those of the plains due to stronger leaching in the uplands than plains. The uplands are geochemically leaching environments while plains are accumulating environments. The laboratory analytical results show that the soils have low organic matter contents (Table 13 and appendix 3).

Table 13: Available nutrients in the topsoils (0-20 cm depth) in Kiarukungu scheme

Parameter	Zone A	Zone B	Zone C
pH-H2O	7.7	5.3	5.3
Hp(me%)	-	0.2	0.2
C (%)	1.53	1.43	1.43
N (%)	0.05	0.13	0.11
Na(me%)	1.28	0.24	0.14
K ,,	0.19	0.2	1.68
Ca ,,	10.8	3.9	4.0
Mg ,,	8.64	1.7	5.08
Mn ,,	0.12	0.1	0.58
P (ppm)	130	62	76
Fe ,,	8.06	33.8	35.8
Cu ,,	0.59	4.99	2.29
Zn ,,	2.22	3.57	4.43

The low organic matter content in the soils is due to lack of application of farmyard manures (FYM) or compost. This has led to a decline in crop yields which is also affected by the continuous cultivation without soil nutrient replenishment. This results in nutrient mining through harvested crops. Therefore use of manures and inorganic fertilizers needs to be enhanced for an increased crop production. The soils of the upper part of the plains (Zone A) show medium alkalinity with a pH of 7.7. The soils are deficient in nitrogen, phosphorus, potassium, copper, iron and zinc. The organic matter as indicated by % carbon is in moderate supply. The soils of zones B and C are of medium acidity with a pH of 5.3 and are low N while organic matter is moderate and zinc is low.

To supplement N, which is deficient in zone A, ammonium sulphate (AS) should be applied at the rate of 250 kg/ha. In zones B and C, the deficient N can be supplied by applying CAN at the rate of 200 kg/ha. As organic matter is moderate in all the zones, application of well decomposed manure or compost to increase the organic matter at the rate of 5 tonnes/ha is necessary. Use of FYM or compost has the advantage of improving topsoil structural stability thereby reducing runoff and erosion. It also improves the nutrients and water holding capacity of the soils in addition to enhancing soil fauna activities thus improving soil physical aspects such as aeration and moisture content.

2.6.4 Vegetation depletion

In the scheme, vegetation degradation is due to cutting of trees, overgrazing and clearing for cultivation. The woodlands and bushlands have been cleared for cultivation, building, furniture, fencing and charcoal burning. With a fast growing population, a change and intensification of the land-use system is expected. Intensified land use without appropriate water conservation measures may endanger the water resources and the soil productivity. The water resource is in great demand in the area and downstream as farmers are involved an in intensive use of the land for cultivation with no addition of inputs.

2.7 POTENTIAL IMPACTS OF RESULTS OF THE STUDY

If implemented, the proposed strategies emanating from the study will ultimately result in higher productivity of rainfed or irrigated agriculture thus increased crop yields per unit area and livestock products especially milk. The resultant impact would be food self sufficiency (security) and income generation. Increased soil water storage capacity would result in long duration groundwater recharge thus making the river and streams to have increased flowing water most of the year. Efficient use of irrigation water by avoiding a lot of loses will result in more water being available to irrigate more land. Growing of high value horticultural crops such as tomatoes, egg plants/brinjals, onions, karela, okra, french beans, soya beans, dudhi, citrus and avocados would create alternative sources of income with more people venturing into this investment thus creating more job opportunities to thus reducing idleness, dependency, consumption of illicit brews, drugs and crimes, etc. Wealth creation and food security would result in improved livelihoods and access to medical and education facilities.

Effective physical, agronomic and cultural soil and water conservation measures would lead to reduced run-off and hence more and clean good quality stream/river water due to reduced siltation and sedimentatiof rivers. Further, incorporation of agro-forestry species in the farming systems, conservation of indigenous trees and planting woodlots would create more carbon sinks as plants use carbon dioxide and release oxygen in their metabolism leading to a healthy environment. In addition, the windy condition of the area would be reduced thus in effect reducing the evapotranspiration.

2.8 CONCLUSIONS AND RECOMMENDATIONS

Population pressure increases the demand, competition and over exploitation of the natural resources leading to accelerated land degradation. There is therefore the need to take the necessary measures to control the degradation processes with measures such as:

1. During clearing of bushes for cultivation, indigenous trees such as *Ficus thonningii*, *Bridelia micrantha*, *Croton machrostachyus*, etc should be conserved. A belt of these indigenous trees should be left at the banks of River Thiba for control of bank erosion.
2. A combination of the appropriate physical, agronomic and cultural methods of soil conservation is necessary. The physical methods suitable in the gently undulating uplands with slight to moderate erosion hazard include construction of well spaced, stabilized, maintained and effective fanya juu terraces. Agronomic measures appropriate for the uplands and plains include strip cropping with crop and pasture combinations, planting adapted cultivars and intercropping. Cultural practices would include contour farming (planting, tilling/ploughing) and crop rotation.
3. The soils show low to moderate levels of organic matter and hence the need to apply FYM or compost. This will improve the structural stability of the topsoils and hence prevent the occurrence of sealing and crusting processes. In addition, N, P and K are deficient and need to be improved in the soils by applying the appropriate fertilizers.
4. Deep ploughing is necessary to prevent the formation of plough pan that would subsequently impede drainage and interfere with soil aeration important for soil fauna and root metabolism.
5. 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. Proper advice to the farmers before application needs to be emphasized.
6. Application of the right amount of irrigation water without over-irrigating is very crucial to avoid the potential danger of causing salinization and/or sodification of the soils as a result of a rise in the level of the groundwater.
7. N-fixing trees/shrubs that are multipurpose need to be integrated into the farming system.
8. There is need to diversify the high value irrigated crops in the area by introducing crops such as the Asian vegetables e.g.okra, karela, dudhi, brinjals, cucumber, water melons, coghets and onions, etc.
9. Population pressure and land tenure iassues are the key driving forces of land degradation. There is a need therefore to sensitize the local community on the benefits of appropriate soil and water management aspects for sustainable agricultural production and conservation of the environment.
10. Monitoring fertility, ESP and EC levels of the soils is important in order to take the necessary remedial measures at the right time.

REFERENCES

Braun, H.M.H. 1984. Evaporation in Kenya. Miscellaneous Paper, Kenya Soil Survey, Nairobi.

FAO, 1977. Guidelines for Soil Profile Description, FAO, Rome.

FAO, 1986. Guidelines: Land evaluation for rainfed agriculture. FAO Soils Bull, 52, FAO, Rome.

FAO-UNESCO, 1997. Soil Map of the World. Revised Legend with corrections and updates. Technical Paper 20, ISRIC, Wageningen.

Gachathi, F. N. 1989. Kikuyu Botanical Dictionary. Publication supported by gtz and printed by AMREF, Printing Dept., Nairobi.

Government of Kenya, 1999. Population Census, Central Bureau of Statistics, Ministry of National Development, Nairobi.

Hinga, G., Muchena, F.N. and Njihia, C.M. 1980. Physical and Chemical Methods of Soil Analysis. National Agric. Res. Labs, Nairobi.

Jaetzold, and Schmidt, 1983. Farm Management Handbook of Kenya, Vol.II/C East Kenya. Ministry of Agriculture, Nairobi, Kenya.

Kenya Soil Survey Staff, 1987. Manual for soil survey and land evaluation. Vol. 1. Miscellaneous paper no. M24, Kenya Soil Survey, Nairobi.

Munsell Color Charts, 1975. Munsell soil color charts, Baltimore, Maryland.

Richards, L. A. (ed). 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook No.60, Washington DC.

Sombroek, W.G., Braun, H.M.H. and Van Der Pouw, B.J.A. 1982. Exploratory Soil Map and Agro-Climatic Zone Map of Kenya. Exploratory Soil Survey Report No.E1, Kenya Soil Survey, Nairobi, Kenya.

UNEP/GEF, 2005. Protecting the Environment from Land Degradation. UNEP's Action in the Framework of the Global Environment Facility.

Weeda, A. 1987. Ratings for land qualities in Kenya. Internal Communication No. 29. Kenya Soil Survey, Nairobi, Kenya.

Woodhead, T. 1968. Potential evaporation in Kenya, E.A.A.F.R.O., Nairobi.

APPENDIX 1: PROFILE DESCRIPTIONS AND ANALYTICAL DATA

Profile Description No. 1
General site information

Soil map unit code	: UPr
Sheet observation no.	: 135/2-1
Location	: zone B
Soil parent material	: pyroclastic rocks
Landform	: uplands
Relief/slopes	: very gently undulating to gently undulating; slopes 1 – 5%
Land use	: cultivation of annuals and keeping livestock
Erosion type	: slight splash erosion
Surface sealing and crusting	: weak, 1 - 2 mm
Internal drainage	: well drained
Effective soil depth	: > 107 cm
Soil classification	: Haplic Ferralsols

Profile description
Horizon Depth

Ap 0-20 cm very dark greyish brown (10YR3/2, moist); clay; weak to moderate, fine to medium, crumby and 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:

AB 20-45 cm dark reddish brown (5YR3/3, 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:

Bu1 45-73 cm dark reddish brown (5YR3/3, moist); clay loam; 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:

Bu2 73-107 cm dark reddish brown (5YR3/4, moist); clay loam; 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:

Btcs 107-150 cm dark brown (7.5YR3/4, moist); gravelly clay loam; porous massive; friable when moist, slightly sticky and slightly plastic when wet; many very fine pores; 60-70%, 2 – 5 cm, iron and manganese concretions; very few fine and medium roots.

Ccs 150+ cm weathering pyroclastic material

Laboratory data for profile description no. 1

Horizon designation	Ap	AB	Bu1	Bu2	Btcs
Depth (cm)	0 - 20	20 – 45	45 – 73	73 – 107	107 – 150
pH-H2O (1:2.5)	5.4	5.7	5.9	5.0	4.8
EC dS/m ,,	0.09	0.06	0.10	0.06	0.07
ECe dS/m	0.27	0.18	0.30	0.18	0.21
C (%)	1.74	1.36	1.24	1.18	0.67
CEC-soil (cmol/kg)	21.8	15.72	10.34	13.78	13.60
CEC-clay (cmol/kg)	18.5	12.5	6.2	20.6	14.4
Exchangeable Calcium ,,	9.38	7.88	3.75	3.12	0.50
Magnesium ,,	4.30	3.97	2.64	3.15	1.66
Potassium ,,	0.98	0.72	0.28	0.36	0.28
Sodium ,,	1.20	0.85	0.45	0.65	0.40
Sum of cations	15.86	13.42	7.12	7.28	2.84
Base saturation (%)	73	85	67	53	21
ESP	5	5	4	5	3
Texture – hydrometer					
Sand %	14	10	10	8	8
Silt %	6	8	4	48	16
Clay %	80	82	86	44	76
Texture class	C	C	C	SiC	C
Silt:clay ratio	0.075	0.10	0.05	1.09	0.2

Profile Description No. 2

General site information

Soil map unit code :PBd
Sheet observation no. : 135/2- 2
Location : zone A
Soil parent material : basalts and basaltic agglomerates
Landform : plains
Relief/slopes : flat to very gently undulating; slopes 0 – 2%
Land use : cultivation of irrigated maize and tomatoes; grazing of livestock
Erosion type : slight splash erosion
Surface sealing and crusting : moderate to strong, 1 – 3 cm surface crusts
Internal drainage : imperfectly drained
Effective soil depth :> 105 cm
Soil classification : Calcic Vertisols, 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 greyish brown (10R3/2, moist); gravelly 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:

Cck 105 cm+ weathering rock

Laboratory data for profile description no. 2

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)	76.80	78.8	53.2	23.6
CEC-clay (cmol/kg)	87.13	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. 3
General site information

Soil map unit code	:PBb
Sheet observation no.	: 135/2- 3
Location	: zone C
Soil parent material	: basalts and basaltic agglomerates
Landform	: plains
Relief/slopes	: very gently undulating to gently undulating; slopes 0 – 2%
Land use	: cultivation of cotton, maize, beans, cowpeas, pigeon peas, mangoes and passion fruits; grazing and bee keeping
Erosion type	: slight splash erosion
Surface sealing and crusting	: weak to moderate, 1 – 2 cm crusts
Internal drainage	: moderately well drained to imperfectly drained
Effective soil depth	: 141+ cm
Soil classification	: Eutric Vertisols, sodic phase

Profile description
Horizon Depth

Ap 0-26 cm very dark grayish 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:

AB 26-64 cm dark brown (7.5YR3/2, moist); clay; weak, medium, subangular blocky and moderate fine to medium, angular blocky structure; slightly hard when dry, friable to firm when moist, sticky and slightly plastic when wet; very many, biopores, very fine and fine pores; common very fine and fine roots; clear and smooth transition to:

Bu1cs 64-110 cm dark yellowish brown (10YR3/4, moist); clay; weak to moderate, very fine to medium, angular and subangular blocky structure; slightly hard when dry, friable to firm when moist, sticky and plastic when wet; medium, broken, clay cutans; 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:

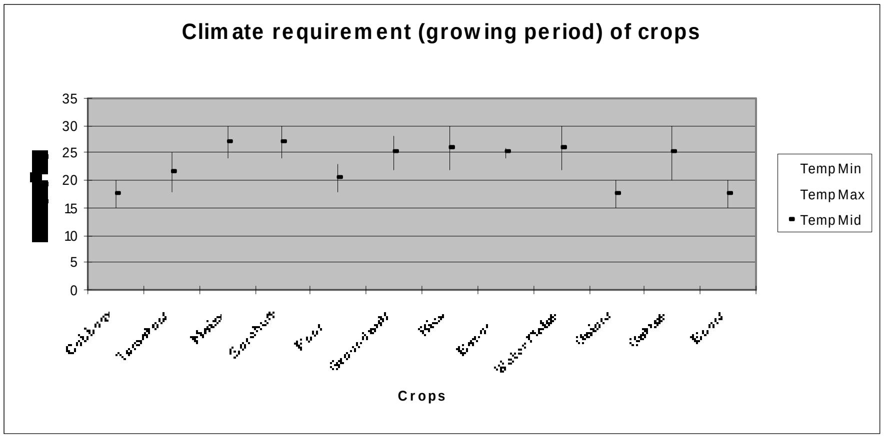
Bu2cs 110-144+ cm dark brown (10YR3/3, moist); gravelly clay; porous massive breaking to weak, fine to medium, subangular blocky structure; slightly hard when dry, friable to firm when moist, sticky and slightly plastic when wet; 50 – 60%, 2 – 5 cm, iron and manganese concretions; many, very fine and fine pores; very few, very fine and fine roots.

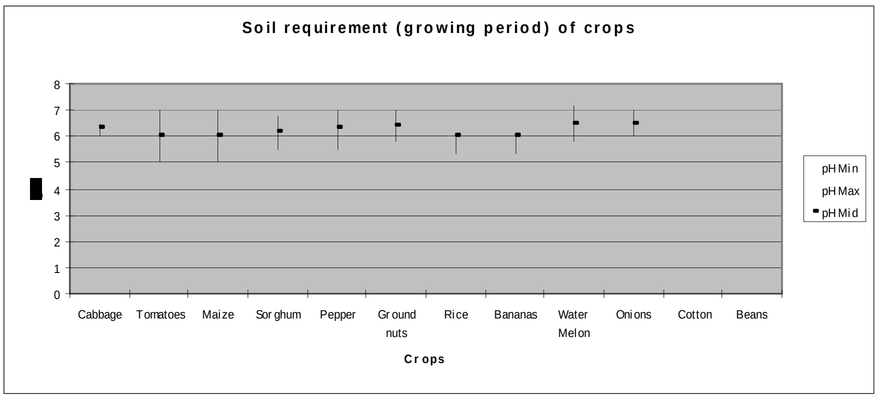
Laboratory data for profile description no. 3

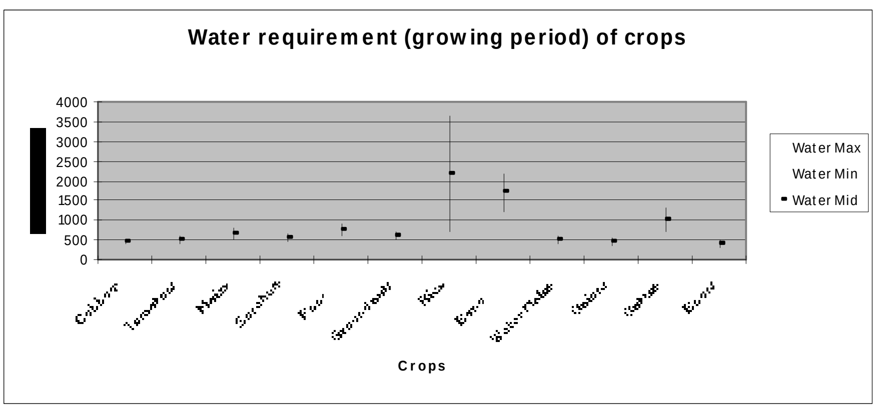
Horizon designation	**Ap**	**AB**	**Bu1cs**	**Bu2cs**
Horizon depth (cm)	0 – 26	26 – 64	64 – 110	110 – 144
pH-H2O (1:2.5)	5.6	5.5	6.1	6.1
EC dS/m ,,	0.07	0.05	0.07	0.04
ECe dS/m ,,	0.21	0.15	0.21	0.12
C (%)	1.63	1.48	1.18	0.76
CEC-soil (cmol/kg)	18.6	21.6	19.48	16.49
CEC-clay (cmol/kg)	15.1	18.7	26.36	24.02
Exchangeable Calcium ,,	5.27	5.09	6.57	4.98
Magnesium ,,	2.88	2.85	3.48	3.80
Potassium ,,	1.44	0.80	0.68	0.68
Sodium ,,	1.45	0.95	0.75	0.80
Sum of cations	11.04	9.69	11.48	10.25
Base saturation (%)	59	45	59	62
ESP	8	4	4	5
Texture – hydrometer				
Sand %	10	10	8	36
Silt %	10	6	34	8
Clay %	80	84	56	56
Texture class	C	C	C	C
Silt:clay ratio	0.125	0.71	0.61	0.14

APPENDIX 2

Climatic, soil and water requirements (growing period) of the envisaged crops







APPENDIX 3. CLASSIFICATION OF SOME SOIL PROPERTIES

Soil reaction (pH) classification

pH	Class name
<4.5	Extremely acid
4.5 – 5.0	Very strongly acid
5.1 – 5.5	Strongly acid
5.6 – 6.0	Medium acid
6.1 – 6.5	Slightly acid
6.6 – 7.3	Neutral
7.4 – 7.8	Mildly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9.0	Strongly alkaline
>9.0	Very strongly alkaline

Classification of EC

EC2.5 (dS/m)	Derived ECe (dS/m)	Class name
0 – 1.2	0 – 4	Non saline
1.2 – 2.5	4 – 8	Slightly saline
2.5 – 5.0	8 – 15	Moderately saline
5.0 – 10.0	15 – 30	Strongly saline
>10.0	>30	Excessively saline

Classification of ESP

ESP	Class name
0 – 6	Non sodic
6 – 10	Slightly sodic
10 – 15	Moderately sodic
15 – 40	Strongly sodic
>40	Excessively sodic

Classification of % C, CEC and % BS

Class name	%C	CEC-soil (cmol/kg)	BS%	Silt/clay
Very low	<4.0	<5	<10	<0.2
Low	0.5 – 0.9	5 – 15	10 – 29	0.20 – 0.59
Medium	1.0 – 1.9	15 – 25	30 – 49	0.60 – 1.00
High	2.0 – 5.0	25 – 40	50 – 79	>1.00
Very high	>5.0	>40	>80	

Kenya Agricultural Research Institute

National Agricultural Research Laboratories

Kenya Soil Survey

SUSTAINABLE LAND MANAGEMENT IN KYEEKOLO SMALLHOLDER IRRIGATION SCHEME, MAKUENI DISTRICT

BY

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KENYA SOIL SURVEY ADVISORY SITE EVALUATION REPORT NO. P 123

DECEMBER, 2006

3.1 INTRODUCTION

Kyeekolo Irrigation Scheme (KYEIS) is also a community based initiative which focuses on economic empowerment of its members through the utilization of natural resources especially soils and water and maintaining a healthy environment. The proposed source of irrigation water for the scheme is the Kyeekolo stream. The local community depends on water from this river for livestock, domestic needs and some irrigated agriculture. The scheme was initiated in 1985 with the main objective of improving household incomes through sustainable utilization of natural resources, mainly spring/stream water and soils through irrigated agriculture. This would in addition enhance food security, wealth creation and a healthy environment. However, the project did not pick up well due to limited capacity on project development and management, inadequate community participation, lack of technical support and know-how, and inadequate resources. Consequently, the project stalled and was revived in 2003. However, it was not until 2005 that agricultural activities started taking place. The group currently has a membership of 60 farmers, 10 of whom are already irrigating their land by tapping water from the upper part of the scheme and delivering it to their farms by gravity using pipes. Thus, the financial strength of the members is the determining factor in the utilization of the Kyeekolo stream water for irrigation.

The need to implement appropriate natural resource management and conservation strategies is crucial in enhancing food security and economic development in the area. Land use planning in the KYEIS is essential for identification of the changes required in land use practices which will increase productivity and opportunities, making decisions on where the changes should be and to avoid misuse of the land resources. The purpose of this work was therefore to provide information on soils, irrigation water and other land resources to facilitate the development of sustainable community based irrigated agriculture in the scheme.

3.2 THE ENVIRONMENT

3.2.1 Location, Communication and Population

Kyeekolo Irrigation Scheme (KYEIS) is situated in Kalongo Location, Kilungu Division, Makueni District, Eastern Province of Kenya. It is located between latitudes 01˚ 46.5‘ and 01˚ 46.8‘ South, and longitudes 37˚ 23.0‘ and 37˚ 23.5‘ East, at an altitude of between 1600-1700 m above sea level (asl). It has an area of about 30 ha and is accessible through the Athi River-Salama-Kilome road and the Machakos-Wote road. Motorable track roads pass through the scheme. The scheme is occupied by the Akamba people whose main activities are farming, livestock rearing and carrying out businesses. Table 1 below shows the population of Kilungu Division as per the population census of 1999 and the projected population to the year 2020.

Table 1: Present and projected population and population density of Kilungu Division (1999 – 2020)

Year	**1999**	**2000**	**2005**	**2010**	**2015**	**2020**
Population	67,741	69,773	80,886	93,769	108,704	126,018
Population density (persons/km^2)	383	394	457	529	614	712

Source: GoK, 1999.

Table 1 show that, the population density of Kilungu Division was 383 persons/km² in 1999 but will almost double by the year 2020 to 712 persons/km². The population statistics indicate a building population pressure which will lead to increased demand, competition and over exploitation of the available resources including soils and water. This will ultimately lead to land and environmental degradation, if the necessary measures to control the processes are not put in place.

3.2.2 Climate

3.2.2.1 Rainfall, agro-climatic zonation, temperatures and potential evaporation

The agricultural potential of an area is mainly determined by the prevailing climatic conditions (rainfall, evaporation and temperature). Rainfall in the area is bimodal with long rains occurring between March and May and short rains from October to December. The scheme occurs in agro-climatic zone (ACZ) III which is classified as semi-humid with a mean annual rainfall of 800-1400 mm. The mean annual evaporation to mean annual rainfall ratio is 0.5-0.65. Zone III has mean annual evaporation of 1450-2200 mm. However the scheme has an annual potential evaporation of 1840 mm. The area occurs in temperature zone 4 which has mean annual temperatures in the range 18-20˚C considered to be warm temperate (Sombroek *et al*., 1982). The area has therefore high to medium potential for agriculture.

3.2.2.2 Evapotranspiration and moisture balance

The potential evapotranspiration (Et) i.e. crop water inversely related to altitude with the low altitude areas having higher potential evapotranspiration than higher altitude areas. The mean annual potential evaporation (Eo) based on Woodhead (1968) altitude equation at an average altitude of 1650 m asl is 1840 mm (Table 2). Potential evapotranspiration is assumed to be 2/3 Eo and is therefore 1227 mm in KYEIS. The rainfall data (r) used is for Kilome District Office's meteorological station data for 21 years. Mean monthly Eo values have been calculated according to Braun (1984).

Table 2: Water balance for KYEIS project area.

Parameter	Month												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Yr**
R	57	48	144	254	123	19	12	8	14	96	265	116	1157
Eo	184	166	184	147	129	129	129	129	166	166	147	166	1840
Et	123	111	123	98	86	86	86	86	111	111	98	111	1230
r-Et	-66	-63	21	156	37	-67	-74	-78	-97	-15	167	5	-74

Data from Table 2 shows tha, the mean monthly and annual rainfall exceeds evapotranspiration demand in the months of March, April and May during the long rains, and November and December during the short rains. The periods January-February and June-October experience moisture deficits thereby requiring irrigation for growing crops. Irrigation technologies that use little water with minimal losses should therefore be considered within the prevailing socio-conomic set up of the group members.

Physiography and geology/parent materials

The physiograpy of the area is predominantly a hilly terrain with slopes of more than 16 % and the associated minor valleys with slopes of 0-5 %. The soils of the hilly area are developed on metamorphic rocks comprising of undifferentiated banded gneisses. The soils of the minor valleys are developed on alluvial and colluvial materials derived from the gneisses. In places the soils are stratified.

3.2.4 Drainage

The main source of water in KYEIS is the Kyeekolo stream with its tributaries with a general flow of west-east direction. The stream has its source of water from seepage at the foot of the hills. The river provides water for domestic and livestock use in addition to providing water to some ongoing smallholder irrigation within the scheme. Individual farmers have trapped the stream water using pipes and delivered it to their farms by gravity. Kyeekolo stream will be the source of irrigation water for the proposed KYEIS. Table 3 shows analytical results of a water sample taken from the proposed intake and the allowable limits for parameters mostly used to classify water quality hazards according to Richards (1954). The parameters include pH, electrical conductivity (EC) which indicates total dissolved salts and hence salinity hazard, residue sodium carbonate (RSC) indicates carbonate and bicarbonate concentration hence alkalinization hazard, and the sodium adsorption ratio (SAR) indicates sodicity hazard. The results indicate that the water from the intake is suitable for irrigation.

Table 3: Irrigation water quality classification from Kyeekolo stream intake

Parameter	**Intake source**	**Suitability class**		
		Safe	**Marginal**	**Unsuitable**
pH	6.5	6.0 – 8.0	≤6.0 – >8.0	<6.0 & > 8.0
EC (dS/m)	0.16	0.0 – 0.75	0.25 – 0.75	>0.75
Sodium (me/l)	1.30			
Potassium (me/l)	0.04			
Calcium ,,	0.13			
Magnesium ,,	0.31			
Carbonates ,,	Trace	0.0 – 1.25	1.25 – 2.5	>2.5
Bicarbonates ,,	1.86	0.0 – 1.25	1.25 – 2.5	>2.5
Chlorides ,,	0.75			
Sulphates ,,	1.3			
SAR	2.77	0.0 – 13.0	7 – 13	>13
RSC	1.42	0.0 – 1.25	1.25 – 2.5	>2.5

3.2.5 Vegetation and Land Use

The area has been cleared for cultivation and therefore only relics of the original natural vegetation are observed in areas where selective clearing of the vegetation was done. The area is considered to have an original vegetation of dry forest and moist woodland. Relics of this vegetation were observed and consisted indigenous trees such as *Bridelia micrantha, Markhamia lutea*, *Croton macrostachyus*, *Croton megalocarpus, Lantana camara*, *Tithonia diversifolia and Acacia mearnsii*. Ferns occur in the area indicating that the soils are acidic (low pH). Agro-forestry is practiced in the area by integration of *Grevillea robusta, Eucalyptus* species, *Azandirachta indica* (Neem), and fruit trees such as *Mangifera* *indica (*mangoes*), Psidium guajava* (guavas), *Carica papaya* (paw paw) and avocadoes. Coffee occurs in some scattered farms. Rainfed cultivation of subsistence crops such as maize, bananas, beans, cassava, sweet potatoes, pigeon peas, dolichos beans, kales, cabbages, cow peas, pumpkins, sorghum and sugarcane is dominant in KYEIS. Application of irrigation water is mainly done for income generating crops such as tomatoes, French beans, kales, cabbages, and paw paws. An investment in irrigation is determined by a farmer's ability to buy irrigation water pipes. Livestock rearing (cattle, goats and sheep), bee keeping, poultry and brick making are important land uses in KYEIS.

3.2.6 Land Tenure

Land ownership in the KYEIS is predominantly free hold with private ownership of the land. The type of land ownership determines the investments done on soil and water conservation measures. Land demarcation helps establish recognized boundaries for individual land ownership and therefore encourages investments on the land or undertaking the necessary soil and water conservation practices. In recent years the farm sizes are decreasing due to inheritance and population pressure resulting in more subdivision of land. Though this may not have reached alarming levels in the area, proper use of the available soil and water resources is crucial for the long term sustainability of the production systems in KYEIS since the land resources are fixed.

3.3 WORKING METHODS

3.3.1 Field soil characterization and collection of other land and environmental data

Soil characteristics were studied from augerhole and mini pit observations. The characteristics which included soil drainage, depth, colour, texture, consistency and presence of concretions were described and recorded on Kenya Soil Survey (1989) standard forms. The soil colour was determined through use of the Munsel Color Chart (1975). A representative soil profile pit for the major soil type in the KYEIS was sited, dug, described (FAO, 1977) and sampled for laboratory chemical and physical analysis. Soil classification was done according to FAO/UNESCO/ISRIC (1997). The soil profile pit sited represented the lower parts of the hilly terrain. Composite soil samples were taken from a 0-20 cm depth for fertility analysis. The composite soil samples were taken from the lower, middle and upper parts of the scheme as shown in Table 4. Information on vegetation, land use, visible degradation features/indicators such as erosion features, plant nutrient deficiency symptoms, 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.

Table 4: Location of soil profile pit and fertility samples

No. and type of observation/sample	Easting	Northing
1 profile pit and fertility	037˚ 23.628'E	01˚ 47.185'S
2 fertility sample	037˚ 23.150'E	01˚ 46.464'S
3 fertility sample	037˚ 23.429'E	01˚ 46.755'S
4 fertility sample	037˚ 23.598'E	01˚ 47.454'S

3.3.2 Field soil physical determinations

The infiltration rates were determined using double ring infiltrometers. Saturated hydraulic conductivity for each identified soil horizon in every profile/mini pit was determined using augered holes of known diameter. Undisturbed soil samples were taken using core rings for bulk density and moisture content determination in the laboratory. Disturbed soil samples were also taken for moisture determination. Soil samples were also taken from the topsoil and subsoil from each of the described profile pit for laboratory determination of specific gravity, sieve analysis (for texture classification) and consistency.

3.3.3 Laboratory analysis

Samples taken from the field were analysed for chemical and physical properties following procedures described by Hinga *et al*. (1980). pH-H2O and Electrical Conductivity (EC) were measured in a 1:2.5 soil/water suspension. Exchangeable cations 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 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 and organic carbon by the Walkley and Black method.

Soil fertility (available nutrients) was determined by the Mehlich method which involves the extraction of soil by shaking for 1 hour with 1:5 ratio 0.1N HCL/0.025N H2SO4. Ca, K and Na were determined by EEL – flamephotometer after anion resin treatment for Ca. Both Mg and Mn were determined colorimetrically. Phosphorus was determined by Vanodomolydophosphoric yellow colorimetrically. Electrical conductivity of the extract (ECe) was estimated to be 3 times EC. Exchangeable sodium per cent (ESP), sodium adsorption ratio (SAR), residue sodium carbonate (RSC) and CEC-clay were respectively calculated according to the following equations:

ESP = Na/CEC x 100
SAR = Na/√(Ca+ Mg)/2
RSC = (CO3 +HCO3) – (Ca xMg)
CEC-clay = (CEC-soil – (4x%C)/%clay)100

The soil texture was determined by the hydrometer method. Bulk density and moisture content for disturbed and undisturbed samples were determined as described by Hinga et al., (1980). The particle density was determined using air pyknometer. The moisture content was determined for each soil horizon at pF 2.0 and 4.2. The total water holding capacity was determined for each horizon as the difference between the water content (in volume basis) at pF 2.0 and 4.2. The total water holding capacity of each profile was determined by the summation of the total water holding capacity of the individual soil horizon. The soil Atterberg limits (liquid and plastic limits) were determined using the Casagrande apparatus.

The aggregate stability was determined by dry sieving. The soil samples were air-dried and put on top of a set of sieves of 2.0, 1.0, 0.5, 0.25 and 0.15 mm, fixed on the vibrax with a unit timer. After shaking for 5 minutes, the weight fractions of the sample retained on the sieves were weighed and the size fraction on each sieve determined. The mean weight diameter (MWD) i.e. the sum of each fraction times the corresponding mean mesh size of the two sieves passing and retaining the fraction was determined and the following formula used to calculate MWD thus:

MWD=∑xiwi, where xi is the mean diameter of each size fraction and w is the proportion of the total sample weight occurring in the corresponding size fraction.

3.3.4 Legend construction

Based on the physiography, a geology/parent material and soil characteristic in that order, a soils legend was made for the identified soils within the scheme. The physiographic units recognized in the area are the lower parts of the hills which constitute the major irrigation area of the scheme and the associated adjacent minor valleys, denoted as H and V respectively. For geology/parent material, the metamorphic rocks consisting of undifferentiated banded gneisses rich in quartzitic and muscovitic composition cover the hills and are denoted by letter U. The alluvial and colluvial materials derived from the undifferentiated gneisses which cover the minor valley are denoted by letter A. Letters r and g represent red and grey soil colour respectively. Letter p indicates occurrence of moderately deep soils (50-80 cm), in some parts of the soil unit.

3.4 SOILS

3.4.1 Soils of the hills and slopes

The soils of the hills are somewhat excessively drained to well drained, moderately deep to very deep, dark red to very dark brown, friable to firm, sandy clay loam to clay and are classified as Ferric Luvisols/Lixisols and Ferralic Cambisols. The soils indicate NPK deficiency. Due to their structure, the soils are prone to sealing and crusting, rill and gully formation, and slumping. The topsoil is dark reddish brown (2.5YR3/4) to dark brown (10YR3/3) with a micaceous, massive platy-like structure which breaks to weak, medium subangular blocky structure. Its consistency ranges from slightly hard to hard when dry, friable to firm when moist, slightly sticky to sticky and slightly plastic to plastic when wet. Texture ranges from sandy clay loam to clay. The subsoil is dark red (2.5YR3/6) to very dark brown (10YR2/2) with a sandy clay loam to clay texture. Structure ranges from weak, fine to medium subangular blocky to weak to moderate, medium, prismatic structure breaking to weak to medium, subangular and angular blocky structure. The consistency ranges from slightly hard to hard when dry, friable to firm when moist and slightly sticky to sticky and slightly plastic to plastic when wet. For description of a representative profile pit, with analytical data, see appendix 1.

3.4.2 Soils of the minor valleys

The soils are moderately well drained to poorly drained, deep to very deep, dark brown to black, friable to firm, mottled, and stratified in places and are classified as Chromic Luvisols; Mollic Gleysols and Fluvisols.

3.5 SOIL HYDRAULIC PROPERTIES AND CROPPING SYSTEMS

3.5.1 Hydraulic conductivity and infiltration rate

Infiltration rate is a very important hydraulic property of soils in partitioning the rain and irrigation water into run-off and water entering the soil profile. It is also the principle determinant of the water supply duration per irrigation setting. Hydraulic conductivity is a measure of the internal drainage, deep water percolation and hence the irrigation efficiency and it is expressed in the following equation:

$$K = (1.15R (\log ho + R/2) - \log ht + R/2))/t$$

Where:

K = Hydraulic conductivity in cm/hour
ho = Initial head in cm
R = Radius of the augerhole in cm
ht = The final head in cm
t = Time for the drop of hydraulic head from ho to ht in hours

In Kyeekolo irrigation scheme, the soils are generally uniform and homogeneous in terms of properties that influence the soil moisture regimes, hence irrigation scheduling. The main crop grown is the French beans for export markets, using sprinkler and furrow irrigation methods. The proposed number of irrigators is 60 each with an average acreage of 2.3 ha. However, the water supply is very limiting, thus requiring savings on water by maximizing the production for every millimeter of water used in the production. This requires increased inputs on soil fertility management and conservation of soil quality, which is currently undergoing severe degradation. The degradation is caused by high soil compactness and erosion on the steep slopes. The soil compactness is reflected in relatively low infiltration rates and hydraulic conductivity as shown in Table 5.

Table 5: Hydraulic properties of the soils of Kyeekolo scheme

Profile No	Depth (cm)	K (cm/hour)
1	0-28	7.8
	28-53	12.4
	53-84	2.0

3.5.2 Bulk density and water retention capacity of the soils

The total water retention capacity of the soils is expressed in volume basis as a product of bulk density and the difference between soil moisture content at pF 2.0 and pF 4.2 (Table 6). The readily available soil water is taken as 50 % of the total available water for irrigation purposes. For the design of irrigation system, the fraction (p) of the total soil water retention capacity at which soil water has to be replenished has to be defined. This is the proportion of the total available soil water that can be depleted without causing the actual evapotranspiration (ETa) to become less than the maximum evapotranspiration (ETm). This means that when soil water is replenished before it becomes less than this fraction, the irrigated crops will not experience moisture stress. Therefore, the value of the fraction depends on the crop, the magnitude of ETm and the soil (Tables 6 and 7).

Table 6: Bulk density and soil moisture retention characteristics in the soil profile

Soil depth (cm)	Bulk density (g/cc)	% soil moisture at pF 2.0	% Soil moisture at pF 4.2	Total soil moisture	Total water holding capacity	Available water holding capacity (mm/m)
0-16	1.37	33.5	12.5	33.6	101.1	50.5
16-50	1.32	31.3	10.8	69.7		
50-127	1.39	34.0	11.4	174.0		
127-150	1.35	31.9	10.9	48.3		

Some crops, such as most vegetables, continually need relatively wet soils to maintain ETa=Etm. Other such as cotton and sorghum, can deplete soil water further before ETa falls below ETm. According to FAO (1986), crops can be grouped according to the fraction (p) to which available soil water (Sa) can be depleted while maintaining ETa equal to ETm (Table 7 and 8).

Table 7: Crop groups according to soil water depletion

Group	Crop types
1	Onion, Pepper, potato
2	Banana, cabbage, cow pea, tomato
3	Alfalfa, bean, citrus, ground nut, pineapple, sunflower, water melon
4	Cotton, maize, safflower, sorghum, soybean, sugar cane

Table 8: Soil water depletion fraction (p) for crop groups and ETm

Crop group	ETm mm/day								
	2	3	4	5	6	7	8	9	10
1	0.50	0.425	0.350	0.300	0.250	0.225	0.200	0.200	0.175
2	0.675	0.575	0.475	0.400	0.350	0.325	0.275	0.250	0.225
3	0.80	0.700	0.600	0.500	0.450	0.425	0.375	0.350	0.300
4	0.875	0.800	0.700	0.600	0.550	0.500	0.450	0.425	0.400

The engineering properties of the soil

The engineering properties considered were particle density, aggregate stability and soil consistence (Atterberg's limits). The three Atterberg's limits (moisture contents in %) determined are liquid limit (LL), sticky limit (SL) and plastic limit (PL) as shown in Table 9.

Table 9: The engineering properties of the soil profile

Depth cm	Particle density g/cc	Aggregate stability					Atterberg's limits		
		xi_1wi_1	xi_2wi_2	xi_3wi_3	x_4iwi_4	$\sum xiwi$	LL	SL	PL
0-30	2.62	1.074	0.148	0.065	0.003	1.290	45.6	38.4	27.3
30-60	2.60	1.411	0.129	0.040	0.001	0.002	32.3	27.9	21.6

3.6 LAND DEGRADATION AND MANAGEMENT

Land degradation is defined as the decline in the productive capacity of an ecosystem due to processes induced by human activities. It leads to a significant reduction of the productive capacity of land. Human activities contributing to land degradation include unsustainable agricultural land use, poor soil and water management practices, deforestation, removal of natural vegetation, frequent use of heavy machinery, overgrazing, improper cropping/rotation and poor irrigation practices. Within the scheme, land degradation is caused by several processes including soil erosion, nutrient depletion and fertility decline, soil surface sealing and crusting, clearance of vegetation/vegetation depletion, and mass wasting (soil slumping).

3.6.1 Erosion susceptibility, sealing and crusting

Soil susceptibility to erosion was determined by taking into consideration the climate (rainfall erosivity), topography (slope steepness and length) and soil erodibility (Weeda, 1987). The soils within the scheme indicate moderate to high susceptibility to erosion (Table 10) while those in the adjacent upper parts of the hilly terrain indicate high to very high susceptibility to erosion. The main contributing factor to erosion susceptibility is slope steepness and slope length compounded by high soil erodibility due to low organic matter content and high silt content relative to clay content in the surface horizons.

Table 10: Erosion susceptibility and Erosion hazard in the project area

Mapping Unit	Erosion Susceptibility	Vegetation/land use/conservation measures/ management	Erosion Hazard
HUp	Moderate to high	Deforestation; cutting of forests/woodlots; growing annuals; up-slope tillage; unmaintained, defective or no terraces; trash lines	Severe - very severe
VXb	Low –moderate	Swampy vegetation (reeds) dominant; arrowroots, sugarcanes, vegetables and bananas	Non- Slight

The high susceptibility to erosion is due to the occurrence of strong splash and rill erosion on bare soils leading to decapitation of the topsoil thus exposing the compact and less fertile subsoil or the weathering rock. Gully erosion occurs along footpaths and cattle tracks. The occurrence of gravelly or stony soil surface indicates selective removal of the fine soil particles by splash erosion from the topsoil leaving the coarse soil components. Once erosion has been triggered, slope steepness and length determine the rate at which it proceeds. Therefore, it is recommended that the upper cultivated parts of the hilly areas adjacent to the scheme with slopes greater than 45% be permanently left under natural and/ or planted vegetation cover to act as water erosion control areas.

To reduce the effect of slope steepness and length on erosion, physical soil conservation measures that would reduce slope length and steepness are necessary. These include bench, fanya juu and stone terraces which would require to be stabilized by planting grasses (also source of livestock fodder) on them. Such grasses are Napier grass, bana grass. Leguminous trees and shrubs may also be planted to act as agroforestry species that may also fix atmospheric nitrogen. Effective control can be attained by combining physical soil and water conservation technologies with agronomic and cultural practices.

The soils indicate moderate to high susceptibility to surface sealing and crusting. This is indicated by the occurrence of moderate to strong, 1-5 cm thick surface crusts on bare soils. Sealing and crusting hinders water from infiltrating into the soil thus generating runoff which leads to rill and gully erosion. In addition, the crusts hinder seedling emergence thus causing non-uniform seedling emergence which affects crop yields. As surface sealing and crusting is due to unstable topsoil aggregates mainly as a result of low organic matter and high silt content in the topsoil, there is need to incorporate farmyard manure (FYM) or compost in the soils to improve the structural stability of the topsoil. This would result in improved water and nutrients holding capacity of the soils, in addition to supplying nutrients upon decomposition.

The U-shaped valleys with slopes of 0-2 % have very low to low susceptibility to erosion while the V-shaped valleys indicate moderate susceptibility to erosion, sealing and crusting. It is however necessary to maintain protective surface cover against raindrops impacts. As the valleys occur on the lower parts of the incised hills, the soils protection against erosion is very much dependent on the land use in the unit and on conservation measures adopted in the adjacent upper hills slopes.

3.6.2 Erosion hazard

Erosion hazard is a measure of the degree of soil erosion that may occur near future. When erosion is already clearly evident, the erosion hazard expresses the intensity of the erosion process or the degree of soil loss which is expected from a specific form of land use, management and conservation practices. In arriving at the erosion hazard classes shown in Table 10, consideration was given to the erosion susceptibility classes, visible erosion features, land use, vegetation type, presence of surface gravels, stones, rocks and boulders, type of conservation measure(s) (physical, biological/agronomic or cultural), their state and effectiveness. As a result, the hilly terrain indicates severe erosion hazard. This is due to lack of terraces in some farms and where they occur are not properly spaced , not maintained and not stabilized at the edges rendering them ineffective in soil erosion control. All these factors were found to cause overflow of collected runoff leading to breaking of the terrace banks. Other causal factors include up-slope tillage, non-application of organic and inorganic fertilizers, and cultivation of annuals dominantly, in some cases as monocrops. The hilly area (unit HUp) is very prone to soil slumping/mass wasting due to steep slopes (>16 %) and vegetation clearing. This leads to enormous soil losses during the rainy seasons through the processes of erosion and soil slumping. Indigenous trees such as *Bridelia micrantha, Kigelia Africana, Croton macrostachyus, Cordia abyssinica, Acacia mearnsii, Mangifera indica, Rhus natalensis and Markhamia lutea,* etc, were found to be very effective in the control of soil erosion.

3.6.3 Mass wasting/soil slumping

This is a predominant phenomenon in the hilly terrain including the area covered by the KYEIS. Where selective clearing of vegetation was done leaving in place indigenous trees as opposed to complete vegetation clearing, soil slumping/land sliding was controlled. It was observed that the indigenous trees were very effective in controlling stream bank erosion. Therefore, stabilization of bench terraces by a combination of the indigenous trees, N-fixing trees and Napier grass should be promoted in the area. In addition, where stones and rock boulders occur, terraces using these materials should also be constructed to enhance conservation of the soil and create more space for cultivation. Contour farming (cropping/cultivation/ploughing) and strip cropping are necessary to control eroded soil from being transported outside individual farms. This allows the retention of any eroded soil within the farm. Over-application of irrigation water either by farmers or due to breakages of water pipes was found to trigger soil slumping in the adjacent areas. Therefore, careful application of the required amount of water is needed together with frequent checking where water pipes could have been broken.

3.6.4 Sedimentation/siltation

A lot of soil is eroded from the hilly terrain by runoff and is deposited into Kyeekolo stream and its valley. The wetlands along the stream with the vegetation of reeds were very effective in sieving the water hence making it clean, implying the effectiveness of the wetlands along the stream as a filter of sediments. There if therefore the need to maintain the wetlands under natural vegetation to act as a buffering and filtering zone of sediments for supply of clean and safe water downstream. The wetlands would also conserve biodiversity in these ecosystems.

3.6.5 Soil fertility decline and soil acidification

The main components of 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 for plant growth. The chemical soil fertility of the soils within the scheme is inherently variable due to differences in mineralogical composition of the metamorphic parent material. The variations are also due to differences in soil management between the farmers and position of the farm along the slope. Generally, the soils of the hilly terrain are highly weathered and are therefore chemically poor as indicated by low base saturation (<50 %), CEC-soil and CEC-clay (< 24 cmol/kg) as shown in Table 11. These parameters indicate high degree of leaching of the exchangeable bases (see appendix 3) .

Table 11: Chemical characteristics of soils of the project area

Parameter	**Topsoil**	**Subsoil**
pH-H2O	5.5	5.5 – 5.8
CEC-soil (cmol/kg)	13.2	10.2 – 19.2
CEC-clay ,,	21.8	16.7 – 32.7
Base saturation (%)	44	40 – 55

Low plant nutrients in the topsoils could be due to leaching, erosion and nutrients mining through harvesting crops. The soils of the the valley bottoms are more fertile due to periodic deposition of materials from the adjacent higher areas. The occurrence of ferns and wattle trees in the area indicates low soil pH. Therefore, the causal factors are mainly naturally induced by the interaction between climate and parent material/geology but accelerated or controlled by anthropogenic factors which include mainly land use and management aspects.

Nutrients are essential for every crop. Therefore, the maintenance or improvement of soil fertility should be an integral part of farm management for both cash and subsistence farming. In the scheme, continuous cultivation takes place resulting in a decline in crop yields due to lack of addition of organic and inorganic inputs, which results in nutrient mining. Therefore, use of farmyard or compost manures and inorganic fertilizers is essential to increase crop production per unit area. The topsoil fertility samples indicate strong to medium acidity with a pH range of 5.0-6.0. Nitrogen, phosphorus and organic matter are low in all the samples K, Ca, Cu and Zn is low in some of the soil samples as shown in Table 12. To improve organic matter content in the soil, well decomposed manure (FYM) or compost should be applied to the soil at the rate of 10 tonnes/ha. 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 the activity of soil fauna thus improving soil physical aspects such as aeration and moisture holding capacity of the soil apart from improving the nutrient holding capacity of the soils. To supplement the deficient N, P and K, fertilizers that are non-acidifying containing these nutrients should be applied such as N: P: K 17:17:17 at the rate of 250 kg/ha. Calcium can be supplied by applying CAN which apart from supplying Ca will also supply N. CAN should be applied at the rate of 200 kg/ha. The presence of some Hp indicates leaching of the bases and the replacement of the exchange sites by aluminium and hydrogen ions. Thus soil degradation by the process of soil acidification and aluminium toxicity is taking place in the scheme.

Table 12 Available nutrients in the topsoils (0-20 cm depth) of the scheme

Parameter	Sample no. 1	2	3	4
pH-H2O	6.0	5.0	5.9	5.0
Hp(me%)	-	0.3	-	0.4
C (%)	1.24	0.90	0.46	0.90
N (%)	0.08	0.07	0.05	0.06
Na (me%)	0.29	0.37	0.17	0.13
K ,,	0.68	0.40	0.18	0.16
Ca ,,	3.6	3.6	1.6	1.4
Mg ,,	2.44	2.85	3.28	2.36
Mn ,,	0.44	0.29	0.36	0.81
P (ppm)(Mehlich)	12	15	5	3
Fe ,,	31.8	37.4	91.4	51.5
Cu ,,	6.83	2.85	0.85	4.43
Zn ,,	8.52	4.56	3.20	4.93

3.6.6 Vegetation degradation

Vegetation degradation is attributed to cutting trees, overgrazing and clearing for cultivation. In the scheme, woodlands and bushlands have been cleared for cultivation, building, furniture, fencing and charcoal production. Increased pressure to clear vegetation in the steep slopes and hilly parts of the scheme, stream valleys and along River Kyeekolo without appropriate water conservation measures will endanger the water resources and soil productivity. There is a need therefore to conserve the remaining vegetation resources in addition to planting more trees for present and future.

3.7 POTENTIAL IMPACTS OF RESULTS FROM THE STUDY

The proposed technologies are to optimize use of rainfall and irrigation water through enhancement of soil and water conservation, soil fertility improvement through use of FYM or compost with application of inorganic fertilizers, timely planting and weeding. Other technologies proposed are contour ploughing/tillage and planting, strip cropping/crop rotation and diversificfation, and use of certified seeds. If implemented, the result will be in increased crop yields per unit area and livestock products especially milk. The resultant impact would be food self sufficiency (security) and alternative sources of household income in the scheme.

Increased soil water storage capacity would result in a longer groundwater recharge thus making the streams to have flowing water most of the year. In addition, effective physical, agronomic and cultural soil and water conservation measures would lead to reduced run-off and hence more and clean good quality stream/river water due to reduced siltation/sedimentation. Growing of diversified high value horticultural crops such as tomatoes, egg plants/brinjals, onions, karela, okra, french beans, soya beans, dudhi, citrus and avocados would create alternative sources of income with more people venturing into this investment thus creating more job opportunities. Wealth creation and food security would result in improved livelihoods and access to medical and education facilities.

Integration of agro-forestry species in the farms and planting woodlots would create more carbon sinks, as plants use carbon dioxide and release oxygen in their metabolism leading to a healthy environment. Planting N-fixing trees/shrubs would help in improvement of the soil fertility. Conservation and good management of the wetlands would result in an enhanced conservation of biodiversity, filtering and buffering capacity in these areas resulting in more clean and safe water downstream. Increased infiltration and greater soil water storage capacity would lead to reduced flooding hazard in the lower parts of the Kyeekolo stream.

3.8 CONCLUSIONS AND RECOMMENDATIONS

Toto control land degradation in the KYEIS area, the following are some of the measures that can be carried out:

1. Areas adjacent to the scheme (with slopes >45 %) need to be left as woodlots/forests, and with mainly indigenous trees such as *Bridelia micrantha*, *Grevillea robusta* and *Croton machrostachyus,* etc. to maintain soil cover. Afforestation with these trees is crucial in the steep areas while selective vegetation clearing should be adopted when opening new areas for cultivation. Agro-forestry in the area should be promoted while *Eucalyptus* species should be replaced gradually with indigenous trees. Planting a belt of these indigenous trees at the edge of the valleys is important for water conservation.
2. A combination of physical, agronomic and cultural methods of soil and water conservation is necessary. The physical methods suitable in the undulating to hilly terrain with moderate to severe erosion hazard include construction of well spaced, stabilized, maintained and effective bench, fanya juu and stone terraces. Agronomic measures would include strip cropping with crop and pasture combinations, timely planting, planting adapted cultivars and intercropping. Cultural practices would include contour farming (planting, tilling/ploughing) and crop rotation.
3. The soils show low levels of organic matter and hence the need to apply FYM or compost.
4. N, P and K are deficient and need to be improved in the soils by applying non-acidifying fertilizers such as N:P:K 17:17:17 or 23:23:0 while CAN should be applied to supply calcium where deficient.
5. The use of pestcides to control pests and diseases may pollute surface and underground water. Therefore application of the right type and quantity is important. Proper advice should be provided to the farmers.
6. N-fixing plants should be incorporated in the farming system in the area. *Tephrosia vogelii* should be considered as it is locally occurring and has multipurpose use as a control of aphids, cutworms, caterpillars, beetles, termites and stem borers, protection of stored maize, control of ticks and repellant for moles, mosquitoes, bedbugs and cockroaches.
7. Strategic parts of the valleys should be left as wetlands for conservation of the biodiversity, and to act as water buffering and filtering areas and thus maintain the quality of the streams water.
8. Roof and rock catchments should be considered for water harvesting.
9. There is need to diversify horticultural crops in the scheme. Such crops would possibly include soya beans, french beans, okra, brinjals, karela, dudhi, onion, bananas and citrus. Diversification is necessary to avoid flooding the market with certain crops which affets the prices of the commodities.
10. There is need to utilize the available water more efficiently for crop production without wastage by adopting technologies that use as little water as possible. This will not only avail more water for more irrigated acreage but will also control soil slumping/mass wasting.
11. The water from Kyeekolo stream is suitable for irrigation and can therefore be used for growing high value horticultural crops. However, monitoring salts and fertility levels in the soils of the scheme is necessary preferably after every 2-3 years.

REFERENCES

Braun, H.M.H. 1984. Evaporation in Kenya. Miscellaneous Paper, Kenya Soil Survey, Nairobi.

FAO, 1977. Guidelines for Soil Profile Description, FAO, Rome.

FAO, 1986. Guidelines: Land evaluation for rainfed agriculture. FAO Soils Bulletin, 52. FAO, Rome.

FAO-UNESCO, 1997**.** Soil Map of the World. Revised Legend with corrections and updates. Technical Paper 20, ISRIC, Wageningen.

Gachathi, F. N. 1989. Kikuyu Botanical Dictionary. Publication supported by gtz and printed by AMREF, Printing Dept., Nairobi.

Government of Kenya, 1999. Population Census, Central Bureau of Statistics, Ministry of National Development, Nairobi.

Hinga, G., Muchena, F.N. and Njihia, C.M. 1980. Physical and Chemical Methods of Soil Analysis. National Agric. Res. Labs, Nairobi.

Jaetzold, and Schmidt, 1983. Farm Management Handbook of Kenya, Vol.II/C East Kenya. Ministry of Agriculture, Nairobi, Kenya.

Kenya Soil Survey Staff, 1987. Manual for soil survey and land evaluation. Vol. 1. Miscellaneous paper no. M24, Kenya Soil Survey, Nairobi.

Munsell Color Charts, 1975. Munsell soil color charts, Baltimore, Maryland.

Richards, L. A. (ed). 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook No.60, Washington DC.

Sombroek, W.G., Braun, H.M.H. and Van Der Pouw, B.J.A. 1982. Exploratory Soil Map and Agro-Climatic Zone Map of Kenya. Exploratory Soil Survey Report No.E1, Kenya Soil Survey, Nairobi, Kenya.

UNEP/GEF, 2005. Protecting the Environment from Land Degradation. UNEP's Action in the Framework of the Global Environment Facility.

Weeda, A. 1987. Ratings for land qualities in Kenya. Internal Communication No. 29. Kenya Soil Survey, Nairobi.

Woodhead, T. 1968. Potential evaporation in Kenya, E.A.A.F.R.O., Nairobi.

APPENDIX 1 – PROFILE DESCRIPTION AND ANALYTICAL DATA

General site information

Soil map unit code	: HUp
Type of observation/area	: profile pit; Kyeekolo Irrigation Project, Kilungu division-Makueni district
Location/altitude	: easting 037˚ 23.628' and northing 01˚ 47.185'; 1722 m asl
Soil parent material	: undifferentiated various banded gneisses
Landform	: hills
Relief/slopes	: hilly; slopes >16%
Land use	: cultivation of maize, beans, cabbages, peas, guavas and avocados
Erosion type	: strong splash and rill erosion between terraces, gully on cattle tracks and footpath
Surface sealing and crusting	: strong, 1 – 3 cm thick
Internal drainage	: well drained
Effective soil depth	: > 150 cm
Soil classification	: Ferralic Cambisols

Profile description

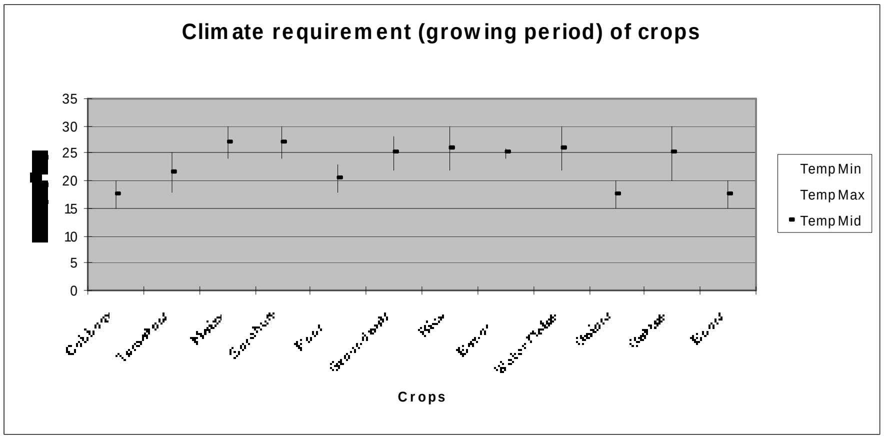
Horizon	Depth
Ap	0-16 cm dark reddish brown (2.5YR3/4, moist);sandy clay/clay; weak, medium, sub-angular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; many biopores and very fine pores; common very fine and fine roots; clear and smooth transition to:
Bw1	16-50 cm dark reddish brown (2.5YR3/4, moist); clay; weak, fine to medium, subangular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; many biopores, many very fine pores; muscovite micas; common very fine and fine roots; clear and smooth transition to:
Bw2	50-95 cm dark brown (10YR3/3, moist); clay; moderate, medium, prismatic structure breaking to weak, medium, subangular and angular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; common very fine pores; quartz gravels and muscovite micas; few very fine and fine roots; gradual and smooth transition to:
Bw3	95-127 cm dark yellowish brown (10R3/4, moist); clay; moderate, medium, prismatic breaking to weak to moderate, medium, subangular blocky structure; hard when dry, friable when moist, sticky and plastic when wet; few very fine pores; muscovite micas; very few, very fine and fine roots; gradual and smooth transition to:
Bw4	127-159cm dark yellowish brown (10R3/6, moist); clay; weak, medium, prismatic breaking to weak, medium, subangular blocky structure; slightly hard to hard when dry, friable when moist, sticky and plastic when wet; few very fine pores; muscovite micas; very few, very fine and fine roots

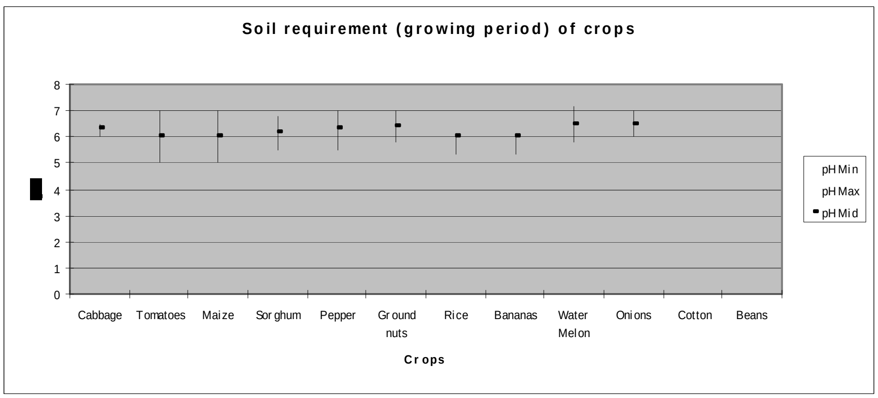
Laboratory data for the profile pit

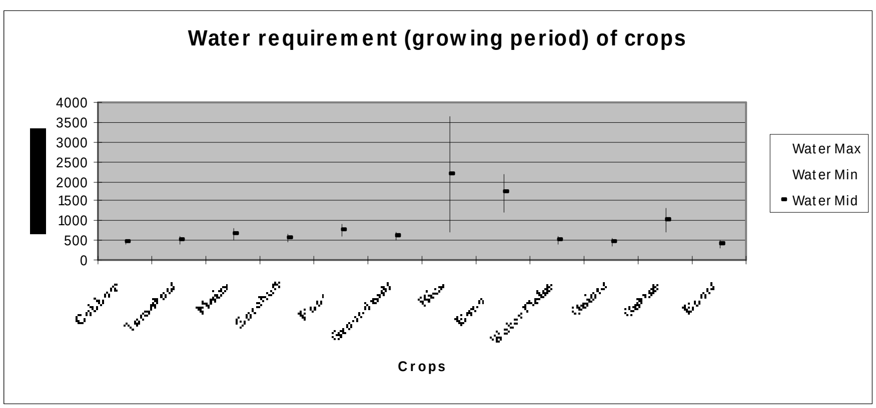
Horizon designation	Ap	Bw1	Bw2	Bw3	Bw4
Horizon depth (cm)	0 - 16	16 – 50	50 - 95	95 - 127	127 – 159
pH-H2O (1:2.5)	5.5	5.5	5.7	5.8	5.8
EC dS/m ,,	0.04	0.03	0.07	0.06	0.05
ECe dS/m ,,	0.12	0.09	0.21	0.18	0.15
C (%)	1.23	1.17	1.20	1.25	0.80
CEC-soil (cmol/kg)	13.2	13.4	19.2	14.0	10.2
CEC-clay (cmol/kg)	21.8	21.8	32.7	21.4	16.7
Exchangeable Calcium ,,	3.48	3.57	7.08	5.71	2.81
Magnesium ,,	1.82	1.76	2.24	1.56	0.91
Potassium ,,	0.24	0.12	0.24	0.14	0.12
Sodium ,,	0.25	0.15	0.40	0.35	0.25
Sum of cations	5.79	5.6	9.96	7.76	4.09
Base saturation (%)	44	42	52	55	40
ESP	2	1	2	2	2
Texture – hydrometer					
Sand %	48	50	46	50	48
Silt %	14	10	10	8	10
Clay %	38	40	44	42	42
Texture class	SC	SC	SC	SC	SC
Silt:clay ratio	0.4	0.2	0.2	0.2	0.2

APPENDIX 2

Climate, soil and water requirements (growing period) of the envisaged crops







APPENDIX 3. CLASSIFICATION OF SOME SOIL PROPERTIES

Soil reaction (pH) classification

pH	Class name
<4.5	Extremely acid
4.5 – 5.0	Very strongly acid
5.1 – 5.5	Strongly acid
5.6 – 6.0	Medium acid
6.1 – 6.5	Slightly acid
6.6 – 7.3	Neutral
7.4 – 7.8	Mildly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9.0	Strongly alkaline
>9.0	Very strongly alkaline

Classification of EC

EC2.5 (dS/m)	Derived ECe (dS/m)	Class name
0 – 1.2	0 – 4	Non saline
1.2 – 2.5	4 – 8	Slightly saline
2.5 – 5.0	8 – 15	Moderately saline
5.0 – 10.0	15 – 30	Strongly saline
>10.0	>30	Excessively saline

Classification of ESP

ESP	Class name
0 – 6	Non sodic
6 – 10	Slightly sodic
10 – 15	Moderately sodic
15 – 40	Strongly sodic
>40	Excessively sodic

Classification of % C, CEC and % BS

Class name	%C	CEC-soil (cmol/kg)	BS%	Silt/clay
Very low	<4.0	<5	<10	<0.2
Low	0.5 – 0.9	5 – 15	10 – 29	0.20 – 0.59
Medium	1.0 – 1.9	15 – 25	30 – 49	0.60 – 1.00
High	2.0 – 5.0	25 – 40	50 – 79	>1.00
Very high	>5.0	>40	>80	

Kenya Agricultural Research Institute

National Agricultural Research Laboratories

Kenya Soil Survey

SUSTAINABLE LAND MANAGEMENT IN KISIOKI SMALLHOLDER IRRIGATION SCHEME, KAJIADO DISTRICT

BY

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4.1 INTRODUCTION

Kisioki Irrigation Scheme (KISIS) is a community based, smallholder irrigation initiative focusing on economic empowerment of its members through the utilization of natural land resources, mainly soils and water. The source of irrigation water is at the confluence of Rombo A and B springs.
The local community depends on water from this stream for livestock, domestic needs and irrigated agriculture. The main objective of initializing the scheme was to improve household incomes and food self sufficiency through sustainable utilization of the spring/stream water and soil resources through irrigated agriculture and advocating environmental conservation. The need to implement appropriate natural resource management and conservation strategies is crucial in enhancing food security and economic development in the scheme. The purpose of this work was therefore to assess the current status of the soils, water and other land resources in order to provide information that would facilitate the development of management strategies for sustainable smallholder irrigated agriculture within Kisioki Irrigation Scheme.

4.2 THE ENVIRONMENT

4.2.1 Location, Communication and Population

The scheme is located in Rombo Location, Oloitokitok Division, Kajiado District in Rift Valley Province. Rombo Location is located at the Kenya-Tanzania border. The scheme is approximately bounded by longitudes 37˚ 45‘and 37˚ 50‘East, and latitudes 00˚ 45‘and 00˚ 50‘South, at an altitude of 1000-1200 m asl. The scheme has an area of about 150 ha, and is accessible through the Oloitokitok-Lassit-Rombo-Taveta road which is partly tarmacked upto Lassit. Other motorable roads and tracks pass through the project area. Rombo shopping centre is within the scheme. The area is cosmopolitan and multi-ethnic in composition with people from different parts of the Kenya and Tanzania. However the Maasai are the dominant people in the area. The people engage in livestock rearing, subsistence and horticultural farming, bee keeping and business activities. Table 1 shows the population of Oloitokitok Division, Kajiado District as per the 1999 population census and the projected population to the year 2020.

Table 1: Projected population of Oloitokitok Division, Kajiado District (1999 – 2020)

Year	1999	2000	2005	2010	2015	2020
Population	95,436	98,295	113,951	132,100	153,140	177,532
Population density	15	16	18	21	24	28

Source: GoK, 1999.

The high concentration of the people in Rombo area is attributed mainly to the high potential soils for agriculture and water availability for irrigated agriculture. Population density in the area is expected to rise in the up-coming Rombo market centre due to business expansion and increase in public and missionary institutions such as schools and dispensaries in the area. According to the above projections, the division population density of 15 persons/km² in 1999 is poised to almost double to 28 persons/km² in 2020. The population statistics imply an increasing population with a corresponding increase in demand and competition of the available resources. With time this trend could lead to over exploitation of the resources, especially soils and water leading to environmental degradation.

4.2.2 Climate

4.2.2.1 Rainfall, agro-climatic zonation, temperature and potential evaporation

The agricultural potential of an area is mainly determined by the climatic conditions especially rainfall, evaporation and temperature factors which are important for crop production. Rainfall in the area is bimodal with long rains occurring in March-May and the short rains between October and December. The scheme occurs in agro-climatic zone (ACZ) V and has a mean annual evaporation to mean annual rainfall ratio of 0.25-0.4 and is classified as semi-arid with a mean annual rainfall of 775 mm. ACZ V has a mean annual evaporation in the range of 1650-2300 mm. Mean annual temperatures are 22˚C – 24˚C which is considered to be warm. It has medium to low potential for agriculture, if soils are not limiting.

4.2.2.2 Evapotranspiration and moisture balance

The potential evapotranspiration (Et) i.e. crop water requirement is related to altitude with the low altitude areas having higher evaporation than higher altitude areas. The mean annual potential evaporation (Eo) for the area based on Wood head (1968) altitude equation at an altitude of 1120 m asl is 2025 mm. Mean annual potential evapotranspiration (Et) is assumed to be 2/3 Eo and is therefore estimated to be 1350 mm in the scheme. Rainfall (r) data has been used for Rombo mission meteorological data record for 16 years. Mean monthly Eo values have been calculated according to Braun (1984).

Table 2: Water balance for the Kisioki irrigation scheme

Parameter	Month												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Yr**
R	54	63	115	152	33	7	5	22	15	53	165	91	775
Eo	202	182	202	162	142	142	142	142	182	182	162	182	2025
Et	135	121	135	108	95	95	95	95	121	121	108	121	1350
r-Et	-81	-58	20	44	-62	-88	-90	-73	-106	-68	57	-30	-535

Data from Table 2 shows that the mean monthly rainfall exceeds evapotranspiration in the months of March, April and November. The area experiences rainfall deficits almost throughout the year. The periods December-February and May-October experience moisture deficits thereby requiring irrigation. Irrigation technologies that use little water with minimal losses and the accompanying appropriate soil and water management strategies should be considered within the prevailing socio-economic set up of the farmers.

4.2.3 Physiography and geology/parent materials

The physiographicallyof the area could be divided into gently undulating to gently undulating uplands with 2-5 % slopes and flat to very gently undulating plains with 0-2 % slopes. The soils are developed on basic igneous rocks which are predominantly olivine basalts, nepheline phonolites and basic pyroclastic rocks.

4.2.4 Drainage

Rombo River is the main source of water in the area and is in form of seepage from the volcanic footridges of Mt Kilimanjaro. The stream provides water for livestock, irrigation of ongoing smallholder farms and domestic use. Furrow irrigation is practiced through gravity. Table 3 shows analytical results of a water sample taken from the proposed intake and the allowable limits or safe level for parameters mostly used to classify water quality hazards according to Richards (1954). The parameters include pH, electrical conductivity (EC) which indicates total dissolved salts and hence salinity hazard, residue sodium carbonate (RSC) indicates carbonate and bicarbonate concentration hence alkalinization hazard, and the sodium adsorption ratio (SAR) indicates sodicity hazard.

The results indicate that the water is marginally suitable for irrigation with medium salinity and low sodium content. The level of bicarbonates content is high and require moderate soil leaching. Plants with moderate salt tolerance such as vegetables can be grown. The water sample from the shallow well has high salinity, low sodium content, high bicarbonate content and RSC. The water is therefore not suitable for irrigation purposes. The water may be used under special management conditions which include permeable soils, adequate drainage and provide considerable leaching. Salt tolerant crops such as barley, cotton, sugarbeet and asparagus can be planted. Periodic addition of organic matter to the soil in the form of farm yard manure or compost can improve the soils productivity.

Table 3: Irrigation water quality classification from River Rombo and well

Parameter	Water source		Suitability Class		
	Intake	Well	Safe	Marginal	Unsuitable
pH	6.5	7.5	6.0 – 8.0	≤6.0 – >8.0	<6.0 & > 8.0
EC (dS/m)	0.16	0.95	0.0 – 0.25	0.25 – 0.75	>0.75
Sodium (me/l)	1.30	8.7			
Potassium (me/l)	0.04	1.28			
Calcium ,,	0.13	0.47			
Magnesium ,,	0.31	4.0			
Carbonates ,,	Trace	Trace	0.0 – 1.25	1.25 – 2.5	>2.5
Bicarbonates ,,	1.86	10.5	0.0 – 1.25	1.25 – 2.5	>2.5
Chlorides ,,	0.75	1.19			
Sulphates ,,	1.3	2.07			
SAR	2.77	5.82	0 – 7	7 – 13	>13
RSC	1.75	6.03	0.0 – 1.25	1.25 – 2.5	>2.5

4.2.5 Vegetation and Land Use

The area has largely been cleared for cultivation and therefore the original natural vegetation is found along the spring as riverine vegetation. The riverine vegetation and remnants of the cleared vegetation in the cultivated areas included *Acacia* x*anthophloea, Balanites aegyptiaca, Tithonia diversifolia, Lantana camara, Croton megalocarpus, Euphorbia candelabrum, Kigelia africana, Bridelia micrantha, Markhamia lutea, Cordia abyssinica Ficus sycomorus, Ficus thonningii, Cassia didymobotrya, Ricinus communis, Carica papaya* (paw paws*), Psidium guajava* (guavas***), Solanum indicum, Salvadora and Datura stramonium.* The occurrence of *Salvadora* indicates that the soils are saline and/or sodic. Some of the tree species have medicinal and cultural values to the community. Among the crops grown in the area include maize, beans, green grams, bananas, mangoes, paw paw, cassava, pigeon peas, tomatoes, brinjals, onions, okra, kales, cabbages, dolichos beans, sunflower, sorghum, arrowroots, cow peas and pumpkins. Livestock rearing (cattle, goats and sheep) is an important land use in the scheme.

4.2.6 Land Tenure

Land ownership in the scheme is currently free hold and privately owned, while some land near the Rombo market center is trust land under the County Council. Some people hire land for cultivation within an agreed duration of time. Hwever, the type of land ownership determines the seriousness with which soil and water management measures are undertaken. Renting land in most cases leads to severe degradation as the tenants are obsessed with making maximum profits with minimal inputs. Thus it is very common for severe wind and water erosion, salinisation and/or sodification to occur on such land, sometimes leading to its abandonment.

4.3 WORKING METHODS

4.3.1 Soil characterization and collection of land resources data and environmental data

The soil characterization was conducted through augerholes and mini pit observations and the characteristics studied were soil drainage, depth, colour, texture, consistency and presence of concretions. The soil colour was determined through use of the Munsel Color Chart (1975). Three representative soil profile pits were dug and described according to FAO (1977) and sampled for laboratory chemical and physical analysis (Table 4). The FAO/UNESCO/ISRIC (1997) was used for soil classification. From five sites/locations around each profile pit within a radius of 10 m, composite soil samples were taken at a depth of 20 cm fertility analysis. Information on vegetation, land use, visible degradation features/indicators such water/wind erosion features, plant nutrient deficiencies, deforestation, waterlogging and siltation/deposition was collected. Also, information on the type of soil and water conservation measures, their maintenance and effectiveness was recorded when traversing the area.

Table 4: Location of the soil profile pits

Profile pit	Easting	Northing
1	037˚ 42.920’	03˚ 03.566’
2	037˚ 42.177’	03˚ 03.106’
3	037˚ 41.944’	03˚ 03.146’

4.3.2 Field soil physical determinations

The infiltration rates were determined using double ring infiltrometers. Saturated hydraulic conductivity for each identified genetic soil horizon in every profile pit was determined using augered hole whose diameter was measured. Disturbed soil samples were taken for moisture determination. Undisturbed soil samples were taken using core rings for laboratory determination of bulk density, hydraulic conductivity and moisture content. Soil samples were also taken from the topsoil and subsoil from each of the described profile pit for laboratory determination of specific gravity, sieve analysis (soil texture classification) and consistency. These determinations were done following the procedures described by Hinga *et al.* (1980).

4.3.3 Laboratory analysis

Samples taken from the field were analysed for chemical and physical properties following procedures described by Hinga *et al.* (1980). pH-H2O and Electrical Conductivity (EC) were measured in a 1:2.5 soil/water suspension. Exchangeable cations were determined by a flamephotometer/atomic absorption after leaching the soils with 1 N ammonium acetate at pH 7.0 while cation exchange capacity was determined after leaching the samples for exchangeable cations (CEC) 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, organic carbon by the Walkley and Black method.

Soil fertility was determined by the 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 (ECe) was estimated to be 3 times EC. Exchangeable sodium per cent (ESP), sodium adsorption ratio (SAR), residue sodium carbonate (RSC) and CEC-clay were respectively calculated according to the following equations:

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

The soil texture was determined by the hydrometer method. Bulk density and moisture content for disturbed and undisturbed samples were determined as described by Hinga *et al.* (1980). The particle density was determined using air pyknometer. The moisture content was determined for each soil horizon at pF 2.0 and 4.2. The total water holding capacity was determined for each horizon as the difference between the water content (in volume basis) at pF 2.0 and 4.2. The total water holding capacity of each profile was determined by the summation of the total water holding capacity of the individual soil horizon. The soil Atterberg limits (liquid and plastic limits) were determined using the Casagrande apparatus.

The aggregate stability was determined by dry sieving. The soil samples were air-dried and put on top of a set of sieves of 2.0, 1.0, 0.5, 0.25 and 0.15 mm, fixed on the vibrax with a unit timer. After shaking for 5 minutes, the weight fractions of the sample retained on the sieves were weighed and the size fraction on each sieve determined. The mean weight diameter (MWD) i.e. the sum of each fraction times the corresponding mean mesh size of the two sieves passing and retaining the fraction was determined and the following formula used to calculate MWD, thus:

MWD=$\sum x_i w_i$, where x_i is the mean diameter of each size fraction and w is the proportion of the total sample weight occurring in the corresponding size fraction.

4.3.4 Legend construction

Based on the physiography, geology/parent material and soil characteristics in that order, a soils legend was made for the different identified soils represented by the profile pits. The physiographic units recognized in the area are uplands denoted as U. For geology/parent material, basic volcanic rocks including basalts, phonolites and basic pyroclastics are denoted by letter B. Letters h and b represent humic topsoil and brown subsoil colour respectively.

4.4 SOILS

Two major soil units were identified in the uplands (units UBb and UBh):

Soils of unit UBb

The soils are well drained, deep to very deep, dark yellowish brown to very dark brown and friable when moist. The topsoil is very dark brown (10YR2/2), with a massive structure due to pulverization during ploughing. It is slightly hard to hard when dry, very friable to friable when moist, sticky and plastic when wet with a texture of sandy clay to clay. The subsoil is dark yellowish brown (10YR3/4) to very dark brown (10YR2/2) with a weak, fine to medium subangular blocky structure. It is slightly hard to hard when dry, very friable to friable when moist, sticky and plastic to slightly plastic when wet and the texture is gravelly clay to clay. The soils are susceptible to sealing and crusting and show weak to moderate 1-3 cm thick crusts on bare surface. The soils are prone to wind and water erosion and are classified as Haplic Luvisols, sodic phase. (For description of a representative profile pit with analytical data, see appendix 1, profile description no.1)

Soils of unit UBh

The soils are well drained to moderately well drained, deep to very deep, very dark greyish brown(10YR3/2) to very dark grey(10YR3/1), slightly hard to hard, very friable to firm, calcareous and sodic. The topsoils are very dark reddish brown (10YR3/2) to very dark grey (10YR3/1). The structure is porous massive due to continuous use of tractor and ox-plough which pulverize the topsoil thus destroying its structure. It is slightly hard when dry, friable when moist, sticky and plastic when wet with a texture range of sandy clay to clay. The soils are susceptible to sealing and crusting showing weak to moderate crusts of 1-3 cm thickness. The soils indicate volcanic ash influence from the positive sodium fluoride test reflected by the high silt/clay ratio of 0.6-0.7 in the topsoils. Slight splash erosion occurs on bare overgrazed surfaces. They are prone to wind erosion. Moderate splash, rill and gully erosion occur on these soils. The soils are classified as Calcic Luvisols, sodic phase and Vertic Luvisols, sodic phase (For description of the soils and representative soil profile pits see appendix 1, profile description nos.2 and 3).

4.5 SOIL HYDRAULIC PROPERTIES AND CROPPING SYSTEMS

4.5.1 Hydraulic conductivity and infiltration rate

Infiltration rate is a very important hydraulic property of soils in partitioning the rain and irrigation water into run-off and water entering the soil profile. It is also the principle determinant of the water supply duration per irrigation setting. Hydraulic conductivity is a measure of the internal drainage, deep water percolation and hence the irrigation efficiency and it is expressed in the following equation:

$$K = (1.15R (\log ho + R/2) – \text{Log } ht + R/2))/t$$

Where:

K = Hydraulic conductivity in cm/hour
ho = Initial head in cm
R = Radius of the augerhole in cm
ht = The final head in cm
t = Time for the drop of hydraulic head from ho to ht in hours

The variations in infiltration rates and hydraulic conductivity (Table 5) for the three different soil profiles in Kisioki irrigation scheme show that, different irrigation schedules are required for different soil types. This starts with determination of the extent and distribution of different soil types and cropping patterns proposed for each soil type. On this basis, appropriate irrigation methods and schedules may be designed for each soil types.

Table 5: Hydraulic properties of the soils of Rombo irrigation scheme

Profile No.	Depth (cm)	K (cm/hour)
1	0-20	4.34
	20-64	1.23
	64-113	2.88
	113-150	3.07
2	0-25	1.33
	64-80	0.67
	80-120	1.37
	120-150	4.90
3	0-15	0.44
	15-60	0.52
	60-113	0.89
	113-143	2.13

4.5.2 Bulk density and water retention capacity of the soils

The total water retention capacity of the soils is expressed in volume basis as a product of bulk density and the difference between soil moisture content at pF 2.0 and pF 4.2 (Table 6). The readily available soil water is taken as 50 % of the total available water for irrigation purposes. For the design of irrigation system, the fraction (p) of the total soil water retention capacity has to be defined, at which soil water has to be replenished. This is the proportion of the total available soil water that can be depleted without causing the actual evapotranspiration (ETa) to become less than the maximum evapotranspiration (ETm). This means that when soil water is replenished before it becomes less than this fraction, the irrigated crops will not experience moisture stress. Therefore, the value of the fraction depends on the crop, the magnitude of ETm and the soil (Table 7 and 8).

Table 6: Bulk density and soil moisture retention characteristics

Profile number	Depth (cm)	Bulk density (g/cc)	Soil moisture at pF 2.0	Soil moisture at pF 4.2	Total moisture holding capacity	Total moisture holding capacity in profile (mm/m)	Total readily available moisture in profile mm/m
1	0-20	1.67	27.7	13.5	28.4	149.8	74.9
	20-64	1.56	28.4	14.0	61.6		
	64-113	1.37	32.9	14.1	88.2		
	113-150	1.23	27.1	14.5	46.6		
2	0-64	1.33	31.5	13.7	113.9	205.1	102.5
	64-80	1.56	36.9	14.2	36.3		
	80-120	1.22	39.1	12.7	105.6		
	120-150	1.48	32.9	15.6	51.9		
3	0-15	1.28	38.2	12.6	38.4	211.5	105.7
	15-60	1.32	35.4	14.8	92.7		
	60-113	1.03	41.2	18.2	121.9		
	113-150	1.12	37.8	16.4	64.2		

Table 7: Crop groups according to soil water depletion

Group	Crops
1	Onion, Pepper, potato
2	Banana, cabbage, cow pea, tomato
3	Alfalfa, bean, citrus, ground nut, pineapple, sunflower, water melon
4	Cotton, maize, safflower, sorghum, soybean, sugar cane

Table 8: Soil water depletion fraction (p) for crop groups and ETm

Crop group	ETm mm/day							
	2	3	4	5	6	7	8	9	10
1	0.50	0.425	0.350	0.300	0.250	0.225	0.200	0.200	0.175
2	0.675	0.575	0.475	0.400	0.350	0.325	0.275	0.250	0.225
3	0.80	0.700	0.600	0.500	0.450	0.425	0.375	0.350	0.300
4	0.875	0.800	0.700	0.600	0.550	0.500	0.450	0.425	0.400

4.5.3 Engineering properties of the soil

The engineering properties considered were particle density, aggregate stability and soil consistence (Atterberg's limits). The three Atterberg's limits (moisture contents in %) determined are liquid limit (LL), sticky limit (SL) and plastic limit (PL) (Table 10).

Table 9: The engineering properties of the soils

Profile No.	Depth cm	Particle density g/cc	Aggregate stability					Atterberg's limits		
			xi_1wi_1	xi_2wi_2	xi_3wi_3	x_4iwi_4	$\sum xiwi$	LL	SL	PL
1	0-30	2.60	0.651	0.239	0.082	0.004	1.000	38.6	38.4	22.3
	30-60	2.60	0.862	0.214	0.744	0.004	1.154	26.5	23.1	18.3
2	0-30	2.64	0.270	0.243	0.128	0.009	0.650	27.8	21.4	17.7
	30-60	2.55	0.937	0.218	0.059	0.004	1.217	27.3	19.9	14.8
3	0-30	2.50	0.722	0.219	0.084	0.004	0.952	34.5	29.5	22.0
	30-60	2.43	0.936	0.226	0.061	0.043	1.228	31.2	26.9	20.5

The particle density for most of the soils falls within the normal range 2.60-2.70. The size distribution of the soil aggregates indicates that the structure is generally well developed and its stability depends on management.

4.6 LAND DEGRADATION AND MANAGEMENT

Decline in the productive capacity of an ecosystem is due to processes of land degradation induced by human activities. The degradation processes may not be so obvious in their initial stages but with time, a significant reduction of the productive capacity of land will be observed. Human activities contributing to land degradation include unsustainable agricultural land use, poor soil and water management practices, deforestation, removal of natural vegetation, frequent use of heavy machinery, overgrazing, improper crop rotation and poor irrigation practices.

Within the scheme area, land degradation is caused by several processes including soil erosion, nutrient depletion, soil surface sealing and crusting, siltation/sedimentation, compaction and soil pulverization, waterlogging, salinization and sodification and vegetation depletion.

4.6.1 Erosion susceptibility, sealing and crusting

Soil susceptibility to erosion was determined by considering climate (rainfall erosivity), topography (slope steepness and length) and soil erodibility (Weeda, 1987). The soils of the scheme indicate low to moderate susceptibility to erosion as shown in Table 10 with the main contributing factor being the relief of the area (slopes of 0-5 %). Inspite of the relief, erosion still occurs when soil is left unprotected. Evidence of some erosion taking place was indicated by presence of stone pedestals in some places and slight splash erosion in some bare top soils. The occurrence of the pedestals indicates that, once the topsoil is not protected they are prone to erosion. Therefore, it is recommended that the banks and the area from where Rombo spring seeps should permanently be left under vegetation cover to act as a water catchment.

Table 10: Erosion susceptibility and erosion hazard in the project area

Mapping Unit	Erosion Susceptibility	Vegetation/land use/conservation measures/ management	Erosion Hazard
UBh and UBb	Very low to low	In the scheme dominant cultivation of irrigated bananas, maize, sorghum, pigeon peas, cassava, tomatoes, paw paws; rare use of manure; cleared wooded bushland; grazing in the area; lack of conservation measures or poorly mainatained ones	Slight

The soils indicate moderate to high susceptibility to surface sealing and crusting. This is indicated by the occurrence of weak to moderately strong, 1-3 cm thick surface crusts on bare soils. Sealing and crusting hinders water from infiltrating into the soil thus generating runoff carrying with it soil particles and nutrients. In addition, the crusts hinder seedling emergence causing non-uniform seedling emergence thereby affecting crops yield. Surface sealing and crusting in the scheme is due to unstable topsoil aggregates mainly as a result of high silt to clay ratio and moderate organic matter content in the topsoils compounded by high ESPs. To control surface sealing and crusting, there is need to incorporate FYM or compost in the soils to improve the structural stability of the topsoils. This would result in improving the water and nutrients holding capacity of the soils. Stable topsoil aggregates would resist detachability by raindrops, applied water and wind. Manure is locally available and therefore its use and beneficial effects in farming should be sensitized to the local people.
A protective surface cover by cover crops or mulch is essential in protecting topsoil from splash and wind erosion.

4.6.2 Erosion hazard

Erosion hazard is a measure of the degree of soil erosion that is likely to occur in the near future. When erosion is already evident, the erosion hazard expresses the intensity of the erosion process or the degree of soil loss which is expected from a specific form of land use, management and conservation practices. It combines the effects of the influence of the more permanent factors such as climate, relief/topography and soil, and the alterable factors of land use management and conservation practices. In arriving at the erosion hazard classes given in Table 11, consideration was given to the erosion susceptibility classes, visible erosion features, land use, type of vegetation, presence of surface gravels, stones, rocks and boulders, type of conservation measure(s) (physical, biological/agronomic or cultural) and their state and effectiveness. Results of this evaluation indicate that the area has slight erosion hazard. Soil and water conservation measures being practiced in the scheme are mainly cultural and agronomic.

4.6.3 Soil compaction, pulverization and waterlogging

The causal factors of soil compaction and pulverization in the area is due to continuous cultivation of the soils using tractors or ploughs, especially when they soils are too wet or too dry. This has resulted in the formation of a compact plough pan at the 15-25 cm soil layer thus resulting in a serious soil degradation process in the scheme. The process destroys the structure of the topsoil thus increasing the soils vulnerability to sealing and crusting. The process also makes the soils prone to wind erosion. Compaction and pulverization reduce water movement into the soil and is a potential trigger of the waterlogging process. Waterlogging reduces the availability of oxygen to the roots and thus interferes with the plant’s metabolism thus leading to reduced crop yields. Therefore timing the ploughing period and varying the ploughing depth could prevent the formation of the plough pan or compact subsoil and destruction of the topsoil structure.

4.6.4 Siltation/sedimentation

Observations in the field showed that, siltation of the irrigation furrows is taking place, in some cases leading to overflow of the water and flooding of adjacent plots. Therefore frequent desiltation of the canals for efficient supply of the irrigation water is necessary to avoid water overflow from the furrows. Stabilization of the furrow banks is important and should be adopted for a long life span of the irrigation structures including furrows.

4.6.5 Salinisation and sodification

Leaching salts by applying the right amount of water and improving the soil's drainage system is useful in curbing salinisation and sodification, processes which are known to turn productive lands to badlands that are eventually abandoned. The results in Table 11 show that the topsoils are slightly alkaline to moderately alkaline with a pH range of 7.1-7.7 (see appendix 3) while the subsoils have a pH range of 6.9-8.2 which is neutral to moderately alkaline. ESP values in the topsoils of profiles 1 and 2 are almost double that of the underlying horizons, indicating that sodification is already taking place. In profile 3, the ESP of the horizon underlying the topsoil is 6 while that of the topsoil is 7 indicating slight sodification process taking place.

Table 11: ECe and ESP values in the topsoils and subsoils

Parameter	Horizon	Profile 1	Profile 2	Profile 3
ESP	Topsoil	13	14	7
	Underlying subsoils	7	6	6
ECe	Topsoil (0 – 20/25 cm)	0.45	0.48	0.81
	Underlying Subsoil (20/25 – 62/80 cm depth)	0.42	0.51	1.05

Visual observations of salt crusts on the soil surface in some parts of the scheme indicated that salinization is already taking place, possibly from the applied irrigation water. The ECe of the topsoils indicates salts accumulation possibly from the irrigation water which is of medium salinity. The potential of salinisation is high and therefore maintaining proper drainage of the soils is important to flush out any accumulating salts. Therefore, improvement of the topsoil structure and deep ploughing are important management aspects. Also an efficient application of irrigation water will prevent the rise of groundwater level and thus prevent salinization by capillarity.

4.6.6 Soil fertility decline

The main factors of soil fertility are soil reaction (pH), organic matter content, availability of major and micro-nutrients 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. The chemical soil fertility of the soils in the scheme is variable due to differences in soil and water managements. The soils indicate high base saturation (>50%) and CEC (>24 cmol/kg) indicating a non-leaching condition Fertility depletion in the scheme is mainly by mining through harvested crops. The pH of the soil ranges from 7.1 to 7.7 making the soils slightly alkaline to moderately alkaline (Table 12). The soils are deficient in N, Cu, and Zn while the organic matter content as reflected by organic carbon varies from low to moderate. Therefore, well decomposed FYM or compost at the rate of 5 tonnes /ha should be applied to increase the organic matter content of the soils. Ammonium sulphate (AS) fertilizer should be applied at the rate of 250 kg/ha, for purposes of supplementing N.

Table 12: Available nutrients in the topsoils (0 – 20 cm depth)

Parameter	Sample 1	Sample 2	Sample 3
pH-H2O	7.7	7.3	7.1
Hp(me%)	-	-	-
C (%)	0.53	1.47	1.74
N (%)	0.04	0.09	0.13
Na(me%)	0.39	0.41	0.43
K ,,	1.69	1.92	2.22
Ca ,,	6.4	6.8	8.0
Mg ,,	5.97	4.8	7.90
Mn ,,	0.20	0.62	0.72
P (ppm)	11	26	50
Fe ,,	5.24	21	17.3
Cu ,,	0.48	0.83	0.93
Zn ,,	1.23	4.22	7.0
EC (dS/m)	0.20	0.19	0.26

Use of farmyard manure or compost has the effect of improving topsoil structural stability thereby preventing surface sealing and crusting thus reducing runoff and erosion. FYM also improves the nutrients and water holding capacity of the soils and in addition, the organic matter enhances the activity of soil fauna thus improving soil physical aspects such as aeration and moisture content.

4.6.7 Vegetation degradation

Vegetation degradation is attributed to the destruction of the original riverine forest and for cultivation, building poles, furniture, fencing posts and charcoal production. With the growing population, a change and intensification of the vegetation use is expected in the scheme. Increased pressure to clear vegetation along the banks of River Rombo and its catchment should be avoided. The vegetation resources in the area need to be conserved for maintenance of haitatas and biodiversity.

4.7 POTENTIAL IMPACTS OF RESULTS FROM THE STUDY

The results from the study are focused on provision of reliable information to the agricultural extensionists on technologies that will optimize use of the land by farmers. These technologies are on use of soill and water conservation, soil fertility improvement through agro-forestry, use of farm yard manure or compost, application of inorganic fertilizers, timely planting, weeding, contour ploughing/tillage, crop rotation and diversification. The overall impacts would be on food self sufficiency (security), income generation/wealth creation, improved livelihoods and a clean environment. Wealth creation and food security would result in improved livelihoods and access to medical and educational facilities.

The use of inorganic fertilizers, pesticides and safe isposal of the containers should be done carefully to avoid pollution of surface and underground water with the agro-chemicals. The protection of River Rombo catchment would result in recharging groundwater thus making the streams to have more flowing water for irrigating more land downstream. Effective physical, agronomic and cultural soil and water conservation measures within Rombo catchment area and the irrigation scheme would lead to reduced run-off and hence more and clean stream/spring water due to reduced siltation/sedimentation. This is bound to reduce the time and money spent in the desiltation of the furrows and canals.

Integration of agro-forestry species in the farming systems and increasing the area under woodlots would create more carbon sinks as plants use carbon dioxide and release oxygen in their metabolism leading to a healthy environment. It is important to conserve the indigenous vegetation of the area some of which has medicinal value. Maintenance of vegetation cover and planting trees along farm boundaries is important in the control of wind erosion in the area. Conservation of the riverine vegetation and good management of the water catchment would promote conservation of biodiversity, filtering and buffering capacity of the soils resulting in unpolluted, clean and safe water downstream. Increased infiltration and more soil water storage capacity would lead to reduced flooding hazard in the lower parts of River Rombo.

4.8 CONCLUSIONS AND RECOMMENDATIONS

The following are some measures that are envisaged to reduce land degradation in the scheme:

1. The riverine vegetation, particularly the indigenous trees growing along the river banks and water catchment areas needs to be conserved. Planting a belt of these trees at the edge of the valleys is recommended. Afforestation is needs to be done in the deforested areas of Rombo catchment.
2. Appropriate physical, agronomic and cultural methods of soil and water conservation practices need to be implemented for sustainable crop production to be realized. The physical methods suitable in the undulating terrain include well spaced, stabilized, maintained and effective fanya juu terraces. Agronomic measures would include strip cropping with good cover crops such as sweet potatoes and mixed cropping, timely ploughing and planting, planting adapted cultivars and intercropping. Cultural practices would include contour farming (planting, tilling/ploughing) and crop rotation.
3. The soils show moderate contents of organic matter and hence the need to apply farm yard manure or compost. Livestock manure is locally available and its use needs to be promoted in the area.
4. N, P and K are deficient and need to be improved in the soils by applying non-acidifying fertilizers. The use of agro-chemicals for crop protection may pollute surface and underground water. Therefore application of the right type and quantity is important, thus proper advice to farmers is important.
5. N-fixing plants should be incorporated in the farming system in the area to improve the soil fertility.
6. Stream banks and water catchment areas need protection for conservation of soils, biodiversity, and as water buffering and filtering areas thus maintaining the quality of the water in the streams.
7. There is need to diversify the horticultural crops grown in KISIS to avoid over production of certain crops leading to very low prices, e.g. soy beans, french beans, okra, brinjals, karela, onion, mangoes, bananas and citrus.
8. Population pressure and land tenure are normally the core driving forces of land degradation. Therefore, there is need to sensitize the local community on the benefits of soil, water and environmental conservation.
9. The water from River Rombo intake is marginally suitable for irrigation as it has medium salinity and low sodium content. The water can therefore be used for growing crops by undertaking the necessary measures that improve drainage of the soils to avoid salinization. Also, incorporation of farmyard manure or compost will improve the soil structure and thus improve the leaching of sodium cations as the process of sodification is already taking place.
10. There is need to utilize the available water more efficiently for crop production by adopting technologies that use minimal water to avoid over-irrigating the soils.
11. Monitoring salinization, sodification and fertility changes needs to be conducted after every 2 – 3 years.

REFERENCES

Braun, H.M.H. 1984. Evaporation in Kenya. Miscellaneous Paper, Kenya Soil Survey, Nairobi.

FAO, 1977. Guidelines for Soil Profile Description, Rome.

FAO, 1986. Guidelines: Land evaluation for rainfed agriculture. FAO Soils Bull, 52, FAO-Rome.

FAO-UNESCO, 1997. Soil Map of the World. Revised Legend with corrections and updates. Technical Paper 20, ISRIC, Wageningen.

Gachathi, F. N. 1989. Kikuyu Botanical Dictionary. Publication supported by gtz and printed by AMREF, Printing Dept., Nairobi.

Government of Kenya. 1999. Population Census, Central Bureau of Statistics, Ministry of National Development, Nairobi.

Hinga, G., Muchena, F.N. and Njihia, C.M. 1980. Physical and Chemical Methods of Soil Analysis. National Agric. Res. Labs, Nairobi.

Jaetzold, and Schmidt, 1983. Farm Management Handbook of Kenya, Vol.II/C East Kenya. Ministry of Agriculture, Nairobi, Kenya.

Kenya Soil Survey Staff, 1987. Manual for soil survey and land evaluation. Vol. 1. Miscellaneous paper no. M24, Kenya Soil Survey, Nairobi, Kenya.

Munsell Color Charts, 1975. Munsell soil color charts, Baltimore, Maryland.

The Organic Farmer. The newspaper for sustainable agriculture in Kenya, No. 16, August, 2006.

Sombroek, W.G., Braun, H.M.H. and Van Der Pouw, B.J.A. 1982. Exploratory Soil Map and Agro-Climatic Zone Map of Kenya. Exploratory Soil Survey Report No.E1, Kenya Soil Survey, Nairobi.

UNEP/GEF, 2005. Protecting the Environment from Land Degradation. UNEP’s Action in the Framework of the Global Environment Facility.

Weeda, A. 1987. Ratings for land qualities in Kenya. Internal Communication No. 29. Kenya Soil Survey, Nairobi.

Woodhead, T. 1968. Potential evaporation in Kenya, E.A.A.F.R.O., Nairobi.

APPENDIX 1: PROFILE DESCRIPTION AND ANALYTICAL DATA

Profile Description No. 1
General site information

Soil map unit code	: UBb
Location/altitude	: 037˚ 42.920'E and 03˚ 03.566'S; 1095 m asl
Soil parent material	: basic volcanic rocks
Landform	: uplands
Relief/slopes	: flat to gently undulating; slopes 0 – 5%
Land use	: grazing and browsing of livestock
Erosion type	: slight splash erosion on bare soil
Surface sealing and crusting	: weak to moderate, 1 – 3 cm thick
Internal drainage	: well drained to moderately well drained
Effective soil depth	: > 150 cm
Soil classification	: Haplic Luvisols, sodic phase

Profile description

Horizon	Depth
Ah	0-20 cm very dark brown (10YR 2/2, moist); sandy clay; massive breaking to weak, fine to medium subangular blocky structure; slightly hard to hard when dry, very friable to friable when moist, sticky and plastic when wet; many biopores and fine pores; many very fine and fine, few coarse roots; clear and smooth transition to:
Bt1	20-64 cm very dark brown (10YR 2/2, moist); sandy clay; weak, fine to medium, subangular blocky structure; slightly hard to hard when dry, very friable to friable when moist, sticky and plastic when wet; many biopores and very fine pores; common very fine and fine, few medium roots; clear and smooth transition to:
Bt2	64-113 cm dark yellowish brown (10YR 3/4, moist); sandy clay; weak, fine to medium, subangular blocky structure; slightly hard when dry, very friable when moist, sticky and plastic when wet; many biopores and very fine pores; few very fine and fine roots; clear and smooth transition to:
BC	113-150+ cm dark yellowish brown (10YR 3/4, moist); gravelly sandy clay; porous massive breaking to weak, medium, subangular blocky structure; slightly hard when dry, very friable to friable when moist, sticky and slightly plastic when wet; many biopores and very fine pores; very few very fine and fine roots.

Laboratory data for profile description no. 1

Horizon designation	**Ah**	**Bt1**	**Bt2**	**BC**
Horizon depth (cm)	0 – 20	20 – 64	64 – 113	113 – 150
pH-H2O (1:2.5)	7.1	7.5	7.8	8.2
EC (dS/m) ,,	0.15	0.14	0.25	0.13
ECe (dS/m)	0.45	0.42	0.75	0.39
C (%)	1.2	1.1	1.1	1.0
CEC-soil (cmol/kg)	23.0	24.6	29.4	22.4
CEC-clay (cmol/kg)	70.1	59.5	75.2	80.7
Exchangeable Calcium ,,	8.78	12.89	15.85	11.73
Magnesium ,,	4.77	4.41	4.90	5.69
Potassium ,,	4.20	1.50	1.22	1.02
Sodium ,,	2.9	1.80	1.70	1.30
Sum of cations	20.65	20.60	23.67	19.74
Base saturation (%)	90	84	81	88
ESP	13	7	6	6
Sand %	60	52	46	56
Silt %	14	14	20	20
Clay %	26	34	34	34
Texture class	SCL	SCL	SCL	SCL
Silt:clay ratio	0.5	0.4	0.6	0.6

Profile Description No. 2

General site information

Soil map unit code :UBh
Location/altitude : 037˚ 42.177'E and 03˚ 03.106'S; 1152 m asl
Soil parent material : basic volcanic rocks
Landform : uplands
Relief/slopes : flat to gently undulating; slopes 0 - 4%
Land use : irrigated cultivation of maize, beans, bananas, onions, cowpeas, pigeon peas, mangoes and pawpaw
Erosion type : not observed on site
Surface sealing and crusting : moderate, 1 – 3 cm thick
Internal drainage : well drained to moderately well drained
Effective soil depth :> 150 cm
Soil classification : Calcic Luvisols, sodic phase

Profile description

Horizon	Depth
Ap	0-25 cm very dark grey (10YR 3/1, moist); sandy clay to clay; porous massive breaking to weak, medium, subangular blocky structure; slightly hard to hard when dry, friable when moist, sticky and plastic when wet; very many biopores and micropores, many medium pores; very many, very fine, fine and medium roots; clear and smooth transition to:
Bt1	25 – 80 cm very dark brown (10YR 2/2, moist); clay; weak to moderate, fine to medium, subangular and angular blocky structure; slightly hard to hard when dry, very friable when moist, sticky and plastic when wet; very many biopores and micropores; common very fine and fine roots; gradual and smooth transition to:
Bt2	80 – 120 cm very dark brown (10YR 2/2, moist); clay; weak, fine to medium, subangular blocky structure; slightly hard when dry, very friable when moist, sticky and plastic when wet; very many biopores and micropores; very few, very fine and fine roots; clear and smooth transition to:
BCk	120 – 150 cm very dark brown (10YR 2/2, moist); clay; porous massive breaking to weak, fine to medium, subangular blocky structure; slightly hard when dry, very friable when moist, sticky and plastic when wet; moderately calcareous; many biopores and micropores, common medium pores; very few, very fine roots.

Laboratory data for profile description no. 2

Horizon designation	Ap	Bt1	Bt2	BCk
Horizon depth (cm)	0 - 25	25 - 80	80 - 120	120 – 150
pH-H2O (1:2.5)	7.6	7.6	7.7	8.1
EC dS/m ,,	0.16	0.17	0.27	0.24
ECe dS/m ,,	0.48	0.51	0.87	0.72
C (%)	1.22	1.45	1.04	0.73
CEC-soil (cmol/kg)	17.2	26.8	31.8	36.6
CEC-clay (cmol/kg)	32.4	70	72.7	99.06
Exchangeable Calcium ,,	13.85	12.07	16.75	23.44
Magnesium ,,	4.12	4.29	4.09	4.53
Potassium ,,	1.72	1.84	1.16	1.72
Sodium ,,	2.50	2.15	1.90	2.45
Sum of cations	22.19	20.35	23.90	32.14
Base saturation (%)	100+	76	75	88
ESP	14	8	6	7
Texture – hydrometer				
Sand %	42	52	42	54
Silt %	20	18	20	12
Clay %	30	38	38	34
Texture class	SCL	CL	CL	SCL
Silt:clay ratio	0.6	0.5	0.5	0.35

Profile Description No. 3

General site information

Soil map unit code	:UBh
Location/altitude	: 037˚ 41.944'E and 03˚ 03.146'S; 1149 m asl
Soil parent material	: basic volcanic rocks
Landform	: uplands
Relief/slopes	: flat to gently undulating; slopes 0 - 4%
Land use	: irrigated cultivation of tomatoes, onions, kales, brinjals, okra, beans, sunflower, maize, sorghum, bananas, cassava, cowpeas, pigeon peas, mangoes and pawpaw
Erosion type	: wind erosion in form of whirlwinds and dust storms
Surface sealing and crusting	: moderate, 1 – 3 cm thick
Internal drainage	: moderately well drained
Effective soil depth	:> 150 cm
Soil classification	: Vertic Luvisols, sodic phase

Profile description

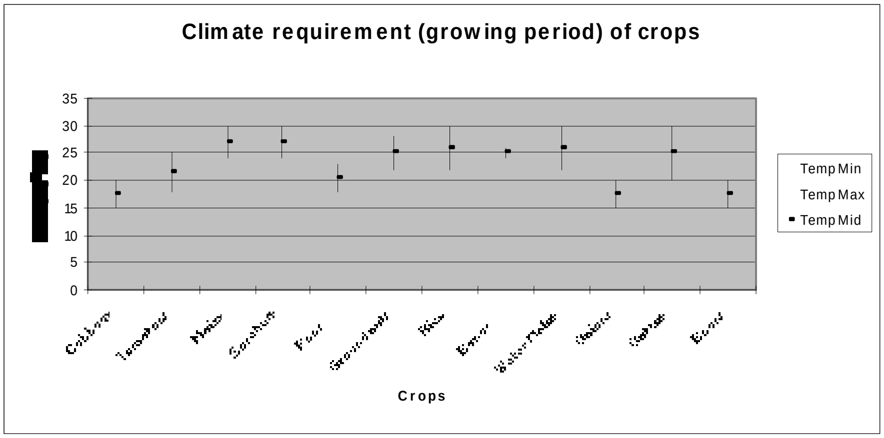
Horizon	**Depth**
Ap	0-20 cm very dark greyish brown (10YR 3/2, moist); silty clay to clay; porous massive breaking to weak, medium to coarse, subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; very many biopores and micropores; very many, very fine and fine roots; clear and smooth transition to:
Bt1	20-62 cm very dark grey (10YR 3/1, moist); clay; weak to moderate, medium to coarse, prismatic structure breaking to weak, medium, subangular blocky and moderate, fine to medium, angular blocky structure; hard when dry, friable to firm when moist, sticky and plastic when wet; thin, broken, slickensides; many biopores and micropores; many, very fine and fine roots; gradual and smooth transition to:
Bt2	62-134 cm very dark brown (10YR 2/2, moist); clay; weak to moderate, fine to medium, prismatic structure breaking to weak, fine to medium, subangular and moderate, fine to medium, angular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; moderate, broken, slickensides; very many biopores and micropores; common, very fine and fine roots; gradual and smooth transition to:
Bt3	134-155 cm very dark greyish brown (10YR 3/2, moist); clay; porous massive breaking to weak, medium, subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; many biopores and micropores; very few, very fine and fine roots.
Ck	155-189 cm very dark brown (10YR 2/2, moist); gravelly clay; porous massive; slightly hard when dry, very friable when moist, sticky and slightly plastic when wet; calcareous; many micropores.

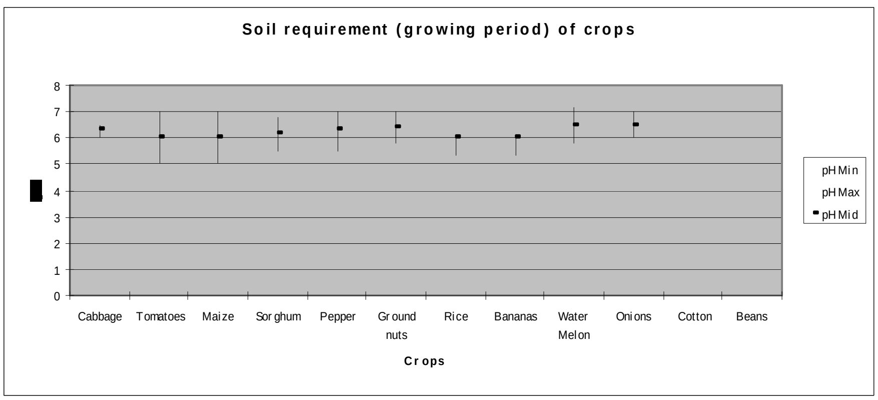
Laboratory data for profile pit no. 3

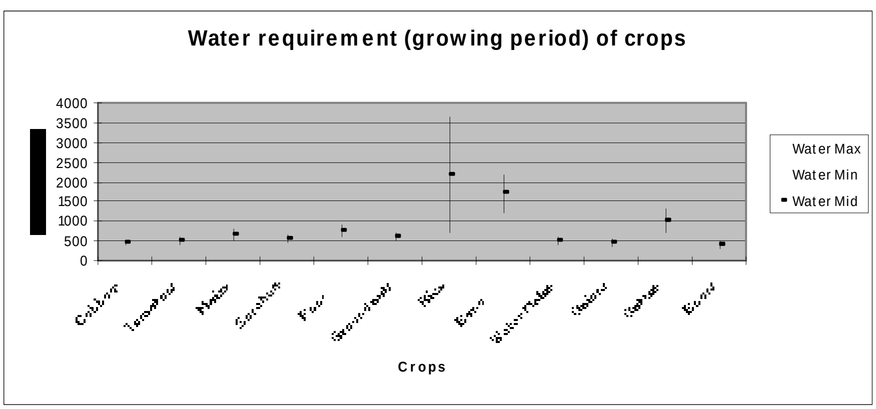
Horizon designation	**Ap**	**Bt1**	**Bt2**	**Bt3**	**Ck**
Horizon depth (cm)	0 - 20	20 – 62	62 – 134	134 - 155	155 – 189
pH-H2O (1:2.5)	7.5	7.4	7.4	7.5	6.9
EC dS/m ,,	0.27	0.35	0.18	0.26	0.23
ECe dS/m ,,	0.81	1.05	0.54	0.78	0.69
C (%)	0.97	2.15	1.04	1.60	1.47
CEC-soil (cmol/kg)	32.2	36.4	29.6	31.2	17.2
CEC-clay (cmol/kg)	83.3	73.2	66.9	68.9	43.5
Exchangeable Calcium ,,	15.99	14.60	14.38	11.78	8.34
Magnesium ,,	5.24	5.12	5.20	5.65	4.39
Potassium ,,	1.92	1.80	1.84	8.0	5.0
Sodium ,,	2.40	2.35	2.25	2.90	2.3
Sum of cations	25.55	23.87	23.67	28.33	20.03
Base saturation (%)	79	66	80	91	100+
ESP	7	6	8	9	13
Texture – hydrometer					
Sand %	44	38	42	42	60
Silt %	22	24	20	22	14
Clay %	34	38	38	36	26
Texture class	SCL	CL	CL	CL	SCL
Silt:clay ratio	0.7	0.6	0.5	0.6	0.5

APPENDIX 2

Climate, soil and water requirements (growing period) of the envisaged crops







APPENDIX 3. CLASSIFICATION OF SOME SOIL PROPERTIES

Soil reaction (pH) classification

pH	Class name
<4.5	Extremely acid
4.5 – 5.0	Very strongly acid
5.1 – 5.5	Strongly acid
5.6 – 6.0	Medium acid
6.1 – 6.5	Slightly acid
6.6 – 7.3	Neutral
7.4 – 7.8	Mildly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9.0	Strongly alkaline
>9.0	Very strongly alkaline

Classification of EC

EC2.5 (dS/m)	Derived ECe (dS/m)	Class name
0 – 1.2	0 – 4	Non saline
1.2 – 2.5	4 – 8	Slightly saline
2.5 – 5.0	8 – 15	Moderately saline
5.0 – 10.0	15 – 30	Strongly saline
>10.0	>30	Excessively saline

Classification of ESP

ESP	Class name
0 – 6	Non sodic
6 – 10	Slightly sodic
10 – 15	Moderately sodic
15 – 40	Strongly sodic
>40	Excessively sodic

Classification of % C, CEC and % BS

Class name	%C	CEC-soil (cmol/kg)	BS%	Silt/clay
Very low	<4.0	<5	<10	<0.2
Low	0.5 – 0.9	5 – 15	10 – 29	0.20 – 0.59
Medium	1.0 – 1.9	15 – 25	30 – 49	0.60 – 1.00
High	2.0 – 5.0	25 – 40	50 – 79	>1.00
Very high	>5.0	>40	>80	