Executive Summary

The National Comprehensive Soil Survey (NCSS) Project was conceived by the managers of Boosting Agriculture and Food Security (BAFS) Project and the leadership of Agricultural Engineering Division, Ministry of Agriculture to build upon the outputs of the Land Resources Survey of Sierra Leone at the reconnaissance level (UNDP/FAO, 1979), by providing an inventory of the soil resources at the semi detailed level to enhance the judicious utilization and management of the soil resources, and contribute to sustainable crop production, food security and protection of the environment.

The survey area covers Kenema district, which is in the Eastern Region, and borders Bo District to the west, the Republic of Liberia to the southeast, Tonkolili and Kono Districts to the north, Kailahun District to the east, and Pujehun District to the southwest. The district comprises 16 chiefdoms including Dama, Dodo, Gaura, Gorama Mende, Koya, Langurama, Niawa, Nomo, Nongowa, Kandu Leppiama, Lower Bambara, Malegohun, Simbaru, Small-Bo, Tunkia and Wandor chiefdoms. Its capital and largest city is Kenema, which is the third most populated city in Sierra Leone, after Freetown and Bo.

The climate is tropical with two pronounced seasons: the rainy season from May to October and dry season from November to April. The annual rainfall varies from 2352 mm in Lower Bambara, Malegohun and Nongowa chiefdoms in the northeast to 4432 mm in Tunkia chiefdom in the southwest. Rainfall distribution is unimodal, with about 95 % of the total annual rainfall occurring in the months of July, August and September, but a peak in August.

The geology is an Assemblage of granites and acid gneisses, granulite facies rocks and greenstone belts of schistose sedimentary and volcanic rocks, which are representative of the oldest zircon 2.90 Ga from zircons in migmatic gneiss, and 2.85 Ga from porphyritic granite inferred to intrude the Kenema Assemblage.

Following an initial literature review, remotely sensed and Geographic Information Systems (GIS) data were downloaded and consolidated into basemaps. Field surveys were conducted to establish the relationship between soil types and landscape units, based on the *catena* approach and Food and Agriculture Organization (FAO) Guidelines for soil description (FAO, 2006). Samples from representative soil profiles located along toposequences were analyzed at the Njala University Quality Control Laboratory (NUQCL) using standard soil analysis methods (ISRIC/FAO, 2002). Soil units were mapped using a GIS algorithm based on a Digital Elevation Model (DEM) and knowledge of soil-landscape relationship. Soils were evaluated for their suitability to support the optimal growth of 19 crops targeted by MAFS. These crops included rice, maize, cassava, sweet potato, groundnut, cowpea, onions, carrot, cabbage, tomato, Robusta coffee, Arabica coffee, cacao, oil palm, cashew, mango, pineapple, citrus and bananas using a rating system based on the Ojanuga modified FAO Guidelines for Land Evaluation (FAO, 1976; revised 2007).

The results of the survey, soil analyses and interpretations are presented in:

A district soil report setting out:

- The geographical context
- The survey methodology
- Soil profile descriptions and their physicochemical properties
- A district soil map at 1:500,000 (digital and hard copy versions)
- Soil capability classification and suitability ratings for each soil type on the soil map
- District statistics on arable land, land capability, soil suitability for major crops, soil fertility
- Challenges, opportunities, risks, and implications for agricultural development

The results of the survey show that five major soil associations exist in the district. These include the Rockland-Segbwema-Vaahun soil association which accounts for 759.5 km^2 (11.9 %), Fanima-Waiima-Baoma soil association which accounts for 358.6 km^2 (5.6 %), Pendembu-Kparva-Tisso soil association which accounts for 2495.7 km^2 (39.3), Ngelehun-Yumbuma-Keya soil association which accounts for 575.9 km^2 (9.1 %) and Manowa-Momenga-Njala sloping soil association which accounts for 196.1 km^2 (3.1 %).

Land Capability Classification shows that arable land in the Kenema District comprise Class I (Ngelehun and Yumbuma series), Class II (Pendembu, Kparva, Tisso, Keya, Manowa, and Momenga series), and class III (Segbwema, Vaahun, Fanima, Baoma, Waiima, and Njala sloping series). The non-arable land is class VI (Rockland series).

Soil suitability analysis indicates that Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping soils are highly suitable (S1) to moderately suitable (S2) for growing food crops such as rainfed rice, irrigated rice, cassava, sweet potato, groundnut, maize and cowpea. For tree crops such as Arabica and Robusta Coffee, Cocoa, Cashew and Oil Palm, Segbwema, Vaahun, Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Manowa, Momenga, Njala sloping soils are moderately suitable (S2) to marginally (S3) suitable. For fruit crops such as Mango, Citrus, Pineapple and Banana, soils of Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Manowa, Momenga series are moderately suitable (S2) for these crops. For vegetables such as Onion, Tomato, Cabbage and Carrot, Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping soils are moderately suitable (S2) to marginally suitable (S3).

Priorities for soil management in the district should mainly target increasing and maintaining soil fertility through liming of those soils which are of high acidity, correct application of fertilizers and organic materials based on soil tests and also soil conservation. The investment strategy should include the conduct of trials on farmers' fields on benchmark sites and scaling up of proven agronomic and cost-effective technologies. Terrace level practices and land cover management involving growing of cover crops, agroforestry and holistic watershed development and management should be promoted in erosion-prone areas.

1 Overview of soil surveys and land evaluation in Sierra Leone and project context

1.1 Brief history

The history of soil surveys in Sierra Leone dates to British Colonial Times. Ojanuga (2008) reported that soil maps (without report) produced prior to 1928, were available at the time of his work in the Forestry Department of the Ministry of Agriculture, Forestry and Food Security. The European Union funded Boosting Agriculture and Food Security Project commissioned a stocktaking to serve as input for the integration of information from previous soil surveys into a unified soil information framework. The report (Rhodes, 2020) briefly presented information obtained from national and regional surveys conducted between 1951 and 2019, for which information was available, at scales ranging from reconnaissance to detailed. The United Nations Development Program (UNDP) and the Food and Agriculture Organization (FAO) of the United Nations sponsored or conducted the most nationally spread surveys. A few district level surveys covering large areas of land were also conducted by FAO and Njala University in the northern, southern, and eastern regions. The private sector has also funded several detailed soil surveys in various parts of the country.

Key information in the stock taking report were summarized in terms of geographic coordinates, size of area surveyed, scale, basis of grouping soil units, mapping units, classification system and land appraisal for crop production. Landform, gravel content and drainage were the most frequent basis for grouping land/soil units. Land suitability ranged from those with no or moderate to slight limitation for a given crop to lands having limitations so severe as to preclude any possibilities for a successful sustained use for a given crop.

Three major soil descriptions and surveys that have greatly influenced national development plans, research and extension work in soils are Odell et al. (1974), UNDP/FAO (1979), and Ojanuga (2008). Following up on the delineation of 16 soil provinces based on physiography, parent material and drainage by Dijkerman (1969), Odell *et al*. (1974) reported on the properties of soils in specific areas in 5 out of 6 soil provinces. Detailed soil profile descriptions and physical and chemical and mineralogical data were presented for 44 soil profiles representing 34 soil series. A detailed soil map of the Njala Area and Soil Association maps of the Torma Bum, Makeni, and Kenema areas were produced. The soils were classified in progressively decreasing order of importance as Ultisols, Inceptisols, Oxisols, Entisols, and Spodosols in the USDA system. Many of the Ultisols and Inceptisols have oxic properties. In the FAO/UNESCO system, they were classified as Nitosols, Cambisols, Ferralsols and Gleysols.

For soil fertility management, they grouped the soils into three main classes, namely, (i) well drained and aerated soils that occur on uplands, colluvial footslopes and terraces; (ii) poorly drained soils without excess sulphur along the major streams, in the bolilands and inland valley swamps and along the coast and (iii) tidal swamp soils high in sulphur. They also provided brief guidelines on the adaptation and management of these soils with a focus on rice, maize, and plantation crops.

UNDP/FAO (1979) conducted a reconnaissance survey of land resources in Sierra Leone and produced a soil map of Sierra Leone at a scale of 1:2,000,000 based on the FAO/UNESCO soil map legend. The map shows 12 soil associations based mainly on quantity and type of gravel in the upland soils and the degree of hydromorphism in the valley bottom soils. Because of the generalized nature of the survey and the resulting small-scale mapping, the legend units were broad. A major output of the project was a Land System map at a scale of 1:500,000. A Land System is an area of land with recurring pattern of landforms, climate, vegetation, and soils.

The UNDP/FAO 1979 reconnaissance survey of land resources in Sierra Leone describes the typical range in soil characteristics found under 44 landscape units, defined as “land systems”, named after a typical location in the country, and grouped under 12 sub-regions and 4 main regions (Figure 1 and Table 1).

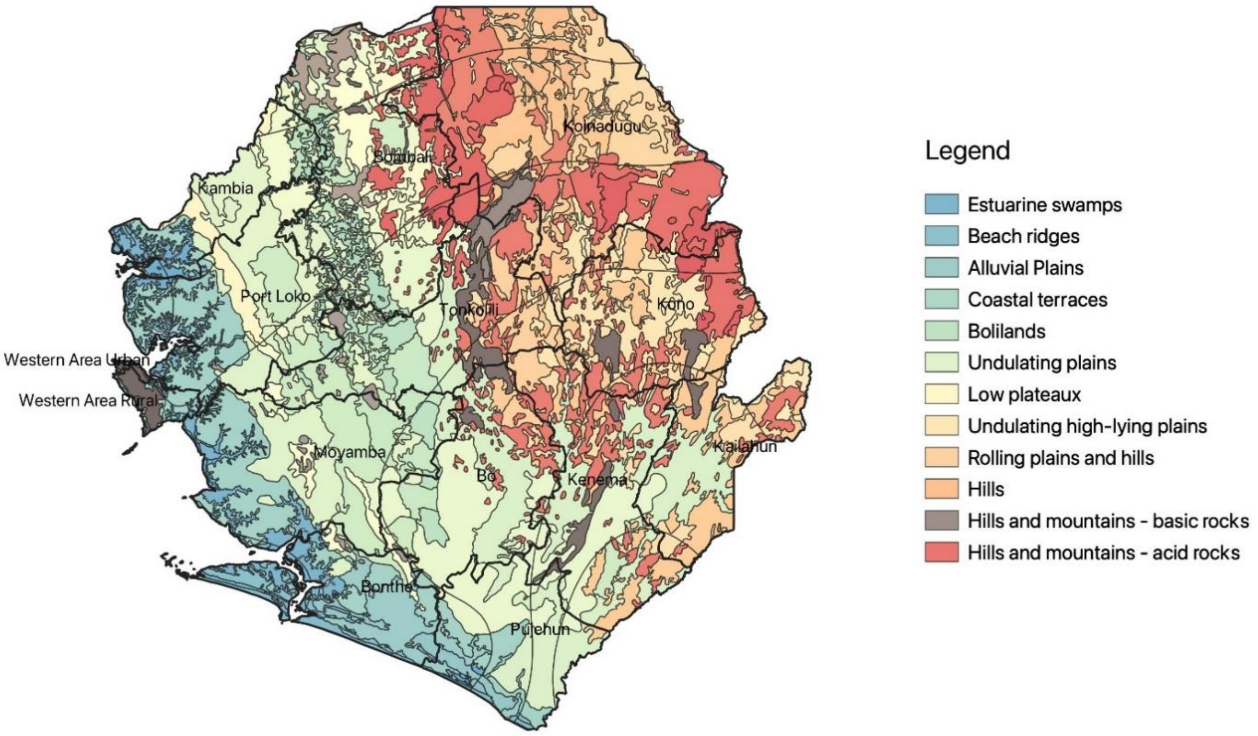

Figure 1. *Land systems map of Sierra Leone (Adapted from UNDP/FAO, 1979)*

Table 1. *Land regions, sub regions and systems of Sierra Leone presented and described in the 1979 Reconnaissance Survey of Sierra Leone (Adapted from UNDP/FAO, 1979)*

Regions	Sub-regions	Land Systems
Coastal Plains	Estuarine swamps	Scarcies, Tasso
	Beach ridges	Turner, Sherbro, Bonthe
	Alluvial plains	Torma Bum
	Coastal terraces	Newton, Hastings
Interior plains	Bolilands	Mabole, Senehun, Rokel
	Undulating plains	Njama, Lunsar, Laia, Blama, Moyamba, Yonibana, Bo, Wari, Borompo, Makundo, Kawakwie, Kamabai
	Low plateaux	Port Loko
Plateaux	Undulating high-lying plateaux	Musaia, Wadu, Koidu, Kailahun, Kombile, Kamaron
	Rolling plains and hills	Bendugu, Sandaru
	Hills	Kabala, Haffia
Hills and Mountains	On basic and ultra-basic rocks	Saionia, Kasewe, Sula, Kangari, Regent
	On acid rocks	Quantamba, Kulufaga, Saiama, Tonkolilini, Loma

The range of soil characteristics found within the 1979 land systems map can be very wide; ranging from well drained shallow soils on hill tops to poorly drained deep soils in the valleys contained within the mapping unit. The goal of the UNDP/FAO (1979) report was to serve as guide for more detailed surveys for investment in commercial agriculture. While the government is promoting these kinds of surveys, it also recognizes the need for paying attention to small holder farmers at the district level. The 44 Land Systems delineated by UNDP/FAO (1979) formed the basis for carrying out the field work of the National Comprehensive Soil Survey (NCSS).

To aid land use planning for optimizing agricultural production, Ojanuga (2008) carried out detailed soil surveys of select areas in 3 districts of Sierra Leone, namely, Falaba within the Moyamba District (Moyamba Land System), Magbafti within the Koya Rural District (Newton Land System) and Rolako within the Bombali District (Bo Land System). He produced soil maps, soil suitability ratings for arable crops, agroforestry & forestry for the Falaba area and identified land management units based mainly on position on the toposequence in each of these areas. One of the recommendations made was that

Sierra Leone should embark on semi-detailed land resources surveys, including soil, water, biological materials, and climate.

Kenema district has attracted quite a good number of soil surveys at the detailed levels mainly targeting tree crop such as cocoa, coffee and oil palm. Soil surveys conducted by Sivarajasingham (1968) and Stark (1968) are evidences of earlier soil surveys undertaken in the district. The four major landscapes identified in the mapped areas were steep slopes and hills, upland erosion surfaces, and colluvial footslopes and terraces Madina, Bandajuma, Segbwema, Baoma, Mokonde and Gbeika series. The semi-detailed soil survey work of Veldkamp (1980), Sutton et al (1980) and Odel et al (1980) further revealed similar soil types and characteristics.

1.2 Project context

1.2.1 Country background

Sierra Leone is in the humid region of West Africa, with a land area of 72,300 km^2, and a population of 7,541,641 at a growth rate of around 2 percent (STATSL, 2022). Based on the human development index (HDI) published in 2016, Sierra Leone was ranked 183rd out of 195 countries (2021/22 UNDP Human Development Report). The Sierra Leone Multi Cluster Survey of 2017 reported 64.8 percent multidimensionally poor people taking into consideration, health, education, living standards, housing, and energy. The Sierra Leone 2018 Integrated Household Survey found 56.8 percent of the people to be monetary poor and 12.9 percent extremely monetary poor. Agriculture is the backbone of the economy and therefore, its development is of strategic importance. However, smallholder farmers exhibit limited agricultural productivity, which makes their dominance in staple crop production mainly for subsistence with rarely any surpluses for sale.

Sierra Leone's current economic and social situation has been shaped by four events in the last three decades: the civil war (1991-2002), the Ebola Virus Disease (EVD) (2014-2015), and more recently the COVID 19 pandemic of 2020 and the Russia-Ukraine war of 2022. The civil war and social unrest years caused a severe economic decline that virtually destroyed the physical and social infrastructure of the country, leading to widespread poverty and over 50,000 human deaths with 1 million both internally and externally displaced. The EVD outbreak that occurred in 2014 worsened the country's development indicators, killing about 3,461 people (WHO, 2015) and further bringing down the whole economy. The Russia-Ukraine war has resulted in sharp rises in price of imported commodities and the downgrading by the IMF of the 2022 growth projection from 3.4 percent in April to 2.4 percent in October 2022.

1.2.2 Government policies and plans, Sierra Leone soils, and the NCSS

The Government of Sierra Leone's Medium-Term National Development Plan 2019-2023 states that improving the productivity and commercialization of the agriculture sector and the protection of the environment is of high priority. The Ministry of Agriculture and Food Security (MAFS) has a National Agricultural Transformation (NAT) Plan 2019-2023, emphasizing management of the natural resources, site-specific management for fertilizer applications involving soil analysis, increased production, and productivity of the priority crops (rice and other cereals, cocoa, coffee, cashew, oil palm, vegetables, legumes, roots and tubers, and spices). The more recent policy orientation of MAFS-NAT 2023 brought out a strategic intervention of relevance to the NCSS, that is, 'Data systems for evidence-based policy making: with output of countrywide agricultural land use zoning and area specific soil surveys carried out using Information Communication Technology (ICT) and innovative data tools leading to an updated map of the soils of Sierra Leone'. The development of the agriculture sector from the current level of low production and productivity of food and cash crops and the management of the soil resources, in transition from a system of bush fallow rotation in the uplands (associated with deforestation and release of greenhouse gases into the atmosphere) to diversified sustainable commercial farming would therefore contribute to the expressed vision and plans of government.

Increasing anthropogenic interference and climate change impacts are causing unprecedented soil degradation affecting the capacity of the soil resources in Sierra Leone to carry-out their functions sustainably. Additionally, soil characteristics and properties are key inputs for assessing erosion, land use suitability and hazard susceptibility analysis, particularly with respect to land use potential, which ultimately provide data to guide long and short-term development and investment decisions.

It is well known that soils of Sierra Leone are highly weathered low activity-clay soils (LACS); they are quite acidic and macro and micronutrient levels in the soils are generally low. There are however gaps in information on their properties and related natural resources because all national soil surveys in the past were done at the reconnaissance level (Dijkerman, 1969; UNDP/FAO, 1979). Given the dynamic nature of soils compounded by climate change, these resources are bound to have undergone pedogenic changes over the past 40 years. These studies did not map the spatial variability of soil fertility and evaluate the status of micronutrients. In the light of all these issues, there is an urgent need for an updated and comprehensive national soil survey for Sierra Leone and the drafting of a strategy for guiding sustainable soil management.

The European Union (EU) being a key supporter of the agriculture and food security sector of Sierra Leone has provided funding for the Boosting Agriculture and Food Security (BAFS) Programme in Sierra Leone. The programme is implemented through MAFS and covers the fifteen agricultural districts in the country. BAFS is the follow-up to the recently completed Agriculture for Development (A4D) programme, funded under the 10th European Development Fund.

Among its many supports to agricultural projects in MAFS, BAFS provided funding to the Agricultural Engineering Division (AED) to conduct a national comprehensive soil survey at the semi-detail level, four times the scale larger than that of the UNDP/FAO 1979 survey. This soil survey consists of a set of specific sub-activities that include (i) provision of material support for specialized laboratories at Njala University and the Sierra Leone Agricultural Research Institute (SLARI), in the form of procurement of specialized laboratory equipment and chemicals; (ii) field morphological description of representative soil profiles along toposequences; (iii) collection and analysis of soil samples; (iv) staff training and logistical support for the AED-MAFS. These set of activities would result in improved access to data, generation of comprehensive soil and land use maps, and soil fertility and land suitability information.

1.2.3 Overall and specific objectives of NCSS project

The overall objective is to conduct a national comprehensive soil survey and generate information for the judicious utilization and management of the soil resources aimed at sustainable crop production in Sierra Leone: The specific objectives are to:

(i) update maps of the agro-climatic/vegetation regions and rice agro ecological zones (ii) establish and map soil fertility management zones; (iii) identify, characterize and map soil types at the semi detailed level and determine land suitability for major crops; (iv) identify, characterize and map major soil types in the lowland rice growing agro-ecologies at the detailed level; (v) strengthen the capacity of staff of the Agricultural Engineering Division of MAFS to undertake soil surveys, interpret soil survey reports and make recommendations on land use and management; (v) enhance the capacity of the NU and SLARI laboratories for producing reliable data for making soil management recommendations; (vi) enhance the capacity of NU and SLARI for remote sensing/GIS work, and (vii) develop a framework for a national strategy on soil management. The expected impact of the project is a contribution to food security improvement, poverty reduction and minimization of environmental degradation in Sierra Leone.

1.2.4 Target groups and final beneficiaries of NCSS

According to the service contract between the National Authorizing Office (NAO) and Njala University, the target groups of the NCSS are Njala University, SLARI, the AED and policy makers of MAFS. Njala University is the leading university in Sierra Leone for agriculture and related environmental sciences. Its mandate is research, teaching, and extension. It has a School of Agriculture and Food Sciences (SAFS) in which the Department of Soil Science is located, a School of Environmental Sciences and a School of Natural Resources Management among other related Schools.

SLARI is responsible for conducting, on behalf of MAFS, agricultural research on crops and livestock through its seven research centers. One of its centers, the Njala Agricultural Research Centre (NARC) is based on the Campus of Njala University. There is close collaboration between NU and SLARI, in research, teaching, and extension.

The AED of MAFS took over some of the functions of the defunct Land and Water Development Division (LWDD) of MAFS. Among other activities, LWDD was involved in the development of swamps and other lowlands for intensified cropping in the rainy and dry seasons.

The final beneficiaries are farmers, traders, consumers, and the nation at large. Most of the population of Sierra Leone are involved in agriculture, predominantly small-scale rainfed subsistence farming. There are also a few large-scale commercial farming enterprises. The traders consist of itinerants, wholesalers, retailers of food crops and exporters of produce of cash crops. The consumers are in rural and urban areas; while the former produce part of their own food, the latter purchase food produced by the former. In the context of a rapidly increasing urban population, rural food production must keep pace with urbanization to avoid a food crisis in the country.

2 How to use this report

This section explains to readers how the soil survey report of the Kono District has been structured with a brief description of the information that can be found in each section (Table 2). The report represents one of a range of NCSS outputs and it is intended specifically for agricultural policy makers, extension officers, university research and teaching staff, research staff of SLARI, farmers, the private sector who seek information about the physical and chemical characteristics of soils at district level.

Table 2. *Soil survey report structure and general guidelines for use of district soil maps and reports*

Sections	Description
Executive summary	Provides an overview of the main soil forming factors, soil types, crop suitability, main limitations and how they can be overcome.
Section 1	Gives a brief history of soil surveys and the project context.
Section 2	Provides a general structure of the soil survey report and the information contained therein.
Section 3	Provides details about the main soil forming factors in the district, i.e., climate, geology, landscape, vegetation, land use and socioeconomics, along with their maps where appropriate.
Section 4	Describes the methods used to conduct the soil survey, study the soil profile pits, determine land capability and evaluation of soil suitability. The outcomes of the latter three activities are provided in the form of maps (soil maps, land capability maps and soil suitability maps for crop targeted by MAFS.
Section 5	Provides detailed information for each soil type identified on the soil map. This includes: (i) How soil types relate to the landscape – this allows users to identify possible ranges in soil characteristics across the landscape of interest including likely inclusions of neighboring soil types. (ii) How soil types correlate with international soil classifications, which allows comparisons with soils elsewhere. (iii) Typical soil surface features, such as stoniness, slope, vegetation, and land use. (iv) Typical (ranges of) physical soil characteristics, such as soil texture, drainage, soil depth, risk of flooding, gravel content. (v) Typical (ranges of) chemical soil characteristics, of topsoil and subsoil, such as soil organic carbon, available phosphorous, soil pH, Al saturation, cation exchange capacity (CEC), base saturation, exchangeable cations (Ca, Mg, K), and micronutrients (Fe, Cu, Zn).
Section 6	Provides detailed information for each soil mapping unit about: (i) the land capability evaluation of Bonthe District into arable and non-arable land and the main land degradation risks and how they can be overcome. (ii) the soil suitability evaluation and the main soil limitations attached to each soil type and how these can be overcome.
Section 7	Provides general information on soil fertility management, land degradation risks and the development of a national strategy for integrated soil fertility management.
Section 8	Provides detail information on soil fertility management strategies for the different soil types for sustainable use.

3 Geographical Context

3.1 Location

Kenema District is located on Longitude -11.600W to -10.782W and Latitude 7.355N to 8.560N in the Eastern Province of Sierra Leone. It is bordered by Bo District to the west, the Republic of Liberia to the southeast, Tonkolili and Kono Districts to the north, Kailahun District to the east, and Pujehun District to the southwest. Its capital and largest city is Kenema, which is the third most populated city in Sierra Leone, after Freetown and Bo. The district has an area of 6,053 km^2 and is comprised of 16 chiefdoms including Dama, Dodo, Gaura, Gorama Mende, Koya, Langurama, Niawa, Nomo, Nongowa, Kandu Leppiama, Lower Bambara, Malegohun, Simbaru, Small-Bo, Tunkia and Wandor chiefdoms (Figure 2). The district is the most populous district in the Eastern province with a population of 609,891 (STATSL, 2017). The economy of the district is largely based on farming, diamond mining and trade.

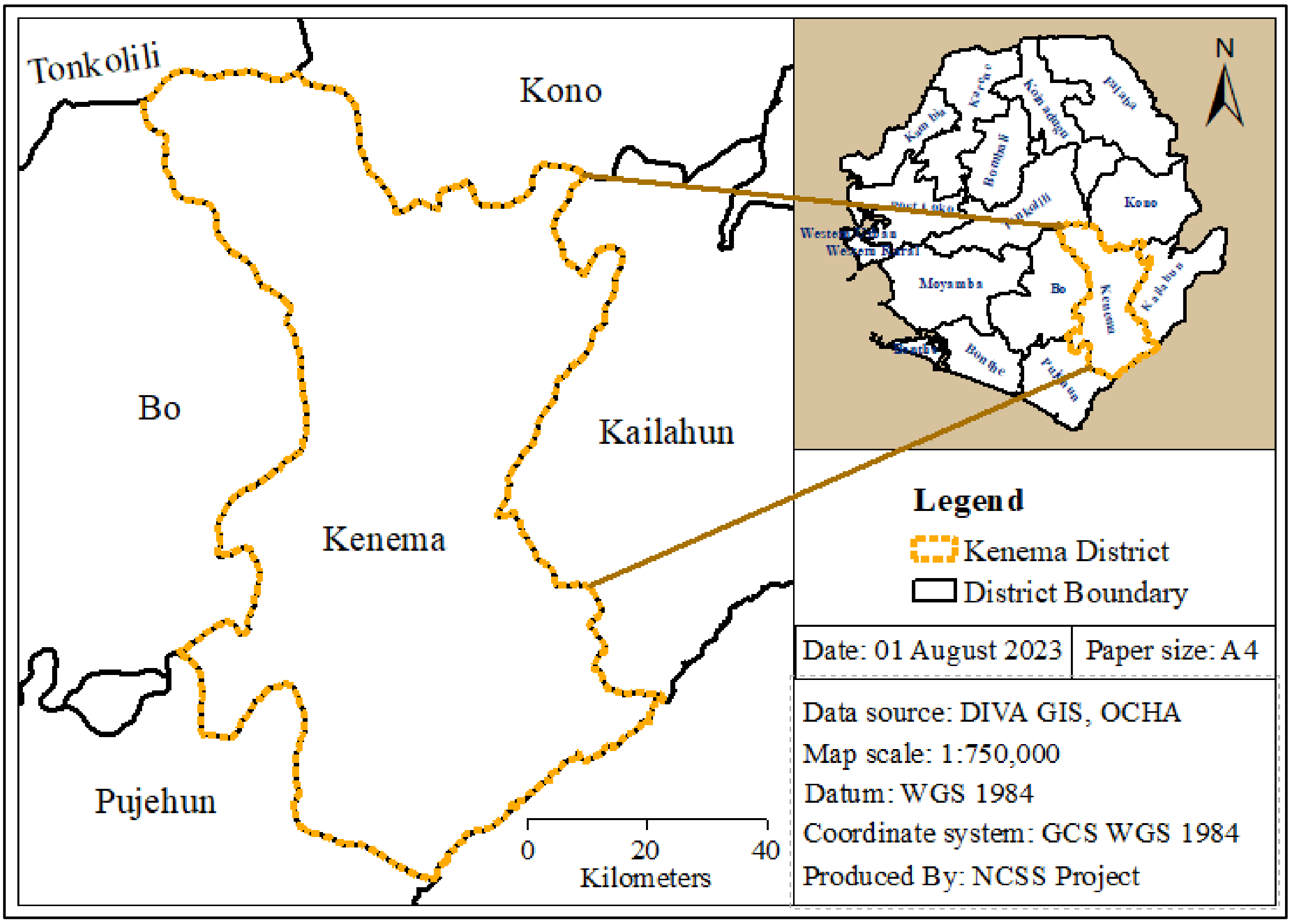

Figure 2. *Location map of Kenema District*

3.2 Climate

The climate is tropical with two distinct seasons, namely the rainy season (May to October) and a dry season (November to April). The annual rainfall ranges from 2352 mm in Lower Bambara, Malegohun and Nongowa chiefdoms in the northeast to 4432 mm in Tunkia chiefdom in the southwest (Amara *et al*., 2020) (Figure 3). Rainfall distribution is unimodal, with about 95 % of the total annual rainfall occurring in the months of July, August and September, but a peak in August. Air humidity is generally high, ranging between 95–100 % during the rainy season, but may drop to as low as 20 % during the Harmattan. The average monthly temperature ranges from around 22°C to 28°C during the year but may rise to a maximum of 36°C, especially in March (Figure 4). The number of sunshine hours per day varies from 6 to 8 in the dry season, and from 2 to 4 during the rainy season. The agro-climatic zone (ACZ) and agro-ecological zone (AEZ) maps of the district are shown in Figures 5 and 6, and this is further depicted in Tables 3 and 4.

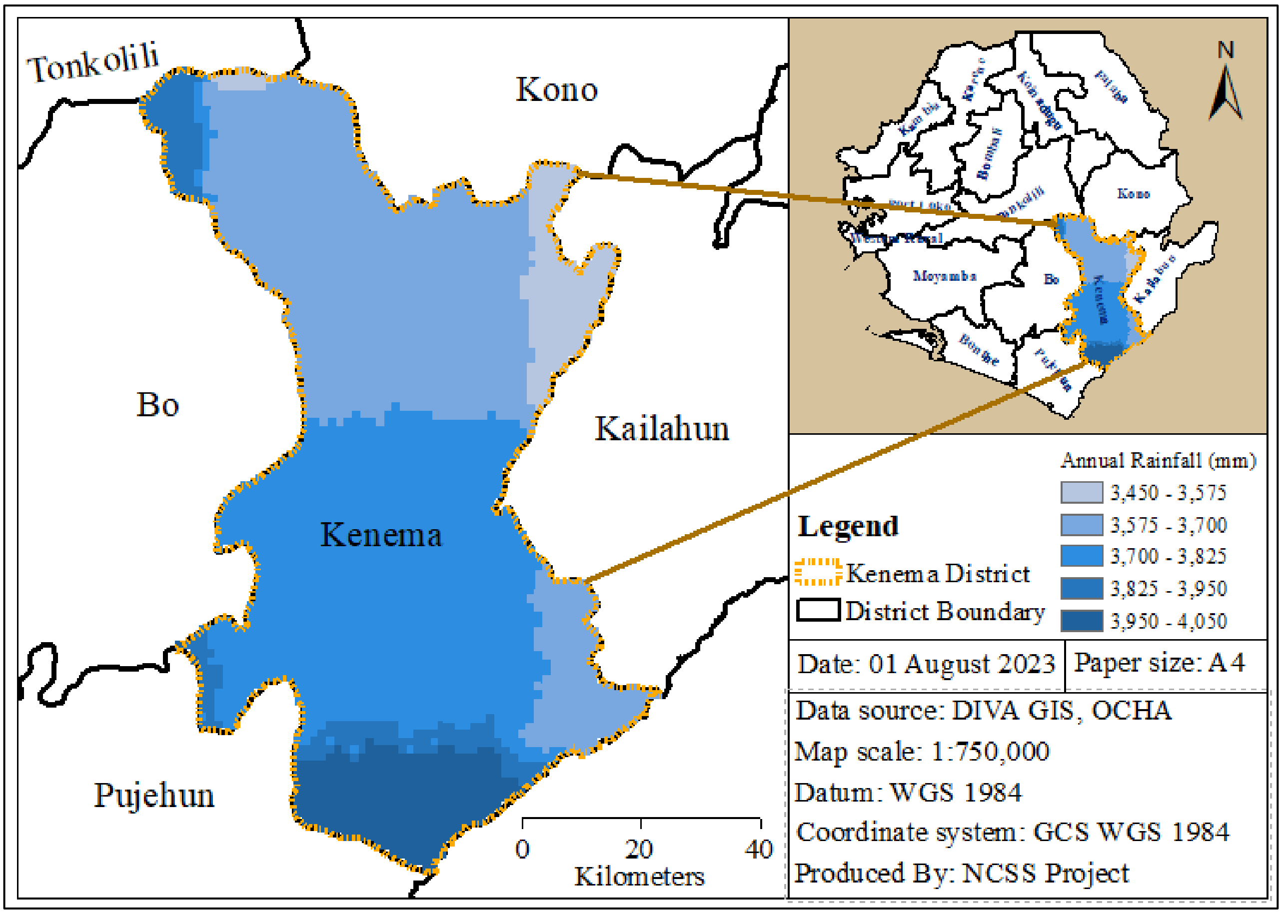

Figure 3. *Annual Rainfall distribution in Kenema District (2021)*

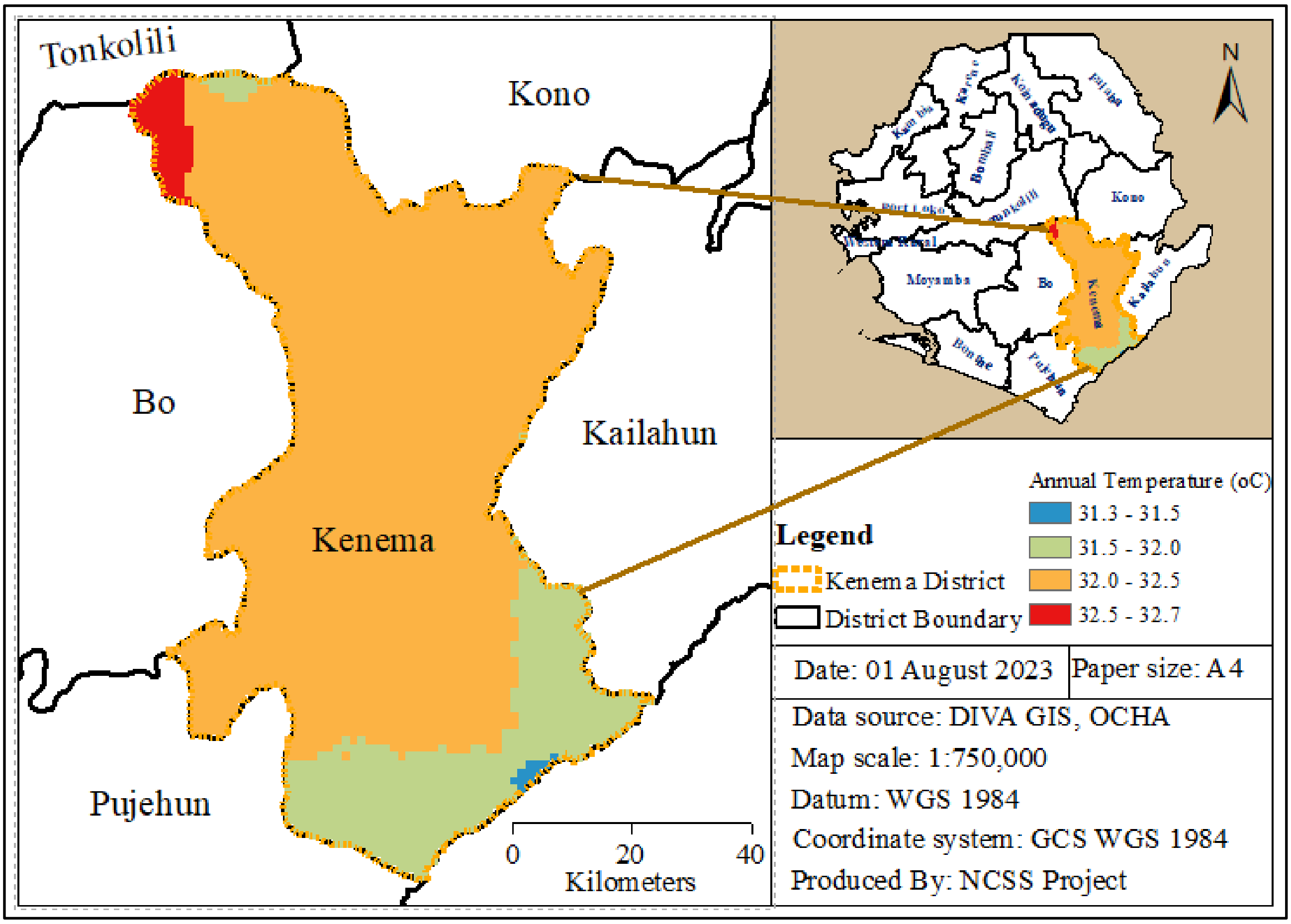

Figure 4. *Annual Temperature distribution in Kenema District (2021)*

Table 3. *Characteristics of the agro-climatic regions of Sierra Leone (Adapted from UNDP/FAO 1979; MAFFS/MFMR 2004)*

Regions	Area (km2)	Dominant landform	Altitude (m)	Average temperature (°C)	Average annual rainfall (mm)	Average length of growing period (days)	Dominant vegetation
Coastal Plains	11,016	Estuarine swamps, alluvial plains, beach ridges and coastal terraces	<150	27.9	3000	260 ±10	Mangrove swamps and grassland
Savannah woodland	27,993	Drainage depressions, undulating plains, low plateau and hills	150-300	28.2	2280	255 ±10	Lophira, savannah woodland, mixed tree savannah, upland grassland and forest regrowth
Rainforest/ savannah	20,712	Plateaus with undulating high-lying plains, low plateaus and hills	150-300	28.5	2730	270-300	Savannah woodland, montane grassland and forest regrowth
Rainforest	12,579	Plateaus with undulating high-lying plains, rolling plains and hills	300-600	28.6	2660	314 ±9	Forest and forest regrowth
Hills and Mountains	14,725	Highly dissected hill ridges	>600	-	-	-	Montane grassland and upland grassland

Table 4. *Characteristics of the agro-ecological zones of Sierra Leone (Adapted from Verheye 1997)*

Zones	Location of representative meteorological station	Length of growing period (days)	Start of growing period	Rainfall (mm)	Length of humid period (days)	Length of dry season (days)
A	Daru	>300	Third decade of February	2500-3000	>240	<70
B	Bonthe	230-270	First decade of March	>3000	230-270	100-120
C	Newton	230-270	First decade of April	>3000	230-270	100-120
D	Bo	270-300	First decade of March	2750-3000	270-300	70-100
E	Yengema	270-300	Second decade of March	2500-2750	230	70-100
F	Kabala	230-270	First decade of April	2000-2500	<210	100-120
G	Makeni	230-270	First decade of April	2750-3000	220	100-120
H	Port Loko	<230	First decade of April	2500-2750	<200	>120
I	Musaia	<230	First decade of April	<2000	<210	>120

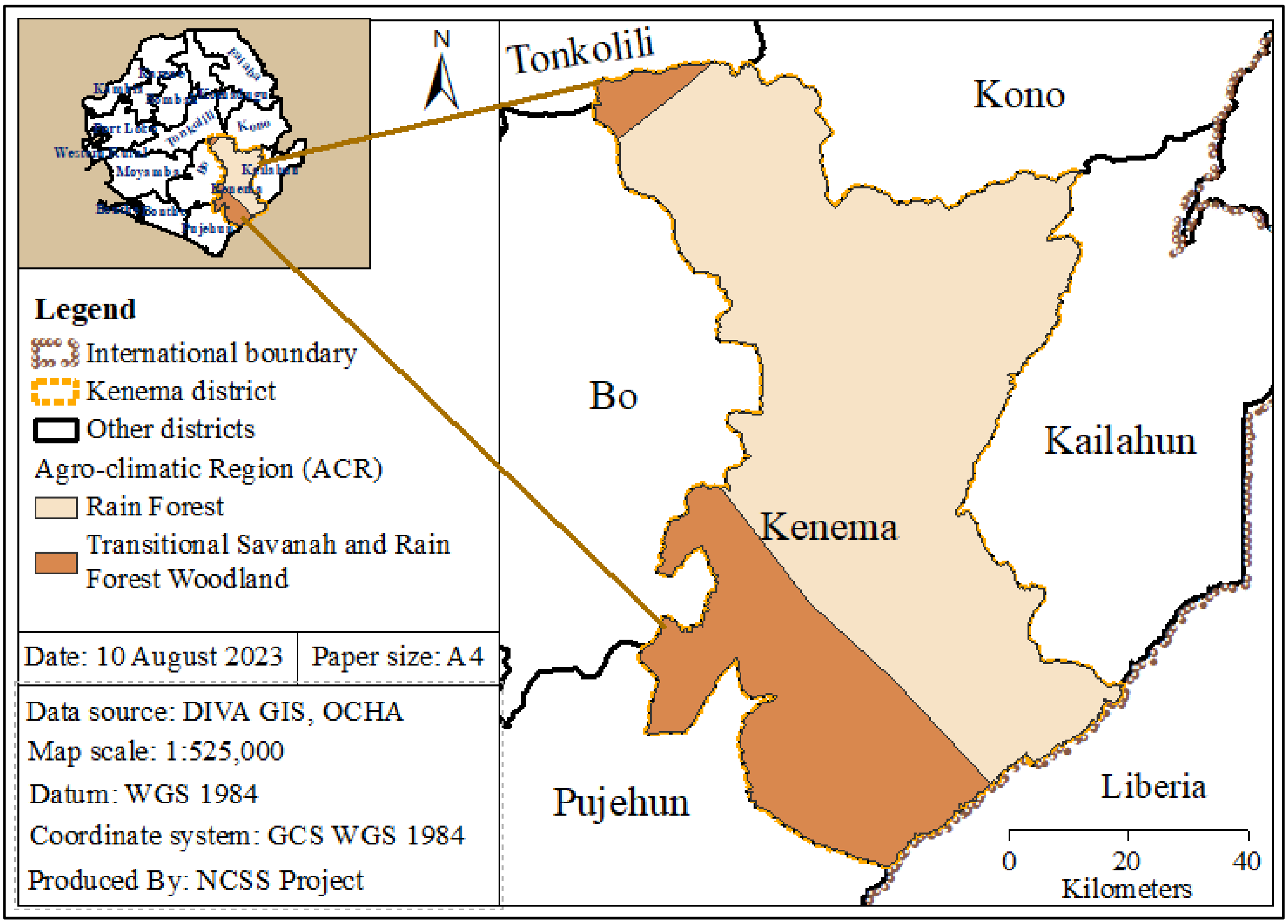

Figure 5. *Agro-climatic regions of Kenema District (Adapted from UNDP/FAO 1979)*

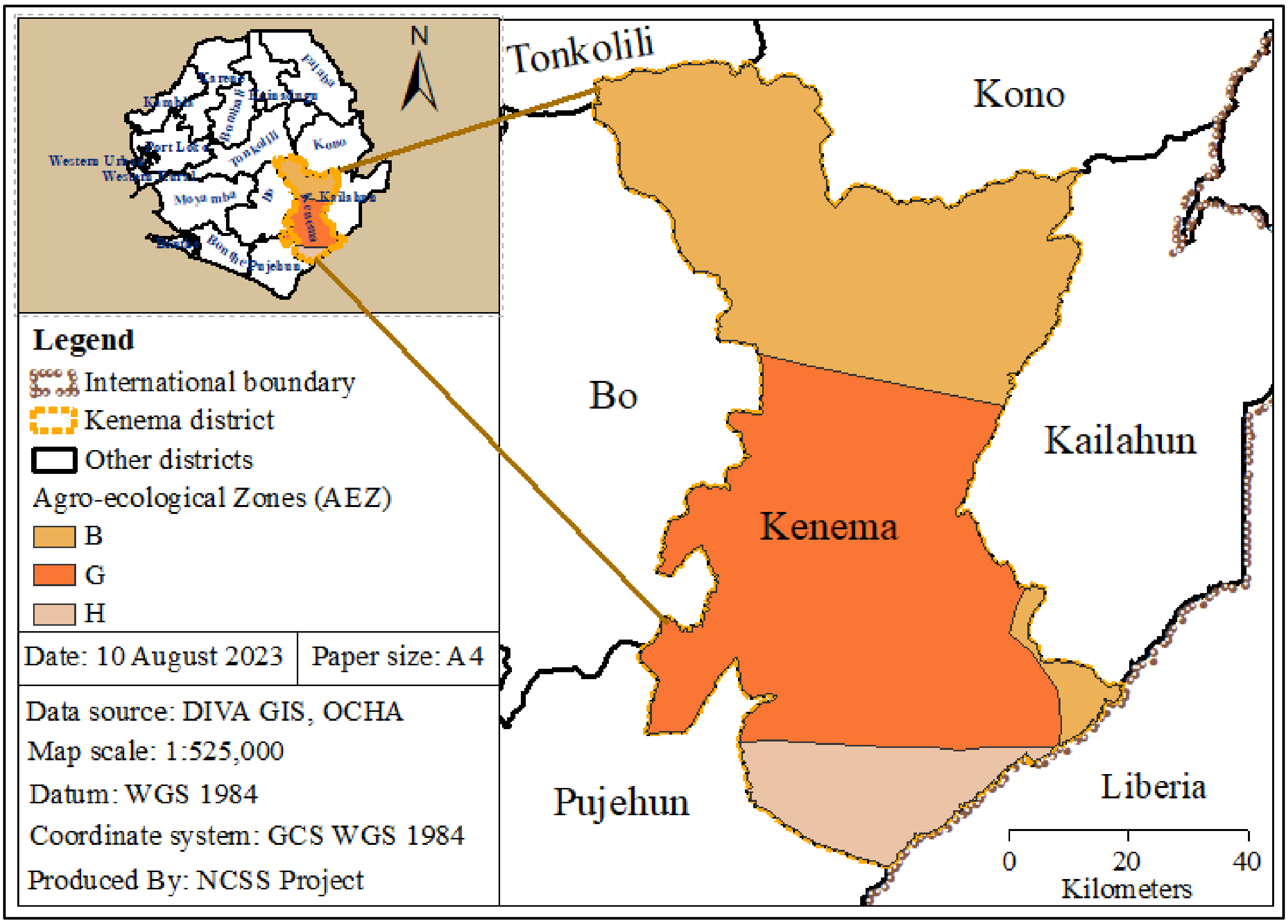

Figure 6. *Agro-ecological zones of Kenema District (Adapted from Verheye 1987)*

3.3 Geology

The geology of the district is an Assemblage of granites and acid gneisses, granulite facies rocks and greenstone belts of schistose sedimentary and volcanic rocks (Figure 7). These rocks are representative of the oldest zircon 2.90 Ga from zircons in migmatic gneiss, and 2.85 Ga from porphyritic granite inferred to intrude the Kenema Assemblage (Thieblemont *et al*., 2001 and references therein; Chan and De Waele, 2010). To the northeast and southeast of the district, the geology is underlain by the Loko Hills Group, which is a stratification of sedimentary and volcanic rocks with intrusions containing anorthosite metagabbro; amphibolite coronite; mafic granulite, ferruginous quartzite, banded ironstone; amphibolites with subordinate serpentinites; porphyroblastic banded gneiss, pyroxene augen gneiss, mylonite; migmatitic gneiss and granitoid. Among these, the porphyroblastic banded gneiss, pyroxene augen gneiss, mylonite fractions are extensive in the district.

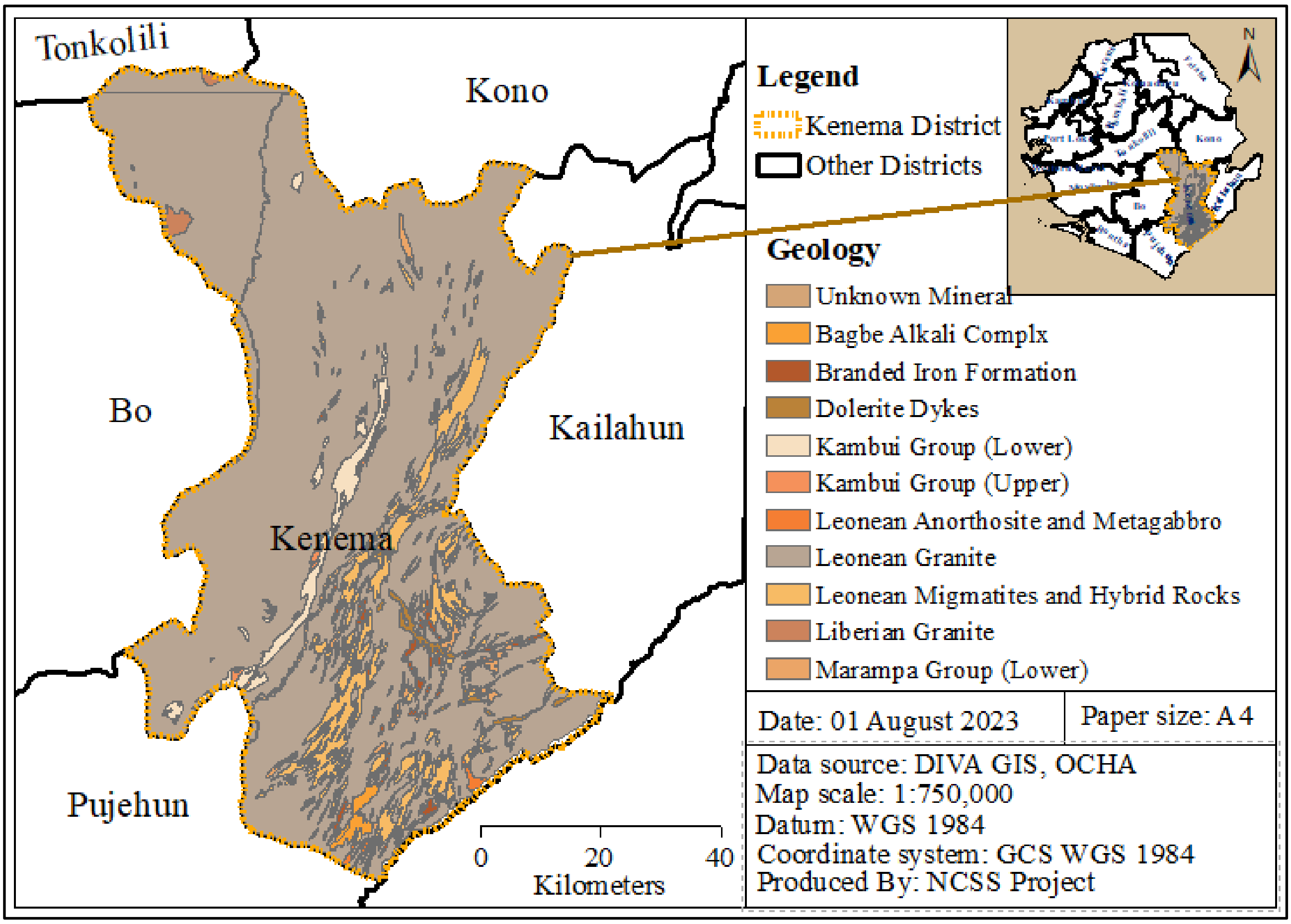

Figure 7. *Geology of Kenema district (Adapted from UNDP/FAO 1979)*

3.4 Land systems

The district comprises of 9 land systems (Figure 8). A land system is defined as an area, or group of area, throughout which there is a recurring pattern of topography, soils and vegetation (Chriatian and Stewart, 1953). The district consists of a series of highly dissected undulating plains, plateau with undulating high-lying plains as well as some hills and mountains, which are located on basic and ultra-basic rocks and acid rocks. The plains and plateaux are old erosion surfaces with generally accordant summits, while similar features are also present at higher elevations on the hills and mountains. These surfaces are usually mantled by a deep colluvial drift composed of pisolitic ironstone gravel and in some cases, indurated ironstone sheet. Much of the landscape is characterized by numerous, narrow, dendritic stream valleys which have been infilled with alluvial and colluvial material to form seasonally flooded inland valley swamps at lower elevations known as valley bottoms. The undulating plains have predominantly very gentle to gentle slopes of 1-5% mantled by a thick layer of densely packed pisolitic ironstone gravels together with narrow swamps and scattered isolated hills. In the northwest the plains are bordered by a flat-topped low plateau with distinctive E-W trending incised valleys which broaden into featureless depressions called bolis. The characteristics of the various land systems are given in Table 5.

Table 5. *Characteristics of land systems of Kenema District (Adapted from UNDP/FAO 1979)*

Land region	Subregion	Land system	Name	Code	Area (km^2)
Interior plains	Undulating plains	Dissected plains with broad valley swamps	Lunsar	13	186.6
		Dissected plains with isolated small hills and common terraces	Blama	15	1686.4
		Intricately dissected hills with isolated small hills	Bo	18	1150.6
Plateaux	Undulating high-lying plateaux	Irregularly dissected plains with isolated rocky hills	Koidu	27	68.9
		Strongly dissected plains with isolated hills	Kailahun	28	521.3
	Rolling plateaux and hills	Intricately dissected association of plains and pointed hills	Bendugu	31	265.5
		Variably dissected association of plains and rocky hills	Sandaru	32	903.9
Hills and Mountains	On basic and ultra-basic rocks	Dissected escarpment and hill ranges	Kangari	38	311.5
	On acid rocks	Complex of rocky hills	Kulufaga	41	1262.4

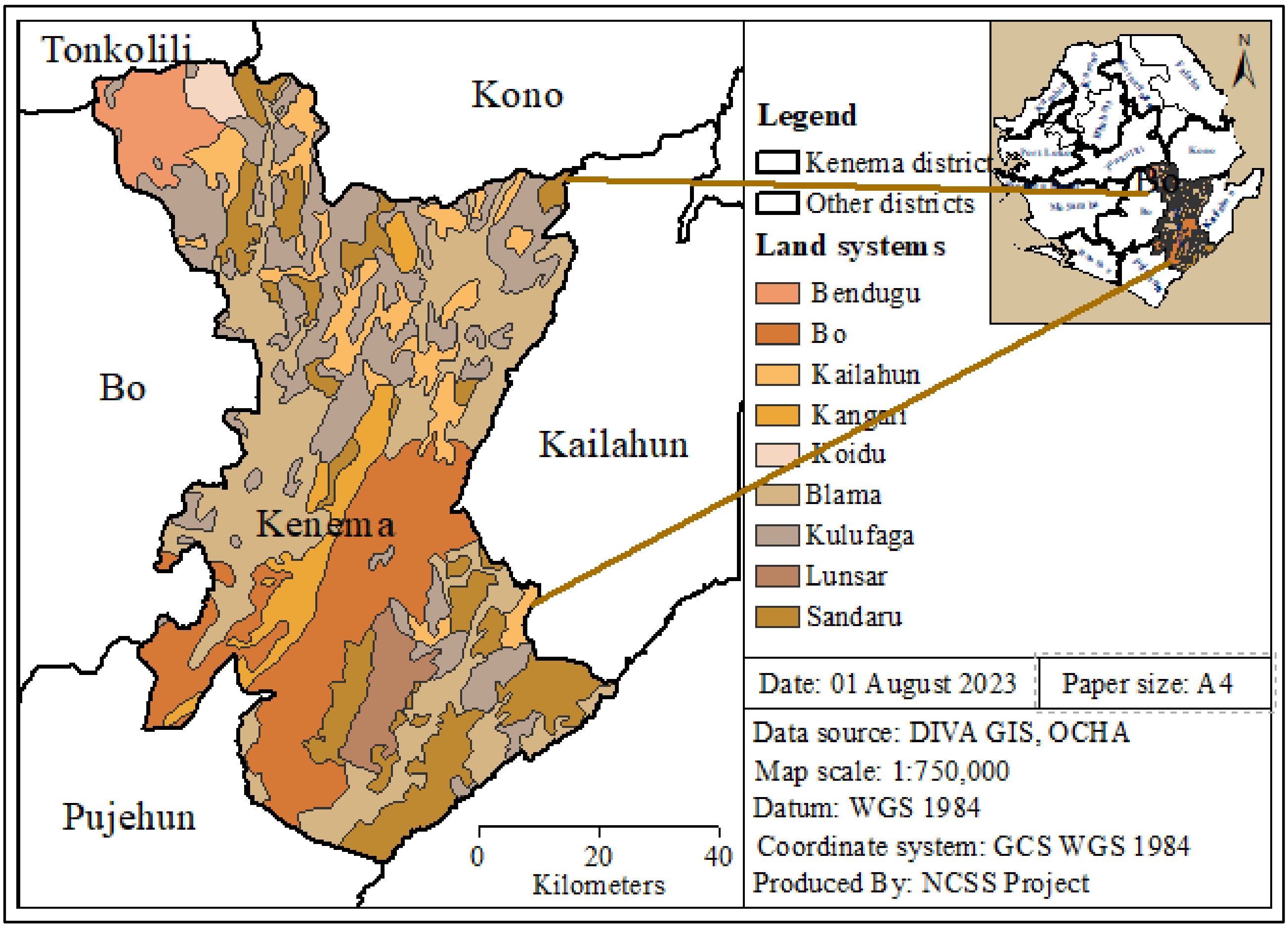

Figure 8. *Land systems of Kenema district (Adapted from UNDP/FAO, 1979)*

3.5 Hydrology

The major rivers in the district include Sewa, Wajei, Moa and Mabiyea, (Figure 9), and these form a network of convergence in the southwest with its head flowing tributaries from northeast and southeastern peripherals. The Moa and Sewa rivers contribute the major portion to the district's hydrology.

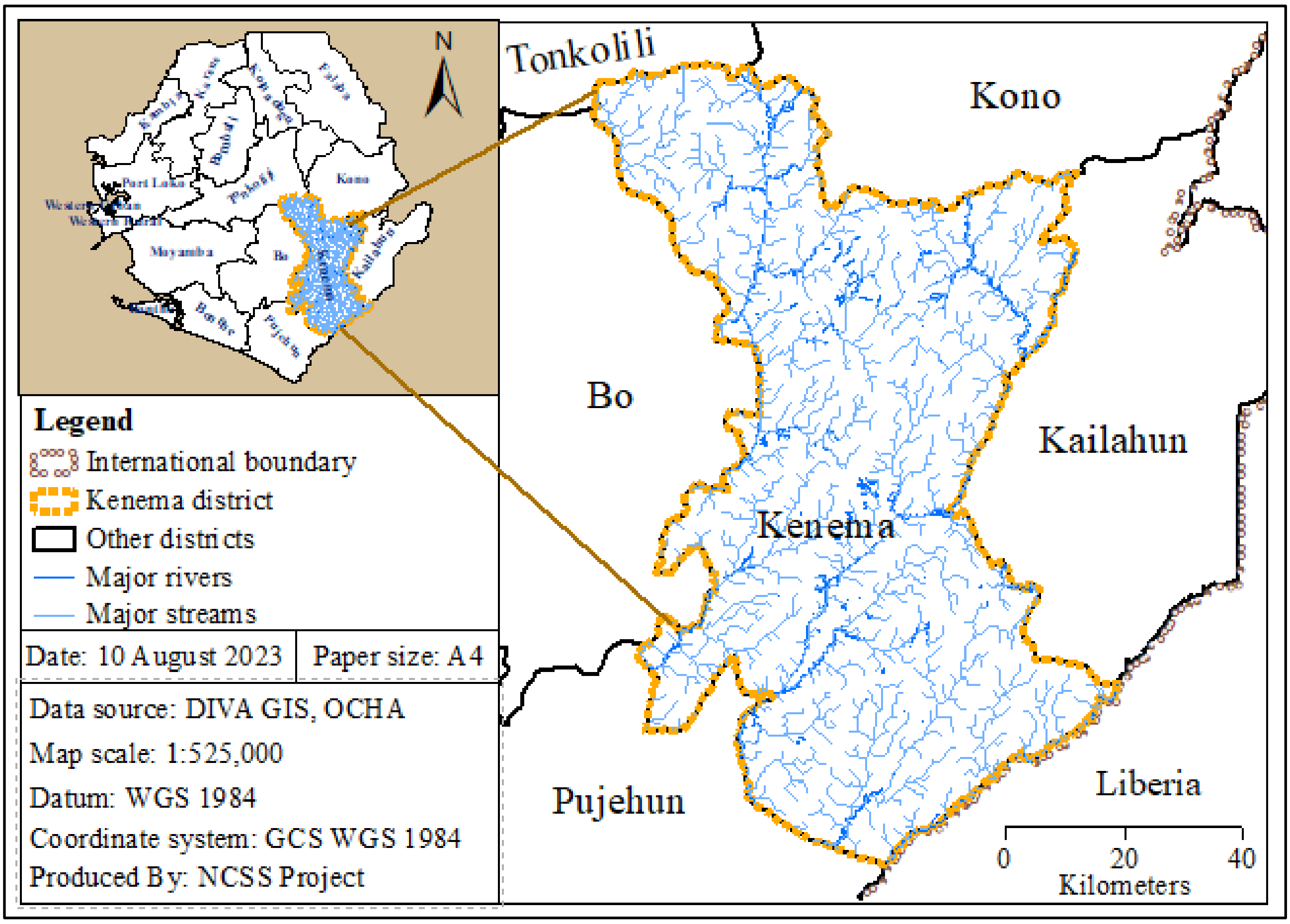

Figure 9. *Hydrology of Kenema District*

3.6 Main soil associations

The soils of Kenema District generally vary depending on the agroecology in which they are found. The upland soils are generally poor, lateritic and prone to heavy leaching while soils of the lowlands especially the inland valley swamps (IVSs) are more fertile and provide the optimum area in terms of water management and environmental sustainability for agricultural production. Generally, the soils can be grouped into five (5) representative soil types (Figure 10), which include 1) gravel soils, 2) gravel-free over gravel soils, 3) river terrace soils, 4) gravel-free soils and 5) colluvial hydromorphic. These soils occur in twelve main associations (Figure 9 and Table 6), namely, 1) weakly developed muds and hydromorphic clays along coastal river; 2) undeveloped to weakly developed sands on coastal beach plains; 3) hydromorphic clays and gravel free ferralitic soils on coastal floodplains; 4) gravel free ferralitic soils on coastal terraces; 5) gravelly ferralitic and plinthic hydromorphic soils on inland terraces, depressions and floodplains; 6) very gravelly ferralitic soils over colluvial gravel on western interior plains; 7) gravelly ferralitic soils over weathered granitic basement or colluvial gravel on southern interior and plateau plains; 8) gravelly nodular ferralitic soils over weathered granitic basement on northern interior and plateau plains; 9) stony and gravelly ferralitic soils over weathered granitic basement or colluvial gravel on low to moderate relief hills; 10) stony and gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from predominantly acid rocks; 11) very gravelly ferralitic soils with shallow soils on moderate hills formed from basic and ultrabasic rocks; and 12) Shallow soils on plateau mountains and lateritic hills and terraces (Table 6).

Table 6. *Main soil types and associations of Kenema District (Adapted from UNDP/FAO 1979)*

No.	Land region	Area (km^2)
1	Gravelly ferralitic over weathered	14007.4
2	Stony and gravelly ferralitic over weathered	9286.6
3	Stony and gravelly ferralitic with shallow soils	10783.4
4	Very gravelly ferralitic with shallow soils	2351.2

3.7 Vegetation and land use

Six major vegetation types have been identified in Kenema district (FAO, 2007), among which are forest regrowth, closed high forest, rock outcrop, rubber plantation, secondary forest and upland crops (Table 7 and Figure 10). The forest regrowth vegetation is derived from the shifting cultivation pattern of farming that is common in the country. The secondary forest is an elongated generally narrow strip of dense secondary forest cover with widths that vary from place to place along the banks of major streams and rivers. The savannah grassland vegetation mainly comprises of Pennisetum purpurenum (the tall grass species commonly referred to as elephant grass). The hydromorphic vegetation comprises of a variety of vegetation species specific to inland valley swamps (IVSs) that have been left to fallow.

Table 7. *Vegetation and land use types of Kenema District (Adapted from FAO 2007)*

No.	Land region	Area (km^2)
1	Closed high forest	1932.5
2	Forest regrowth	33210.3
3	Secondary forest	602.7
4	Rock outcrop	776.9
5	Rubber plantation	149.6
6	Upland crops	286.4

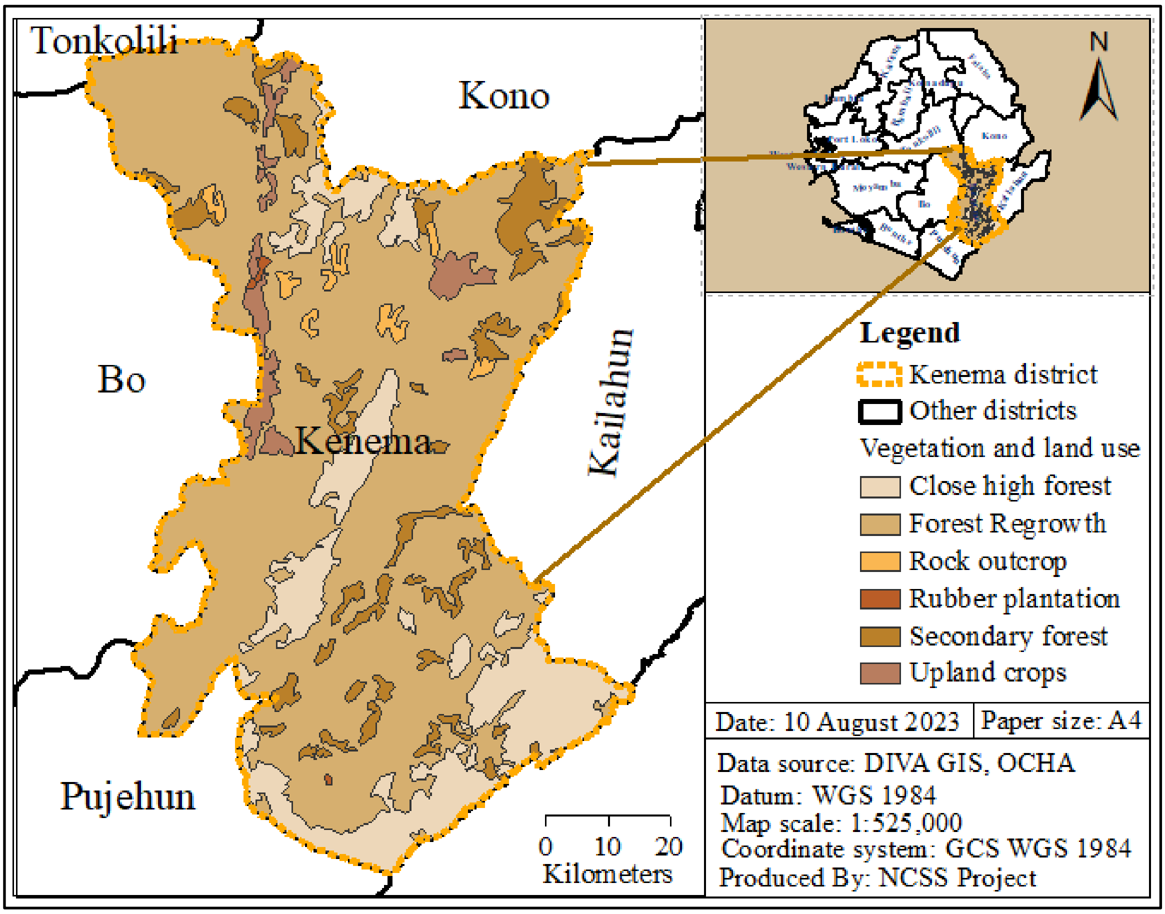

Figure 10. *Vegetation and land use of Kenema District (FAO, 2007)*

3.8 Socio-economy

The livelihoods are largely dependent on food and cash crop cultivation, and a majority of households add hired hands to their own family labor. Rice and cassava are the major food crops grown, consumed and traded. Cocoa, coffee, kola nut and oil palm tree crops provide major employment opportunities in the district. Both upland and lowland rice are cultivated. These commodities are a primary source of income for most households – either through sales or through employment as farm labor. Mostly wealthier households own plantations while middle and poorer households are employed to maintain and harvest the trees. Plantain and banana are also grown but to a lesser extent than rice and cassava. Timber plays a greater role in the socioeconomic growth of the district. Mostly, households harvest trees for charcoal production and to supply domestic construction materials but while this income source remains minor in comparison to cash crops, in recent years it has become more important. Diamond and gold mining occur on a localized level, and has been a more important part of households' income but while mining is a localized phenomenon in the district, however, they are currently less prevalent and more regulated than in the past years.

3.9 Environmental hazards

The district is prone to landslides, flooding, drought, epidemics, tropical storms, thunder & lightning (Mattai, 2017). The frequency of these natural hazards ranges from very rarely (for coastal erosion, drought, storm surge and sea level rise) to rarely (for landslides and epidemics), sometimes (for tropical storms), often (for flooding) and frequently (for thunder and lightning) while the magnitude rages from trivial (for coastal erosion, storm surge and sea level rise) to moderate (for landslides, flooding, tropical storm and thunder & lightning), large (for drought), and very large (for epidemics).

4 Soil survey methodology

4.1 The planning phase of the survey

Prior to the commencement of field work, a soil survey methodology workshop was organized to ensure harmonization of soil survey techniques among the three teams working in different districts. During the same period, all existing soil data of Kenema District were harmonized into a unified framework to allow correlation of previously surveyed and mapped soils with the current soil survey exercise.

The 1979 land system map of Sierra Leone (UNDP/FAO, 1979) was digitized into district maps by the Soil Database and Information System (SDIS) unit of the NCSS project and prepared in both hard copy and .tiff GIS format for use as base maps in planning and conducting the district soil survey. The AED staff of the MAFS district offices led the process of setting the transect lines on the hard copy of the land system map on which the survey team will traverse, using the free (not grid) survey methodology. The MAFS district staff who had computers were encouraged to download the free Google Pro GIS application and were trained on how to overlay the district land system map in .tiff GIS format on their google maps.

5.2 How the survey was conducted

Once the survey team fully understood the survey terrain on google map, including the various locations, communities, landforms, and rivers along/across which the transect line will cross, the coordinates of these geographical locations and the transect points to be examined for digging profile pits and/or auger borings were inputted into the GPS handset. The "Go To" command of the GPS was then activated to guide the navigation of the survey team to the point/place of interest on the transect line.

Two transect lines (Figure 12) were drawn (as close to main motor ways as possible, guided by the experience of the terrain by the local MAFS staff) from west to east of the district map through as many land systems as possible to ensure the systematic observation of the various soils on the landscape elements (summit, shoulder, backslope and toeslope) within each land system polygon. If these soils repeat themselves in the same sequence on the landscape elements for the same land system, irrespective of the district the land system is located, they are identified as a soil association and labelled as a mapping unit. One unique sequence of soil associations constitutes a mapping unit and named by the soils individuals that make up the association. For example, map unit A constitutes X soil series, Y soil series and Z soil series is called the x, y, z soil association.

4.3 Soil profile excavation and soil sample collection

Representative soil profile pits of dimension 2m x 1.2m x 1.5m, were excavated at each landscape position within a land system for detailed morphological description using the FAO (2006) guidelines for soil description (Figure 13). These guidelines for soil description were transformed into a digital format from which a KoboCollect app version was developed and used for field data entry.

Soil samples were collected from each horizon and analysed for physicochemical properties at the Njala University and SLARI soil laboratories following the ISRIC/FAO (2002). To enhance the quality of the results, a 0.1 % number of samples was sent to the IITA Analytical Services Laboratory (ASLab) for validation analysis. The field and laboratory data were used to determine the suitability rating to produce crops selected by MAF for each identified soil type using the FAO framework for land evaluation (FAO, 1976; FAO, 2007).

4.4 Benchmark soils

High-resolution soil monolith photos taken of a pedon (representative soil profile of a soil type) at the location/district where it was first described in a toposequence within a land system, served as a Benchmark soil for comparing, classifying, naming and discussing any other soils with similar morphology. The concept of benchmark soils speeded up the free survey as it limited the number of profile pits dug for the same soil types. Instead, soil augers were used to make quick excavation to confirm or deny the presence of the same or new soil type and establish the boundary between soil types. The use of benchmark soils also eliminated the confusion of given different names to soils of the same morphology as has been the practice in Sierra Leone when independent surveys were undertaken by soil surveyors in different districts. For example, the Njala series carries the same morphology and landscape position as the Makeni series. For the NCSS project, most of the benchmark soils were first describe in the Moyamba district. Where, soils of the same morphology exist in other districts, they were represented by one benchmark soil photo, but their chemical and morphological properties were recorded, and averages and ranges noted.

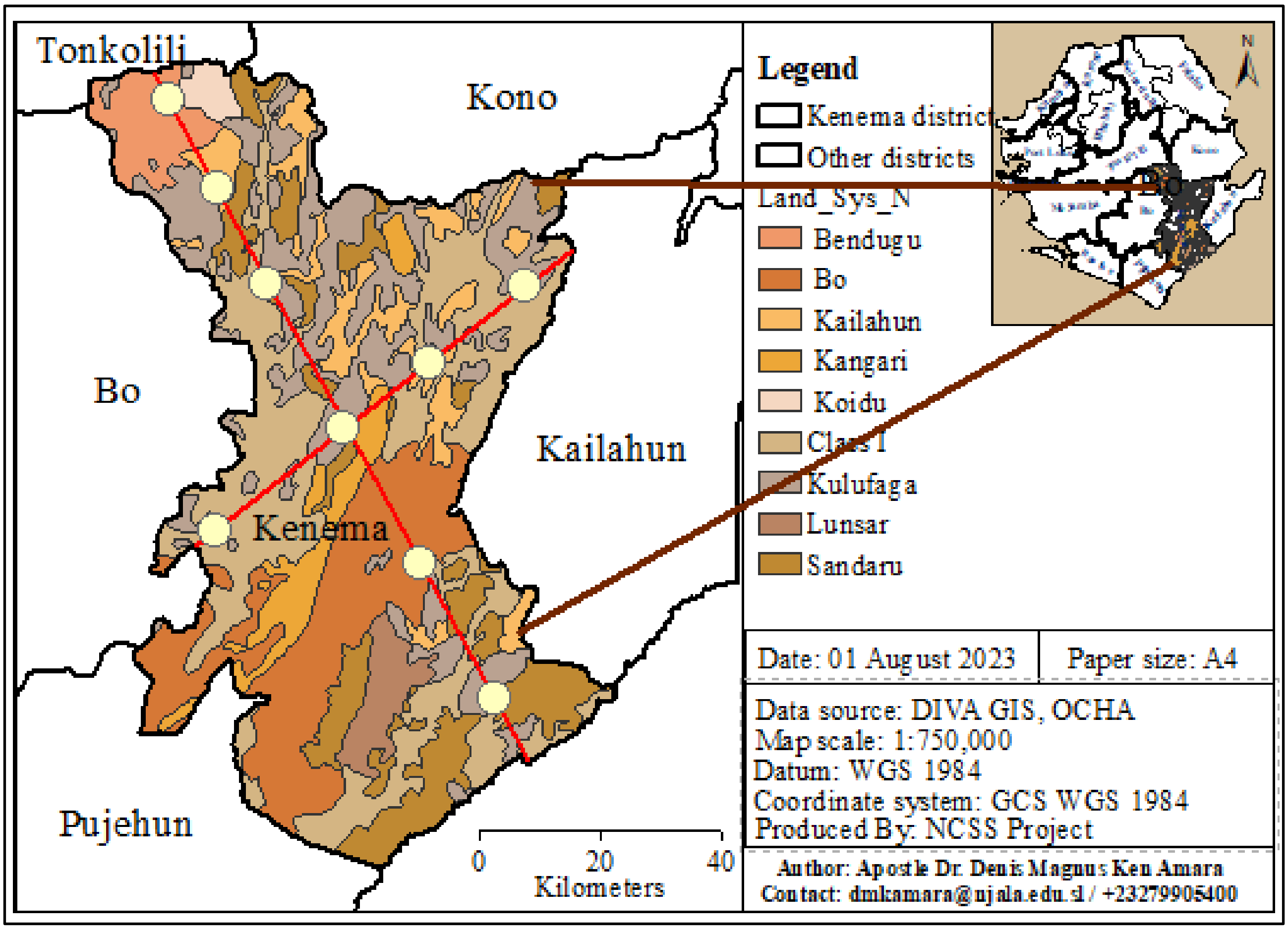

Figure 11. *Transect lines running through soil profile locations in preparation for a free-soil survey (adapted from Brady and Weil, 2008)*

District: Kenema; **Chiefdom**: Kandu Leppiama; **Village**: Nafamie; **GPS location**: 7.99034°/11.333
Elevation: 141m; **Physiography**: Undulating plain; **Landform/facet**: Dissected plain; **Parent Mate**
Weathered Residium; **Landscape position**: Summit/ crest; **Slope**: 6-8%; **Vegetation**: Bush regrowth
grasses; **Erosion class and intensity**: e3, severe; **Drainage and permeability:** Well drained and ra
Ground water depth: Above 160cm; **Moisture:** Profile is dry throughout; **Landuse**: Fallow shi
cultivation; **Major crops grown**: Pineapple.

Land System:

Classification : USDA Taxonomy: Orthoxic Palehumult **FAO-UNESCO:** Dystric Nit

Mapping Unit: KEN008
Gravelly soil
(PLATE 015)

Horizon (cm)	Morphological Description
Ap (0 – 35)	Dark grayish brown (10YR4/2 dry) and very dark gra brown (10YR3/2 moist); gravelly sandy loam; mode coarse, crumbly; slightly hard (dry), friable (moist); not st and not plastic; few fine, medium, plenty coarse pores; pl very fine, fine and few medium roots; presence of term millipedes, ants and other insects; clear and wavy boundar horizon below.
Bv1 (35 – 69)	Yellowish brown (10YR 5/4 dry) and dark yellowish br (10YR4/4 moist); gravelly sandy clay loam; moderate, co crumbly; slightly hard (dry), friable (moist); not sticky and plastic; plenty very fine, fine, medium, very few coarse po plenty very fine, fine, few medium roots; presence of term ants and other insects; clear and wavy boundary to hor below.
Bv2 (69 – 151+)	Yellowish brown (10YR 5/6 dry) and dark yellowish br (10YR4/6 moist); gravelly sandy clay; moderate, co crumbly; slightly hard (dry), friable (moist); slightly sticky slightly plastic; few very fine, fine and plenty medium, coarse pores; common very fine, plenty fine, and few med roots; presence of termites, ants and other insects; clear wavy boundary to horizon below.

Figure 12. *A benchmark soil, first described in Nafamie, Kandu Leppiama chiefdom, Kenema District to compare and represent all pedons described as the Njala sloping series that carry a similar morphology*

Soil samples were collected from each horizon of a soil profile and analysed for physicochemical properties at the Njala University and SLARI soil laboratories following the ISRIC/FAO (2002). To enhance the quality of the results, a 0.1 % number of samples was sent to the IITA Analytical Services Laboratory (ASLab) for validation analysis. The field and laboratory data were used to determine the suitability rating to produce crops selected by MAFS for each identified soil type using the FAO framework for land evaluation (FAO, 1976; revised by FAO, 2007).

4.5 Land Capability evaluation

Land capability evaluation of the soil associations identified in Kenema District were conducted according to the procedure and guidelines provided in Agriculture Handbook No. 210 (Klingbiel and Montgomery, 1961). This provided the basis for separating arable from non-arable lands for the purpose of planning agricultural land use in the district. Appropriate soil conservation measures for the sustainable use of the soils were also indicated.

Land capability codified tables: Land capability classes were colour coded as recommended by Klingbiel and Montgomery (1961) as follows:

i. Light green - Land capability class 1
ii. Yellow - - Land capability class II
iii. Red - - Land capability class III
iv. Blue - - Land capability class IV
v. Dark-green - Land capability class V
vi. Orange - - Land capability class VI
vii. Brown - - Land capability class VII
viii. Purple - - Land capability Class VIII

Land capability classes 1- IV were classified as arable and land capability classes V-VII as non-arable.

4.6 Soil Suitability evaluation

Soil suitability evaluation was conducted for 19 priority crops identified by MAFS for Sierra Leone. The crops included (1) Rice under 4 methods of production (Rainfed upland rice, Rainfed bunded rice, Natural flooded rice and Irrigated rice), (2) Other food crops (Cassava, Maize, Sweet potato, Ground nut and Cowpea), (3) Vegetables (Onion, Cabbage, Tomato and Carrot), (4) Tree crops (Cacao, Arabica coffee, Robusta coffee, Cashew, Oil palm), and (5) Fruit trees (Mango, Citrus, Pineapple and Banana). The optimal growth conditions for these crops were taken from Land Evaluation Part 3 (Sys et al., 1993). Using the 1976 FAO parametric method of land suitability evaluation, the landscape, climatic and soil properties collected in the field for each soil was matched against the internationally recognised optimal growth requirements of the target crops (Sys *et al*. 1993).

To expedite the matching process, a soil suitability algorithm was developed according to the FAO (1976) protocol to determine the Land Productivity Index (LPI) required for grouping the soils into suitability classes in decreasing order of crop productivity and constraints of S1> S2 >S3> N1 >N2. The limitations of the soils to the production of specific crops are coded as follows: f = fertility (pH, cation exchange capacity (CEC), Base saturation), s = soil physical characteristics (texture, bulk density), t = topographic (slope), w = wetness (drainage, flooding) and n = salinity / alkalinity).

The allocation of equal percentage weightings (100%) to the performance of the climatic, landscape and soil qualities in meeting a crop requirement as required by the FAO (1976) Land evaluation method, to the tropical soils resulted in the soils being mainly classified in the N1 and N2 classes on account of the zero (0) rating allotted to the poor performing chemical properties, particularly pH and CEC (Ojanuga, 2008). To avoid this problem with the FAO (1976) Land evaluation protocol for Sierra Leone soils, the Ojanuga recommendation of allocating a weighting of 80% to climatic and landscape and 20% to the chemical properties was found to produce more realistic LPIs for evaluating soil suitability. A soil suitability algorithm was therefore programmed to reflect the Ojanuga recommended weightings. Except for this modification in weightings, the parametric method prescribed by FAO in determining LPIs for the classification of soil suitability remained unchanged. The suitability classes were set according to Table 8.

Table 8. *Keys for defining soil suitability classes and limitations (FAO, 1976)*

Suitability class	Aggregate stability class	Soil limitations
S1 = Highly suitable	S1 = 75-100	f = fertility
S2 = Moderately suitable	S2 – 74-50	S = soil physical characteristics
S3 = Marginally suitable	S3 = 49-25	T = topography (slope)
N1 = Currently not suitable	N1 = 24-15	W = wetness (drainage)
N2 = Permanently not suitable	N2 = 14-0	N = salinity/alkalinity

Soil suitability codified tables: Soil suitability classes were colour coded as recommended by AbdelRahman et al (2016) as follows:

i. green - S1 soil suitability
ii. grey - S2 soil suitability
iii. brown - S3 soil suitability
iv. saffron - N1soil suitability
v. yellow - N2 soil suitability

4.7 Production of maps

4.7.1 Soil maps

Soil maps were produced at a 1:500,000 scale using GIS algorithms trained by the relationship between soil and landscape attributes, which were established during the field survey phase. The ArcGIS and QGIS were used to develop the soil maps, using soil association as mapping units. The area extent of each soil associations was calculated in the GIS environment.

4.7.2 Land capability maps

Land capability mapping was done to classify the land units in accordance to their fitness for specific kinds of land uses on the basis of their suitability and non-suitability for cultivation. The maps were produced at a 1:500,000 scale using GIS algorithms trained by the relationship of five physical factors such as lithology (characteristics of parent materials), edaphology (kind of soil and its influence on land use), topography (shape and feature of land), gradient (slope of the land) and biotic (vegetation/ land use/ land cover). The base map of the district was prepared using the topographic map and digital elevation model (DEM) of the district. This was used to delineate the areas having different category of general elevation and slopes. The slope map together with the analyzed soil properties were used to identify the soil types. Based on the criteria of land capability classification explained above, classes were assigned to the delineated areas using standard colours specific to the classes as mentioned above in section 4.5.

4.7.3 Soil suitability maps

The production of soil suitability maps required the separation of the soil individuals (whose unique land and soil data are used to determine how well it meets the requirement of a crop for optimal growth/yield) relative to the other soil individuals in the association/toposequence. This was achieved by overlaying the soil association polygon on an ALOS/PAR Digital Elevation Model (DEM) of the district (having a spatial resolution of 12.5m) and clipping them together using the extraction-by-mask technique in the Spatial Analyst toolbox. The clipped soil association raster was classified according to the elevation ranges each soil individual occupied in the toposequence within a land system. Soils at the summit and shoulder were put into the highest elevation class, followed by soils on the back slopes and lowest, soils at the foot slope. The soil association raster files were converted to polygons and assigned the soil suitability codified colours of the different suitability classes as per section 4.6.

4.8 Data storage

All data generated including field data, laboratory data and interpretive maps were stored in the national Soil Database and Information System (SDIS) office for easy query and retrieval by end users through a web-based soil information system.

4.9 Limitations of the methodology

Soil individual boundaries in the soil maps were estimated using the following remote sensing technique: the soil association polygon was overlain on a Digital Elevation Map (DEM) of the district (having a spatial resolution of 12.5m) and clipped together (or extraction by mask). The clipped raster soil association polygons were classified according to the elevation ranges each soil individual occupy in the toposequence within a land system. Soils at the summit and shoulder were put into the highest elevation class, followed by soils on the back slopes and lowest, soils at the foot slope. The raster soil association files were converted to shape files and assigned the colours as indicated in the colour codified table in section 4.3.

5 Description and classification of soils of Kenema District

5.1 Description of soils of Kenema District

5.1.1 Soils located on sloping terrains

These are soils found on slopes, which contain weathering bedrock pieces in their subsoil or even solid bedrock. They are usually, fairly fertile, especially if the bedrock contains some weatherable minerals. They should not be used for upland farms, because the erosion danger is great. They can best be put into forest or used for tree crops such as coffee, cocoa, or oil palm.

Map unit 1: Rockland-Segbwema-Vaahun soil association

The ***Rockland-Segbwema-Vaahun*** soil association is a group of soils formed from alluvial parent materials on isolated steep hills and slopes, with some dominated by rock outcrops.

5.1.1.1 Rockland series

Photo 1. *Typical position of Rockland soil series in Kenema District*

The *Rockland series* is a land type that is used to delineate land areas that are dominated by bedrock at the surface. In Kenema district, a good proportion of this land type accounts for soils located on hills and steep slopes and granite domes (usually called *monadnocks*, that are higher above the surrounding areas. These monadnocks are widely scattered on steep slopes and isolated hills, especially around the Kambui Forest reserve area. The slope ranges from 10-15 %. A common attribute of this land type is the presence of rock outcrops usually covering 25% to 35% of the land surfaces. In most cases, the bedrock is often found at or near the soil surface. Also, a thin soil layer of thickness ranging between 1 to 50 cm may occur as pockets of soil at certain locations.

The *Rockland series* are usually unsuitable for the production of economic plants and should be left with its scanty natural vegetation for watershed protection, wildlife use, or esthetic purposes. The morphological and chemical properties of the Rockland series are presented in Table 9. Chemically, Rockland soils are marginal for crop production due to their nutrient status. The organic carbon content is high in both topsoil and subsoil horizons. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is high in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K and Na are low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is high in topsoil horizon and low in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is high in topsoil horizon and moderate in subsoil horizon.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the sloping nature of the landscape, runoff potential is high and erosion is a serious challenge especially where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN001, of the *Rockland* series, are given in Appendices 1a and 1b.

Table 9. *Key land, morphological and chemical properties of Rockland series*

Soil Series Name	Rockland
International soil name	Dystric Nitosol
Slope range	8.2 %
Soil surface stoniness	Rocky
Typical position in the landscape	*See Plate 1*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Sandy loam
Drainage	Well drained and rapid
Colour of the topsoil:	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist)
Colour of the subsoil	Brown (10YR4/3 dry) and dark brown (10YR3/3 moist)
Soil depth	Very deep (>150 cm)
Nature of obstruction	Rock outcrops

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.07	4.53
Available phosphorous (Bray P1 (mg kg-^{1})	15.11	12.96
Acidity (pH in 1:1 soil to water ratio)	4.5	4.5
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	4.50	3.61
Exchangeable Calcium (cmol kg^{-1} soil)	1.07	1.06
Exchangeable Magnesium (cmol kg^{-1} soil)	2.2	1.29
Exchangeable Potassium (cmol kg^{-1}soil)	0.19	0.19
Exchangeable Sodium (cmol kg^{-1} soil)	0.21	0.21
Exchangeable Acidity (cmol kg-1 soil)	0.83	0.88
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	8	5.33
DTPA extractable Iron (cmol kg^{-1})	4.3	2.66
DTPA extractable Copper (cmol kg^{-1})	4.7	4.10
DTPA extractable Zinc (cmol kg^{-1})	9.54	4.79

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.1.2 Segbwema series

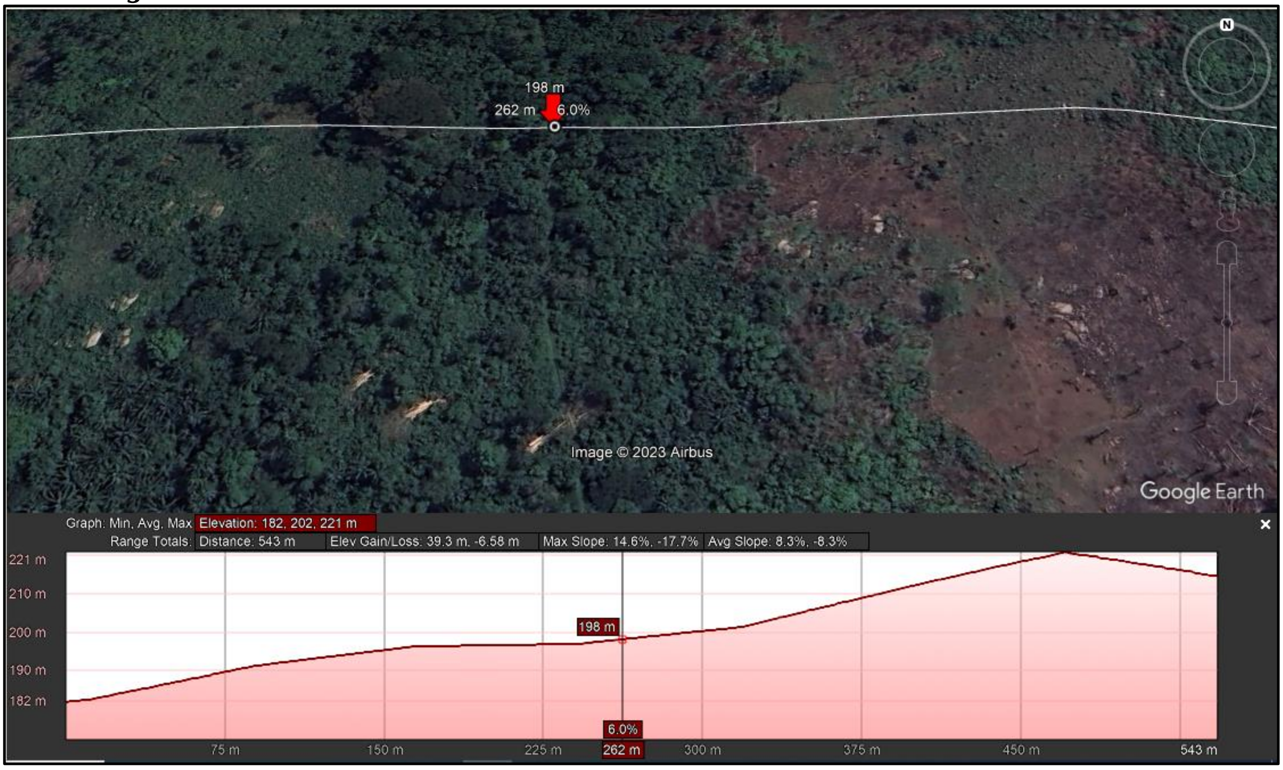

Photo 2. *Typical position of Segbwema soil series in Kenema District*

Segbwema soils occur on slopes, typically with gradients less than those of Vaahun soils. Segbwema soils are formed from fine-grained granodiorite, which is low in quartz and high in ferromagnesium minerals and feldspars. In these soils, the textures are typically sandy clay loam in the A and C horizons and clay loam in the B horizon. Some detrital hardened plinthite gravel may be present in the upper layers though in most areas, the soil may be devoid of any ironstone gravels but rather replaced with a gravel-free layer of about 50 – 100 cm. In some areas, pieces of rock fragments and mica flakes are visible, with bedrock occurring at a depth of about 120 cm. Textures are loam to clay loam in the topsoil and clay loam in the subsoil. The topsoil of the A_1 horizon is yellowish brown (10YR5/4 dry) and dark yellowish brown (10YR4/4 moist), which qualifies as an ochric epipedon. At some locations, the topsoil colour ranges from yellowish brown to very dark brown (10YR4/2 dry – 10YR3/2 moist). Subsoil colors are typically yellowish brown (10YR 4/6 dry) and yellowish brown (10YR3/6 moist). Segbwema soils are well drained and are never waterlogged at the surface.

Chemically, Segbwema soils are very low in plant nutrients (Table 10). The organic carbon content is moderate in both topsoil and subsoil horizons. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is high in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is high in topsoil horizon and moderate in subsoil horizons. The exchangeable Ca, Mg, K and Na are low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, while the DTPA extractable Co and Zn (cmol kg^{-1}) are high in topsoil and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity.

Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the sloping nature of the landscape, runoff potential is high and erosion is a serious challenge especially where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN002, of the *Segbwema series* is given in Appendix 2a and 2b.

Table 10. *Key land, morphological and chemical properties of Segbwema series*

Soil series name	Segbwema	
International soil name	Ferralic Cambisol	
Slope range	6.3 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 1*	
Texture of the topsoil (0 – 20cm)	Sandy clay loam	
Texture of the subsoil (at 50cm)	Sandy clay loam	
Drainage	Well drained and rapid	
Colour of the topsoil:	Yellowish brown (10YR5/4 dry) and dark yellowish brown (10YR4/4 moist)	
Colour of the subsoil	Yellowish brown (10YR 4/6 dry) and yellowish brown (10YR3/6 moist)	
Soil depth	Very deep (>150 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.83	1.2
Available phosphorous (Bray P1 (mg kg-^{1})	15.92	13.8
Acidity (pH in 1:1 soil to water ratio)	3.6	3.9
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	2.83	4.6
Exchangeable Calcium (cmol kg^{-1} soil)	0.26	1.33
Exchangeable Magnesium (cmol kg^{-1} soil)	0.46	0.76
Exchangeable Potassium (cmol kg^{-1}soil)	0.12	0.21
Exchangeable Sodium (cmol kg^{-1} soil)	0.11	0.24
Exchangeable Acidity (cmol kg^{-1} soil)	1.88	2.03
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	21	11
DTPA extractable Iron (cmol kg^{-1})	5.24	4.04
DTPA extractable Copper (cmol kg^{-1})	411.2	140.1
DTPA extractable Zinc (cmol kg^{-1})	21.48	11.1

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.1.3 Vaahun series

Photo 3. *Typical position of Vaahun soil series in Kenema District*

Vaahun soils are associated with the steepest slopes on which soil develops, and their solum tends to be less than 100 cm thick. These soils develop in coarse-grained granite high in quartz and low in dark ferromagnesium minerals. Most of the fine gravel and sand is quartz. The fine-earth fraction (< 2.0 mm) is sandy clay loam in the surface horizon and clay in the subsoil.

The A_1 horizon is yellowish brown (10YR5/4 dry) and dark yellowish brown (10YR4/4 moist). The subsoil colour is yellowish brown (10YR 4/6 dry) and yellowish brown (10YR3/6 moist). Vaahun soils are well drained.

Chemically, Vaahun soils are very low in plant nutrients (Table 11). The organic carbon content is low in both and subsoil horizons. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca and Mg are low in both topsoil and subsoil horizons, exchangeable K is high in topsoil horizon and moderate in subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co and Zn (cmol kg^{-1}) are high in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the sloping nature of the landscape, runoff potential is high and erosion is a serious challenge especially where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN003, of the *Vaahun series* is given in Appendix 3a and 3b.

Table 11. *Key land, morphological and chemical properties of Vaahun series*

Soil series name	Vaahun	
International soil name	Orthic Ferralsol	
Slope range	6.5 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 1*	
Texture of the topsoil (0 – 20cm)	Sandy clay loam	
Texture of the subsoil (at 50cm)	Sandy clay loam	
Drainage	Well drained and rapid	
Colour of the topsoil:	Yellowish brown (10YR5/4 dry) and dark yellowish brown (10YR4/4 moist)	
Colour of the subsoil	Yellowish brown (10YR 4/6 dry) and yellowish brown (10YR3/6 moist)	
Soil depth	Very deep (>120 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	0.84	0.52
Available phosphorous (Bray P1 (mg kg-^{1})	15.77	11.23
Acidity (pH in 1:1 soil to water ratio)	4.5	5.1
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	5.04	4.10
Exchangeable Calcium (cmol kg^{-1} soil)	2.83	2.24
Exchangeable Magnesium (cmol kg^{-1} soil)	0.36	0.27
Exchangeable Potassium (cmol kg^{-1}soil)	0.33	0.28
Exchangeable Sodium (cmol kg^{-1} soil)	0.43	0.36
Exchangeable Acidity (cmol kg^{-1} soil)	1.09	0.95
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	11	23.7
DTPA extractable Iron (cmol kg^{-1})	2.728	2.73
DTPA extractable Copper (cmol kg^{-1})	5.216	5.81
DTPA extractable Zinc (cmol kg^{-1})	4.77	4.97

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.2 Soils on located dissected uplands of high weathered materials

Map unit 2: Fanima-Waiima-Baoma soil association

The ***Fanima-Waiima-Baoma*** soil association are a group of soils formed from alluvial parent materials on dissected uplands of high weathered materials.

5.1.2.1 Fanima series

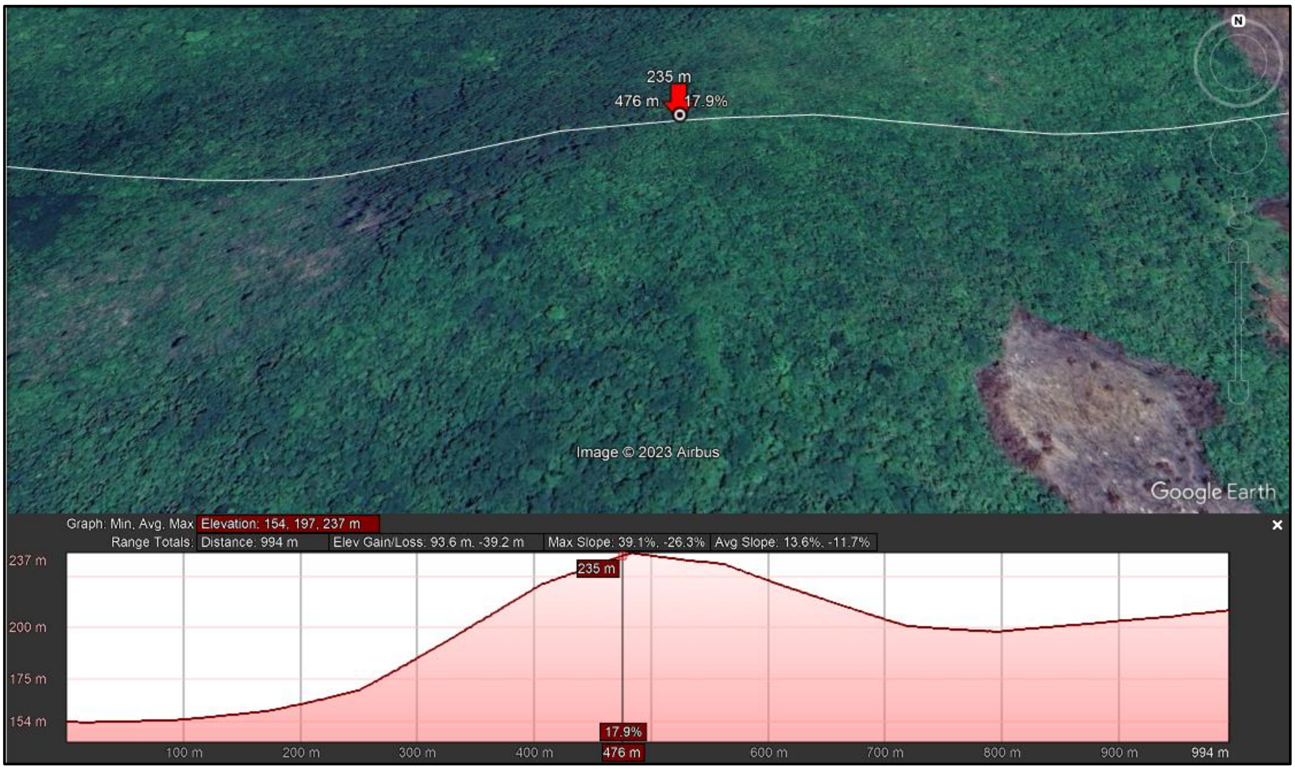

Photo 4. *Typical position of Fanima soil series in Kenema District*

Soils of *Fanima series* consist of gravelly colluvial or residual material throughout their profiles. They are composed mainly of sequioxides, which are hardened ironstone gravels and red and yellow laterized rock fragments. The gravel content in these soils generally increases with depth~ from 20% in the topsoil to 50% in the subsoil. The content of laterized rock fragment is high in the lower subsoil. Laterite sheet may occur at some depth in the profile. In the surface horizon, the gravels tend to be rounded, which may be as a result of (1) movement over a short distance or (2) intense rainfall, which may be caused by slaking due to solution or abrasion between nearby gravels or external weathering of the gravels.

In some cases, a gravel-free surface layer of 25 cm thickness may be either present or absent depending on the relief. Textures are usually gravelly sandy clay loam in the surface horizon, and gravelly clay in the subsoil. Surface soil colours are weak red (7.5R5/3dry - 7.5R4/3 moist). Subsoil colours are usually red (7.5R5/6 dry - 7.5R4/6 moist)**.** These soils are well drained and are never waterlogged.

Nutrient status of Fanima soils is generally low for plant growth (Table 12). Chemically, Fanima soils are moderate in plant nutrients. The organic carbon content is high in both topsoil horizon and subsoil horizons. The available phosphorus (Bray P1) is moderate in topsoil horizons and low in subsoil horizons. The pH is low in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in topsoil horizons and low in subsoil horizons. Exchangeable K is high in both topsoil and subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1} moderate) is in topsoil horizon and low in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is high in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN004, of the *Segbwema series* is given in Appendix 4a and 4b.

Table 12. *Key land, morphological and chemical properties of Fanima series*

Soil series name	Fanima
International soil name	Orthic Ferralsol
Slope range	2.5 %
Soil surface stoniness	NA
Typical position in the landscape	*See Plate 2*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Gravelly sandy clay
Drainage	Well drained and rapid
Colour of the topsoil:	Weak red (7.5R5/3dry) and weak red (7.5R4/3 moist)
Colour of the subsoil	Red (7.5R5/6 dry) and red (7.5R4/6 moist)
Soil depth	Very deep (>120 cm)
Nature of obstruction	NA

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.96	1.58
Available phosphorous (Bray P1 (mg kg-^{1})	15.48	11.59
Acidity (pH in 1:1 soil to water ratio)	4.2	4.4
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	6.66	5.46
Exchangeable Calcium (cmol kg^{-1} soil)	2.91	2.59
Exchangeable Magnesium (cmol kg^{-1} soil)	1.77	1.0
Exchangeable Potassium (cmol kg^{-1}soil)	0.34	0.32
Exchangeable Sodium (cmol kg^{-1} soil)	0.44	0.4
Exchangeable Acidity (cmol kg^{-1} soil)	1.20	1.16
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	10	7.5
DTPA extractable Iron (cmol kg^{-1})	5.248	4.86
DTPA extractable Copper (cmol kg^{-1})	0.1	2.99
DTPA extractable Zinc (cmol kg^{-1})	14.68	9.73

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.2.2 Baoma series

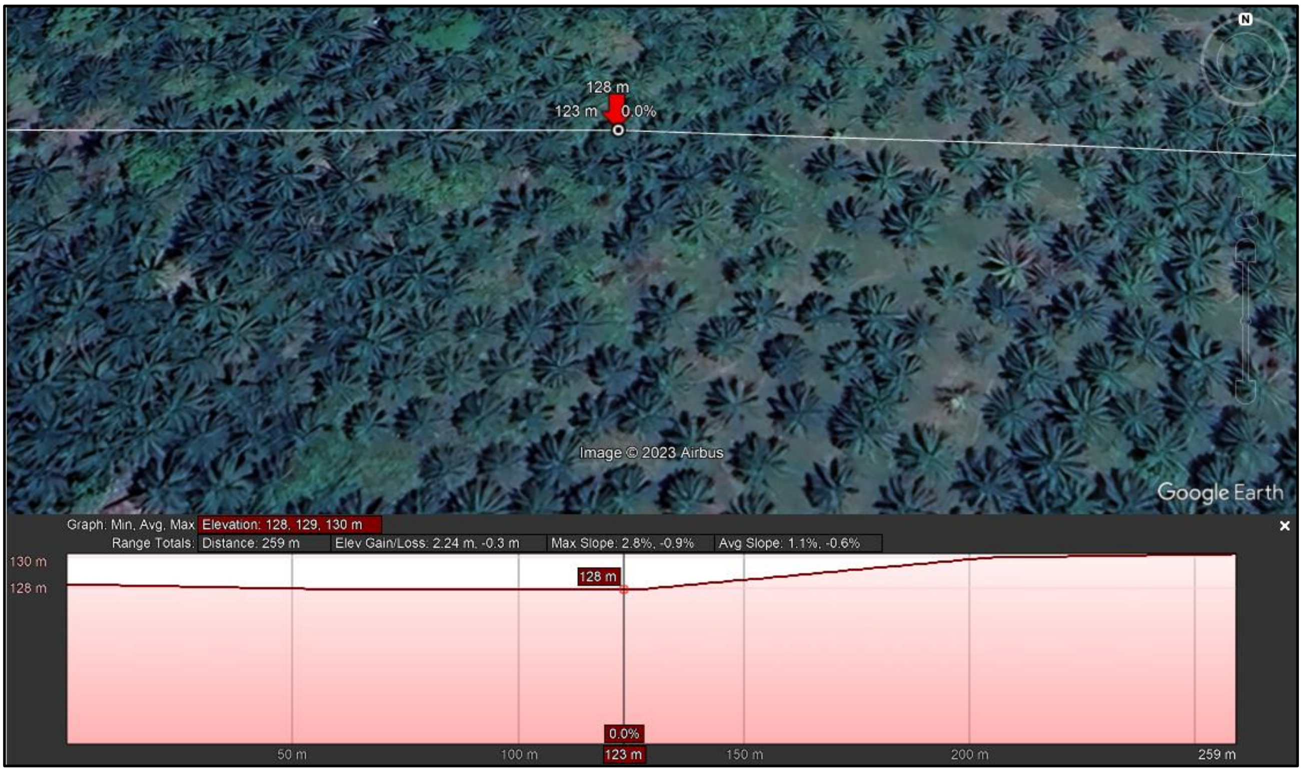

Photo 5. *Typical position of Baoma soil series in Kenema District*

Soils of *Baoma series* have 25-60 cm of gravel free colluvial or residual material over a gravelly subsoil. The gravel content in the sub soil1 is usually less than 30% throughout the rest of the profile. The gravels are predominantly ironstone gravels, high in sesquioxides, composing mainly of iron oxides that are residual in nature.

The textures are sandy clay loam in the topsoil A1 or A_P horizon but gravelly clay in the subsoil. The topsoil colours are usually brown (10YR5/3dry) and brown (10YR4/3 moist). Subsoil colours are yellowish brown (10YR5/6 dry) and dark yellowish brown (10YR4/6 moist). The soils are well drained and are never waterlogged.

The soils of Baoma series are low in plant available nutrients (Table 13). Chemically, Baoma soils are moderate in plant nutrients (Table 13). The organic carbon content is moderate in topsoil horizon and moderate in subsoil horizon. The available phosphorus (Bray P1) is low in both topsoil and subsoil horizons. The pH is high in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca and Mg are low in both topsoil and subsoil horizons, exchangeable K is high in both topsoil and subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co and Zn (cmol kg^{-1}) are high in both topsoil and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN005, of the *Baoma series* is given in Appendix 5a and 5b.

Table 13. *Key land, morphological and chemical properties of Baoma series*

Soil series name	Baoma	
International soil name	Orthic Ferralsol	
Slope range	8-10 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 2*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Gravelly sandy clay	
Drainage	Well drained and rapid	
Colour of the topsoil:	Brown (10YR5/3dry) and brown (10YR4/3 moist)	
Colour of the subsoil	Yellowish brown (10YR5/6 dry) and dark yellowish brown (10YR4/6 moist)	
Soil depth	Very deep (>150 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.75	1.78
Available phosphorous (Bray P1 (mg kg-^{1})	11.96	7.83
Acidity (pH in 1:1 soil to water ratio)	4.4	4.4
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	5.58	5.98
Exchangeable Calcium (cmol kg^{-1} soil)	3.17	2.71
Exchangeable Magnesium (cmol kg^{-1} soil)	0.45	0.36
Exchangeable Potassium (cmol kg^{-1}soil)	0.36	0.32
Exchangeable Sodium (cmol kg^{-1} soil)	0.32	0.26
Exchangeable Acidity (cmol kg^{-1} soil)	1.28	2.33
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	7	12.3
DTPA extractable Iron (cmol kg^{-1})	3.2	2.78
DTPA extractable Copper (cmol kg^{-1})	610	216.4
DTPA extractable Zinc (cmol kg^{-1})	12.53	9.15

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.2.3 Waiima series

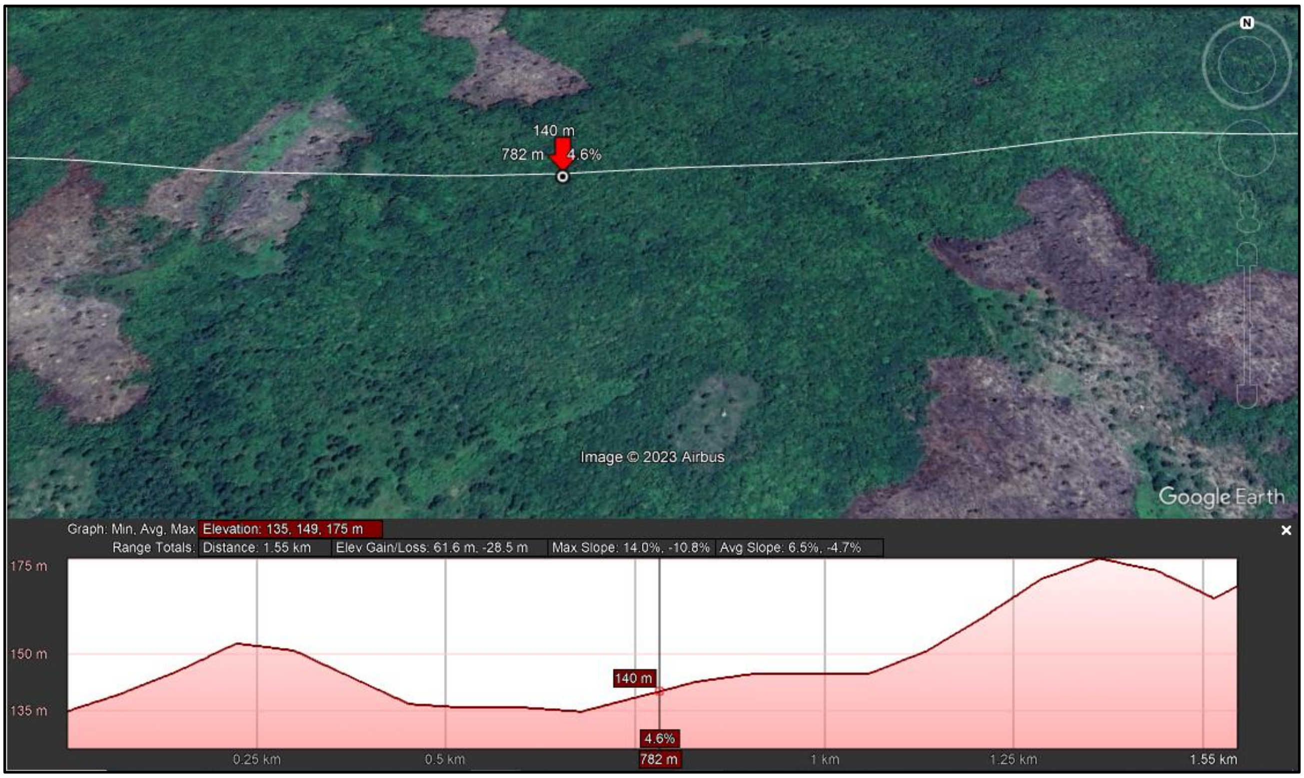

Photo 6. *Typical position of Waiima soil series in Kenema District*

Soils of *Waiima series* are similar to those of *Fanima series*. However, they differ in terms of weathered rock fragments as the former contains higher percentage of weathered rock fragments in the gravelly fraction, than the later. The soils are formed from gravel-free colluvium over gravelly subsoil that is high in weathered rock fragments. The gravel-free surface layer is less than 25 cm but may be absent in some cases. The textures are usually gravelly sandy loam in the surface A1 horizon, and gravelly sandy clay loam or gravelly sandy clay in the subsoil. The gravel content increases with depth. The topsoil colours are light brown (7.5YR6/4 dry) and brown (7.5YR5/4 moist) while the subsoil colours are usually strong brown (7.5YR5/6 dry) and brown (7.5YR4/4 moist). The thickness and colour of the surface horizon qualify them for the umbric epipedon. The soils are well drained and never waterlogged.

Plant nutrients levels are generally low (Table 14). Chemically, Segbwema soils are very low in plant nutrients. The organic carbon is moderate in topsoil horizon and low in subsoil horizon. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is high in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca, Mg, K and Na are low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is moderate in topsoil horizon and high in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is high in both topsoil and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity.

Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN006, of the *Waiima series* is given in Appendix 6a and 6b.

Table 14. *Key land, morphological and chemical properties of Waiima series*

Soil series name	Waiima
International soil name	Dystric Nitosol
Slope range	8-10 %
Soil surface stoniness	NA
Typical position in the landscape	*See Plate 2*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Gravelly sandy clay loam
Drainage	Well drained and rapid
Colour of the topsoil:	Light brown (7.5YR6/4 dry) and brown (7.5YR5/4 moist)
Colour of the subsoil	Strong brown (7.5YR5/6 dry) and brown (7.5YR4/4 moist)
Soil depth	Very deep (>150 cm)
Nature of obstruction	NA

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.71	0.83
Available phosphorous (Bray P1 (mg kg-^{1})	14.97	14.84
Acidity (pH in 1:1 soil to water ratio)	4.2	4.45
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	2.40	2.56
Exchangeable Calcium (cmol kg^{-1} soil)	0.52	0.24
Exchangeable Magnesium (cmol kg^{-1} soil)	0.44	0.97
Exchangeable Potassium (cmol kg^{-1}soil)	0.14	0.12
Exchangeable Sodium (cmol kg^{-1} soil)	0.14	0.11
Exchangeable Acidity (cmol kg^{-1} soil)	1.16	1.13
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	57	16.75
DTPA extractable Iron (cmol kg^{-1})	4.14	3.07
DTPA extractable Copper (cmol kg^{-1})	3.988	4.07
DTPA extractable Zinc (cmol kg^{-1})	4.77	4.82

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.3 Soils located on colluvial footslopes and upper terraces

Map Unit 3: Pendembu-Kparva-Tisso soil association

This group of soils includes imperfectly drained soils on colluvial footslopes and upper tributary terraces, poorly drained soils in stream valleys and around the edge of swamps, and very poorly drained soils in the lowest parts of inland valley swamps. The soils are widely scattered along the drainage networks in the district. They make up the inland valley swamps and patches of elongated nearly level to flat plains, usually referred to as *semi-bolis*.

5.1.3.1 Pendembu series

Photo 7. *Typical position of Pendembu soil series in Kenema District*

Soils of *Pendembu series* are occur on gentle slopes between the upland and the alluvial floodplains or swamps. They are developed from fine-loamy colluvium and alluvium. The textures are fine sandy loam in the surface horizon and sandy clay loam in the B horizon. The very dark gray (10YR 3/1) Aa horizon is usually 12 to 26 cm thick, which qualifies them to have ochric epipedon. Subsoil colors in the B horizon are yellowish brown (10YR 5/4) to yellow (2.5Y 7/6) with prominent red mottles in the lower subsoil. These soils are imperfectly drained because of seepage and are waterlogged at the soil surface during one to two months of the rainy season.

Plant nutrient status in soils of Pendembu series is low (Table 15). Chemically, Segbwema soils are very low in plant nutrients. The organic carbon content is moderate in topsoil horizons and low in subsoil horizons. The available phosphorus (Bray P1) is high in topsoil horizons and moderate in subsoil horizons. The pH is moderate in topsoil horizons and high in subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is moderate in topsoil horizons and low in subsoil horizons. The exchangeable Ca is moderate in topsoil horizons and low in subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K is high in both topsoil and subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, while DTPA extractable Co and Zn (cmol kg^{-1}) are high both topsoil and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN007, of the *Pendembu series* is given in Appendix 7a and 7b.

Table 15. *Key land, morphological and chemical properties of Pendembu series*

Soil series name	Pendembu
International soil name	Dystric Nitosol
Slope range	3 %
Soil surface stoniness	NA
Typical position in the landscape	*See Plate 3*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Sandy clay loam
Drainage	Well drained and rapid
Colour of the topsoil:	Light gray (2.5Y7/1dry) and gray (2.5Y6/1 moist)
Colour of the subsoil	Yellowish brown (10YR 5/4 dry) to yellow (2.5Y 7/6 moist)
Soil depth	Very deep (>174 cm)
Nature of obstruction	Massive clay layer in subsoil

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.56	0.97
Available phosphorous (Bray P1 (mg kg-^{1})	21.5	17.2
Acidity (pH in 1:1 soil to water ratio)	4.9	4.4
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	9.44	6.85
Exchangeable Calcium (cmol kg^{-1} soil)	6.05	3.34
Exchangeable Magnesium (cmol kg^{-1} soil)	1.85	1.28
Exchangeable Potassium (cmol kg^{-1}soil)	0.59	0.37
Exchangeable Sodium (cmol kg^{-1} soil)	0.84	0.49
Exchangeable Acidity (cmol kg^{-1} soil)	0.11	1.36
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	13	8
DTPA extractable Iron (cmol kg^{-1})	4.456	3.04
DTPA extractable Copper (cmol kg^{-1})	7.788	6.17
DTPA extractable Zinc (cmol kg^{-1})	11.34	12.38

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.3.2 Kparva series

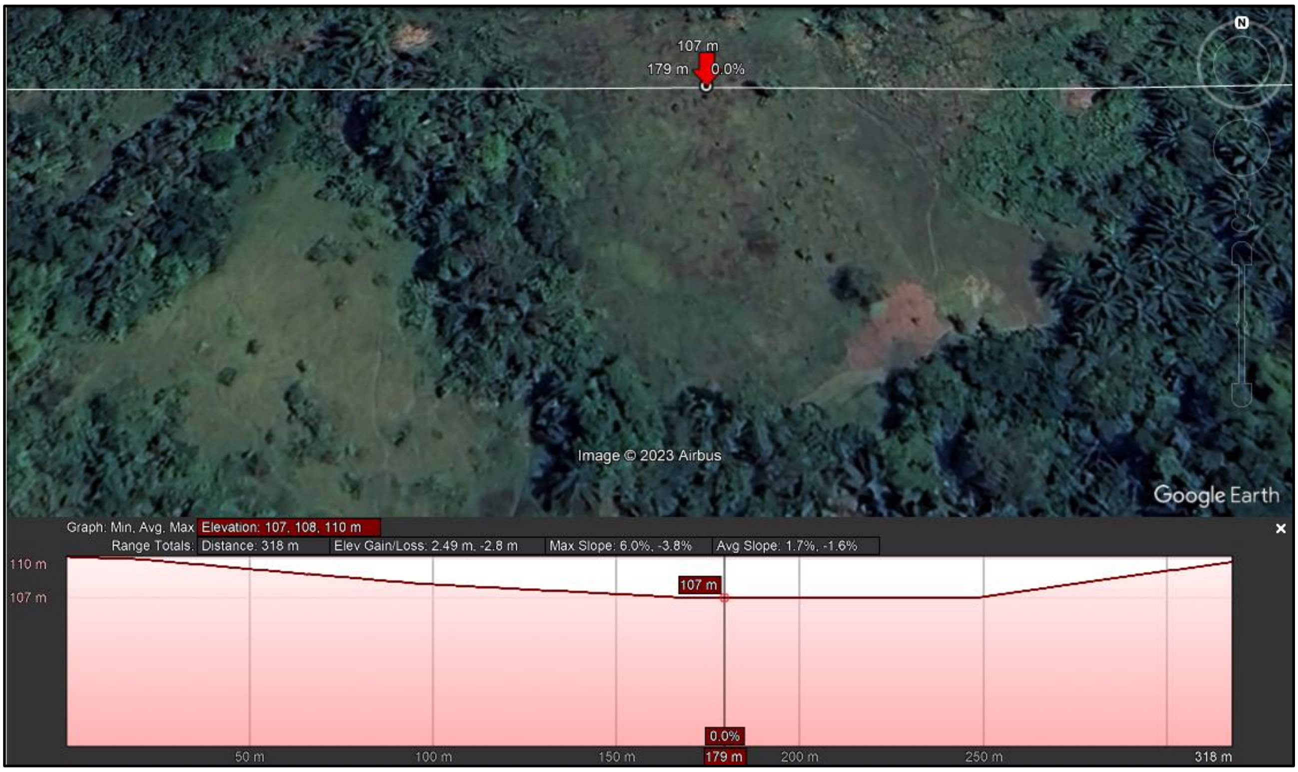

Photo 8. *Typical position of Kparva soil series in Kenema District*

Kparva soils occur on nearly level terrain, on slopes of less than 2 %, around the edges of swamps and in low areas at the bottom of slopes from the upland to alluvial floodplains. These soils have developed from fine-loamy colluvium and alluvium. The textures are sandy clay loam in the surface horizon, sandy clay in the B horizon, and usually sandy clay loam in the subsoil with occasional thin gravelly layers.

The A_1 horizon is Light gray (2.5Y7/1 dry) and dark gray (2.5Y6/1 moist) and is usually less than 10 inches (25 cm) thick (ochric epipedon). Colors in the B horizon are Light yellowish brown (2.5Y6/3 dry) and light olive brown (2.5Y5/3 moist) with light yellowish-brown (2.5Y 6/4) mottles in the upper part, and white (2.5Y 8/2) with strong brown (7.SYR 5/6) mottles in the lower part. Kparva soils are poorly drained and are waterlogged at the soil surface for two to four months, including submergence of about one month. Because of flooding, seepage, and the low topographic position of Kparva soils, the water table recedes slowly.

Chemically, Kparva soils are very low in plant nutrients (Table 16). The organic carbon content is moderate in both topsoil and subsoil horizons. The available phosphorus (Bray P1) is moderate in topsoil horizons and low in subsoil horizons. The pH is high in topsoil horizons and moderate in subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca and Mg are low in both topsoil and subsoil horizons, exchangeable K is moderate in both topsoil and subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is moderate in topsoil horizon and low in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is high in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN008, of the *Kparva series* is given in Appendix 8a and 8b.

Table 16. *Key land, morphological and chemical properties of Kparva series*

Soil series name	Kparva	
International soil name	Dystric Nitosol	
Slope range	1-2 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 3*	
Texture of the topsoil (0 – 20cm)	Silty clay loam	
Texture of the subsoil (at 50cm)	Silty clay	
Drainage	Poorly/ imperfectly drained and slow	
Colour of the topsoil:	Light gray (2.5Y7/1 dry) and dark gray (2.5Y6/1 moist)	
Colour of the subsoil	Light gray (2.5Y7/2 dry) and dark gray (2.5Y6/2 moist)	
Soil depth	Very deep (>140 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.71	1.09
Available phosphorous (Bray P1 (mg kg-^{1})	8.14	5.87
Acidity (pH in 1:1 soil to water ratio)	4.2	4.6
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	6.68	4.42
Exchangeable Calcium (cmol kg^{-1} soil)	2.61	1.79
Exchangeable Magnesium (cmol kg^{-1} soil)	0.58	0.23
Exchangeable Potassium (cmol kg^{-1}soil)	0.31	0.25
Exchangeable Sodium (cmol kg^{-1} soil)	0.25	0.14
Exchangeable Acidity (cmol kg^{-1} soil)	2.93	2.01
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	6	8
DTPA extractable Iron (cmol kg^{-1})	3.04	2.21
DTPA extractable Copper (cmol kg^{-1})	4.324	2.68
DTPA extractable Zinc (cmol kg^{-1})	10.74	5.77

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.3.3 Tisso series

Photo 9. *Typical position of Tisso soil series in Kenema District*

Soils of *Tasso series* have restricted bedrock, usually formed on gravelly or gravel-free colluvial or alluvial material over bedrock. The bedrock usually occurs between a depth of 40 and 110 cm, which poses limitation for crop production. These soils are found in the bottomlands and along narrow stream terraces.

Textures are sandy loam or gravelly sandy loam in the topsoil, and sandy clay loam or gravelly sandy clay loam in the subsoil. The content of ironstone gravel is usually between 25 and 35% by volume. The topsoil colours are usually gray (2.5Y5/1 dry) and dark gray (2.5Y4/1 moist) or lighter. This bright colour of the surface horizon qualifies it for the ochric epipedon. The subsoil colours are light brownish brown (2.5Y6/2 dry) and grayish brown (2.5Y5/2 moist). The drainage is moderately well to imperfect. The soils are usually not waterlogged at the surface, but water may occur within the profile, patched over the bedrock. The depth of the water table during the rainy season is related to the depth of bedrock.

Plant nutrient levels are relatively low in Tisso soils (Table 17). Chemically, Tisso soils are low in plant nutrients. The organic carbon content is moderate in topsoil horizons and low in subsoil horizons. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is high in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg and K is moderate in both topsoil and subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is moderate in topsoil horizons and low in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is high in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN009, of the *Tisso series* is given in Appendix 9a and 9b.

Table 17. *Key land, morphological and chemical properties of Tisso series*

Soil series name	Tisso	
International soil name	Lithic Dystric Nitosol	
Slope range	3-5 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 3*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Sandy clay	
Drainage	Moderately well to moderately slow	
Colour of the topsoil:	Gray (2.5Y5/1 dry) and dark gray (2.5Y4/1 moist)	
Colour of the subsoil	Yellow (2.5Y7/6 dry) and olive yellow (2.5Y6/6 moist)	
Soil depth	Very deep (>140 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.67	0.9
Available phosphorous (Bray P1 (mg kg-^{1})	13.65	8.9
Acidity (pH in 1:1 soil to water ratio)	3.5	4.0
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	6.80	5.89
Exchangeable Calcium (cmol kg^{-1} soil)	2.09	2.25
Exchangeable Magnesium (cmol kg^{-1} soil)	2.27	1.68
Exchangeable Potassium (cmol kg^{-1}soil)	0.27	0.28
Exchangeable Sodium (cmol kg^{-1} soil)	0.18	0.2
Exchangeable Acidity (cmol kg^{-1} soil)	1.99	1.49
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	3	7
DTPA extractable Iron (cmol kg^{-1})	5.408	2.997
DTPA extractable Copper (cmol kg^{-1})	1.196	1.799
DTPA extractable Zinc (cmol kg^{-1})	10.14	12.83

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.4 Soils located on colluvial and lower concave slopes

This group of soils includes imperfectly drained soils on colluvial footslopes and upper tributary terraces. Some are poorly drained soils located at valley bottoms and around the edge of swamps. They also include very poorly drained soils located in the lower flanks of inland valley swamps. These soils are widely scattered along the drainage networks in the mapped area.

Map Unit 4: Ngelehun-Yumbuma-Keya soil association

5.1.4.1 Ngelehun series

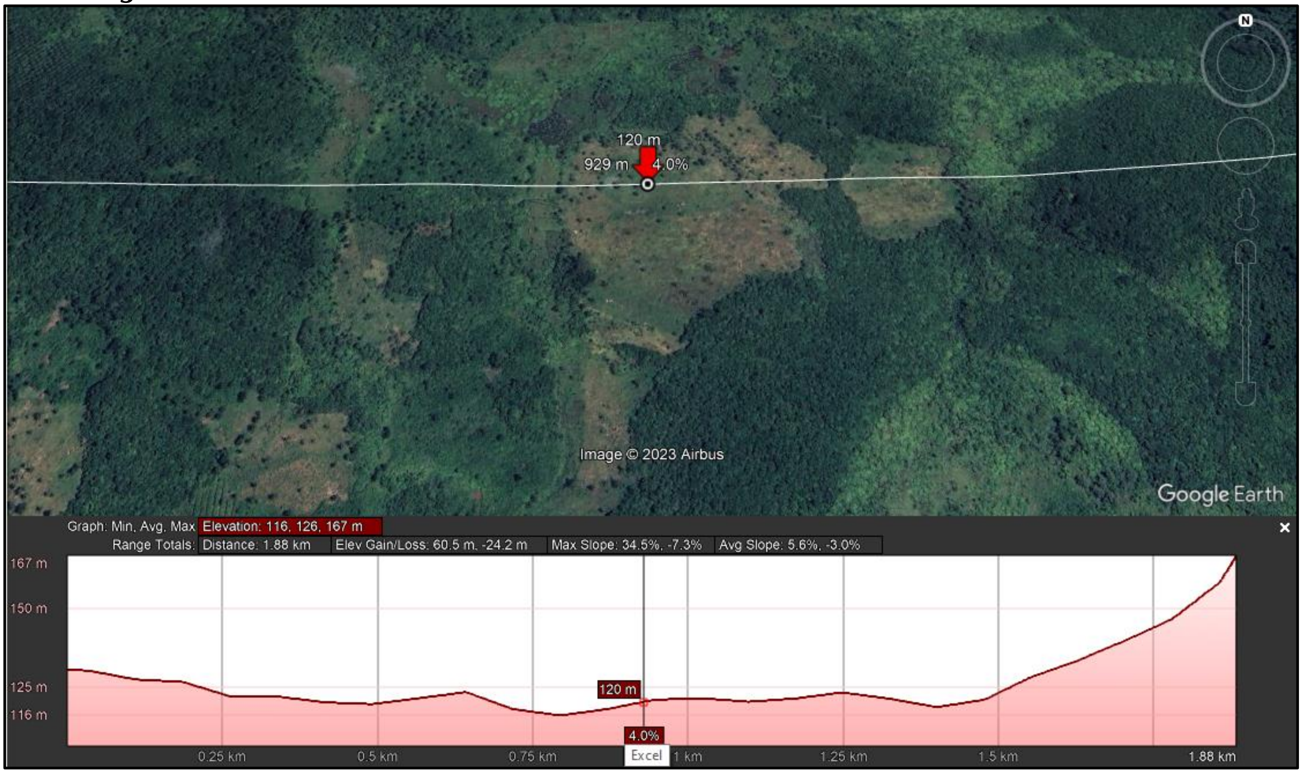

Photo 10. *Typical position of Ngelehun soil series in Kenema District*

Soils of Ngelehun series usually occur on lower concave colluvial footslopes usually adjacent to the soils of Yumbuma series. The parent material is gravel-free colluvium or alluvium over residual gravelly subsoil. The gravelly layer usually cosists of hard to soft medium and coarse ironstone gravels, with few quartz pebbles. The gravel content is usually above 60% by volume. Unlike soils of the Yumbuma series, the gravelly layer occurs between 60 and 110 cm below the surface horizon.

The topsoil textures are sandy loam and those of subsoil sandy clay loam and very gravelly sandy clay. The surface horizon is often less than 25 cm thick, and as a result, it qualifies for the ochric epipedon. The colour of the topsoil vary from very dark grayish brown to dark brown (10YR 3/2 – 10YR 3/3), and the colours of subsoil are yellowish brown to brownish yellow (10YR 5/4 – 10YR 6/6). The soils are moderately well drained , and are seldom waterlogged.

The nutrient status of plant available nutrients in Ngelehun soils (Table 18) seem to be relatively better than those of Pendembu, Kparva and Tisso soils. The organic carbon content is moderate in topsoil horizons and low in subsoil horizons. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is low topsoil horizons and moderate in subsoil horizons, exchangeable K is high in both topsoil and subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, while DTPA extractable Co and Zn (cmol kg^{-1}) are high in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid. A detailed description and analytical data for a representative profile, KEN010, of the *Ngelehun series* is given in Appendix 10a and 10b.

Table 18. *Key land, morphological and chemical properties of Ngelehun series*

Soil series name	Ngelehun	
International soil name	Plinthic Ferralsol	
Slope range	3-5 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 4*	
Texture of the topsoil (0 – 20cm)	Silty loam	
Texture of the subsoil (at 50cm)	Silty clay	
Drainage	Moderately well to moderately slow	
Colour of the topsoil:	Gray (2.5Y5/1 dry) and dark gray (2.5Y4/1 moist)	
Colour of the subsoil	Light brownish brown (2.5Y6/2 dry) and grayish brown (2.5Y5/2 moist)	
Soil depth	Very deep (>170 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1	0.78
Available phosphorous (Bray P1 (mg kg-^{1})	15.63	12.6
Acidity (pH in 1:1 soil to water ratio)	4.7	4.6
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	5.77	6.06
Exchangeable Calcium (cmol kg^{-1} soil)	3.02	2.73
Exchangeable Magnesium (cmol kg^{-1} soil)	0.7	1.17
Exchangeable Potassium (cmol kg^{-1}soil)	0.35	0.33
Exchangeable Sodium (cmol kg^{-1} soil)	0.46	0.3
Exchangeable Acidity (cmol kg^{-1} soil)	1.24	1.53
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	4	4.5
DTPA extractable Iron (cmol kg^{-1})	3.2	2.5
DTPA extractable Copper (cmol kg^{-1})	6.224	4.854
DTPA extractable Zinc (cmol kg^{-1})	9.54	13.43

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.4.2 Yumbuma series

Photo 11. *Typical position of Yumbuma soil series in Kenema District*

Soils of *Yumbuma series* occur on colluvial and concave foot slopes and in depressions in summits of the Dissected Uplands. In the flat summit areas, these soils are usually associated with the A and B slope phases of *Fanima* ans *Waiima* series. On the concave footslopes, these soils occur on gravel-free colluvium.

The parent material is gravel-free colluvium over residual gravelly subsoil. In some places, soft laterite sheet may occur within 110-140 cm of the surface soil. The residual gravels are usually hard and angular, high in sesquioxides. The gravel content is usually 50 percent or more by volume in the subsoil. In some areas, decomposing rock fragments occur in the subsoil. The gravel content is at depths between 25 and 60 cm below the surface horizon.

Textures are sandy loam to sandy clay loam in the topsoil, and gravelly sandy clay loam and gravelly sandy clay in the subsoil. The A1 or Ap horizon is thin and usunlly light in col our (ochric epipedon). Surface soil colours are light gray (2.5Y7/2 dry) and light brownish gray (2.5Y6/2 moist). Subsoil colours are pale brown (2.5Y7/3 dry) and light yellowish brown (2.5Y6/3 moist). The soils are moderately well drained to well drained and are not usually waterlocged.

The chemical status of Yumbuma soils are somehow lower than those of Ngalehun series (Table 19). The organic carbon content is moderate in topsoil horizon and high in subsoil horizon. The available phosphorus (Bray P1) is high in topsoil horizons and moderate in subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is moderate in topsoil horizons and low in subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K is high in topsoil horizons and moderate in subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (μS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co and Zn (cmol kg^{-1}) are high in both topsoil and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the flat nature of the landscape, runoff is almost negligible and erosion is not a major challenge, except where the vegetation cover is tampered with. Permeability is slow.

A detailed description and analytical data for a representative profile, KEN011, of the *Yumbuma series* is given in Appendix 11a and 11b.

Table 19. *Key land, morphological and chemical properties of Yumbuma series*

Soil series name	Yumbuma	
International soil name	Dystric Nitosol	
Slope range	1-2 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 4*	
Texture of the topsoil (0 – 20cm)	Silty loam	
Texture of the subsoil (at 50cm)	Silty clay	
Drainage	Imperfectly/ poorly drained to slow	
Colour of the topsoil:	Light gray (2.5Y7/2 dry) and light brownish gray (2.5Y6/2 moist)	
Colour of the subsoil	Pale brown (2.5Y7/3 dry) and light yellowish brown (2.5Y6/3 moist)	
Soil depth	Very deep (>150 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.44	2.19
Available phosphorous (Bray P1 (mg kg^{-1})	15.55	12.45
Acidity (pH in 1:1 soil to water ratio)	4.5	4.6
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	8.50	4.80
Exchangeable Calcium (cmol kg^{-1} soil)	3.97	1.93
Exchangeable Magnesium (cmol kg^{-1} soil)	2.6	1.19
Exchangeable Potassium (cmol kg^{-1}soil)	0.42	0.25
Exchangeable Sodium (cmol kg^{-1} soil)	0.42	0.17
Exchangeable Acidity (cmol kg^{-1} soil)	1.09	1.24
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	5	6
DTPA extractable Iron (cmol kg^{-1})	1.312	1.42
DTPA extractable Copper (cmol kg^{-1})	4.768	4.63
DTPA extractable Zinc (cmol kg^{-1})	21.48	10.29

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.4.3 Keya Series

Photo 12. *Typical position of Keya soil series in Kenema District*

Keya soils occur in depressions in the lowest parts of inland valley swamps throughout the district. Though not extensive, they are important and easily recognized features in the landscape. The vegetation is raphia palms, sedges, and other plants that tolerate very wet conditions. Keya soils develop in coarse loamy colluvium and alluvium transported from surrounding higher areas.

Textures are variable, both vertically and horizontally, but are distinctly coarser than in the associated Ngelehun and Yumbuma soils. The upper horizons of Keya soils are typically loamy sand, and lower horizons are usually sandy loam. The colours of the surface A_1 horizon, usually of 15 – 25 cm thickness, are grayish brown to dark grayish brown (2.5Y 5/2-4/2) while subsurface horizons are grayish brown (2.5Y 5/2). Keya soils are very poorly drained, being entirely waterlogged for three to five months and submerged more than one month. Late in the dry season, the water table usually drops to depths of about 10 to 180 cm.

The nutrient status of Keya soils (Table 20) is somehow similar with those of Yumbuma series. The organic carbon content is moderate in both topsoil and subsoil horizons. The available phosphorus (Bray P1) is moderate in topsoil and subsoil horizons. The pH is high in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is moderate in topsoil horizons and low in subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K is moderate in topsoil horizons and low in subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co and Zn (cmol kg^{-1}) are high in both topsoil and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the flat nature of the landscape, runoff is almost negligible and erosion is not a major challenge, except where the vegetation cover is tampered with. Permeability is slow.

A detailed description and analytical data for a representative profile, KEN012, of the *Keya series* is given in Appendix 12a and 12b.

Table 20. *Key land, morphological and chemical properties of Keya series*

Soil series name	Keya	
International soil name	Dystric Nitosol	
Slope range	2-4 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 4*	
Texture of the topsoil (0 – 20cm)	Silty loam	
Texture of the subsoil (at 50cm)	Silty clay	
Drainage	Imperfectly/ poorly drained to slow	
Colour of the topsoil:	Gray (5Y6/1dry) and olive gray (5Y5/1 moist)	
Colour of the subsoil	Light gray (5Y7/1dry) and gray (5Y6/1 moist)	
Soil depth	Deep (>115 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2	1.34
Available phosphorous (Bray P1 (mg kg-^{1})	10.95	9.03
Acidity (pH in 1:1 soil to water ratio)	4.2	4.4
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	8.37	6.83
Exchangeable Calcium (cmol kg^{-1} soil)	1.64	1.20
Exchangeable Magnesium (cmol kg^{-1} soil)	2.99	2.10
Exchangeable Potassium (cmol kg^{-1}soil)	0.23	0.19
Exchangeable Sodium (cmol kg^{-1} soil)	0.28	0.23
Exchangeable Acidity (cmol kg^{-1} soil)	3.23	3.11
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	21	11
DTPA extractable Iron (cmol kg^{-1})	3.208	2.12
DTPA extractable Copper (cmol kg^{-1})	9.632	6.65
DTPA extractable Zinc (cmol kg^{-1})	4.76	2.37

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.5 Soils located on upland eroded surfaces with gravelly surface and subsoil

Map Unit 5: Manowa-Momenga-Njala sloping soil association

The *Manowa-Momenga-Njala sloping soil association* comprises of upland soils located on old erosion surfaces, usually containing 35-75% hardened plinthite gravels. The fine earth fraction (< 2.0 mm) is usually sandy clay loam or sandy clay. These soils are gravelly in nature and low in available water-holding capacity and plant nutrients. Some occur on steep slopes and contain harmful amounts of exchangeable aluminum, especially in the subsoil. Mainly, these soils are used for shifting cultivation, with upland rice and cassava as the main crops. A long fallow period is advisable. The strongly sloping areas are best adapted to tree crops and forestry.

5.1.5.1 Manowa series

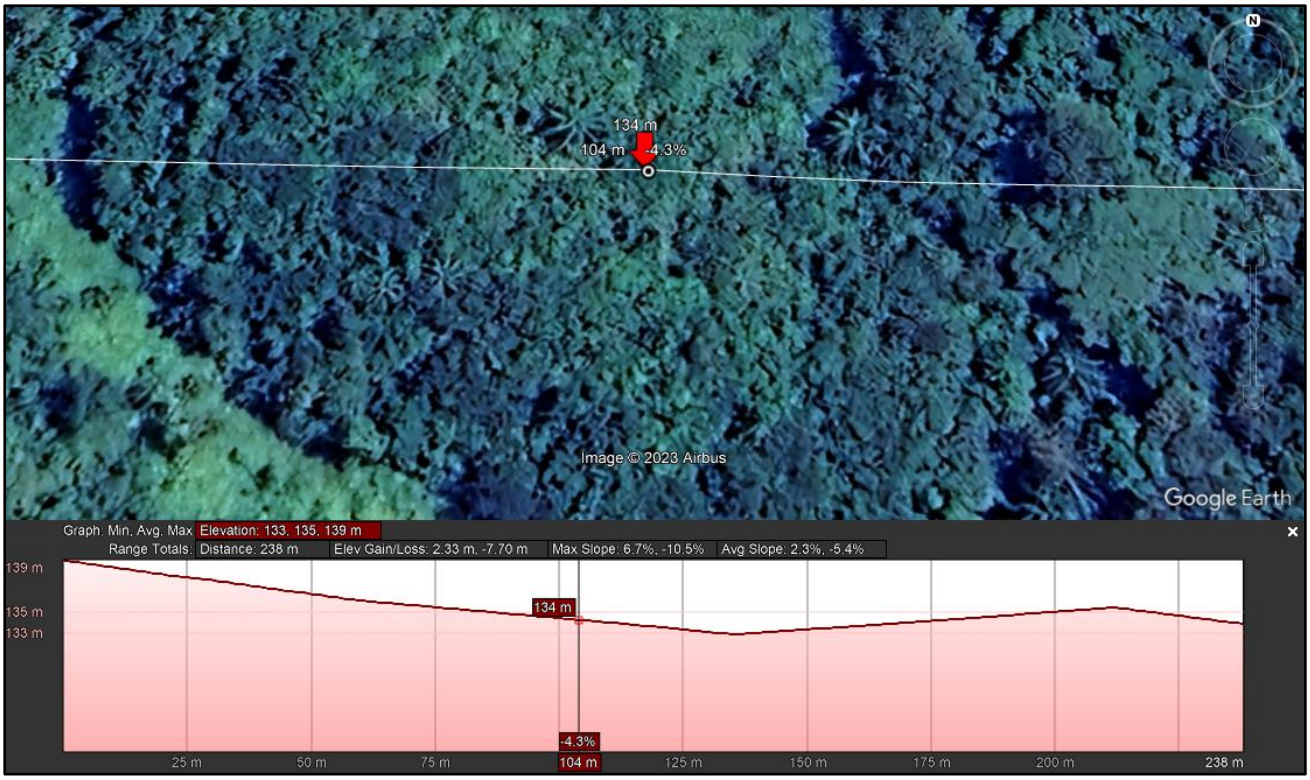

Photo 13. *Typical position of Manowa soil series in Kenema District*

Manowa soils are the most extensive ones on the upland erosion surfaces, especially between Kenema and Pendembu. They are often associated with Fanima soils. Manowa soils usually occur on convex summits and convex upper slopes. Manowa soils have developed in very gravelly (usually more than 60 percent gravel by volume), reworked material. The gravels are predominantly dark-coated, dense, hardened plinthite glaebules. The fine earth (< 2.0 mm) is sandy clay loam in the At horizon, sandy clay in the upper subsoil, and clay in the lower subsoil. The A1 horizon is usually low in gravel content. The dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist) A horizon is usually 25 to 51 cm thick (umbric epipedon). The subsoil is usually yellowish brown (10YR 5/4 dry) and dark yellowish brown (10YR4/4 moist). Manowa soils are moderately well drained and are never waterlogged at the surface (Table 2).

Chemically, Manowa soils are very low in plant nutrients (Table 21). The organic carbon content is moderate in topsoil horizon and low in subsoil horizon. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is high in topsoil horizons and moderate in subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, while exchangeable K and Na low low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is high in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is moderate in topsoil and subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is high in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the very gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN013, of the *Manowa series* is given in Appendix 13a and 13b.

Table 21. Key land, morphological and chemical properties of Manowa series

Soil series name	Manowa
International soil name	Dystric Nitosol
Slope range	4-6 %
Soil surface stoniness	Soil surface is partially covered with patches of dried grasses but immediate areas show evidence of fine gravels occurring in patches on the surface
Typical position in the landscape	*See Plate 5*
Texture of the topsoil (0 – 20cm)	Gravelly sandy loam
Texture of the subsoil (at 50cm)	Gravelly sandy clay loam
Drainage	Well drained to rapid
Colour of the topsoil:	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist)
Colour of the subsoil	Yellowish brown (10YR 5/4 dry) and dark yellowish brown (10YR4/4 moist)
Soil depth	Deep (>150 cm)
Nature of obstruction	NA

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.36	0.61
Available phosphorous (Bray P1 (mg kg-^{1})	13.76	14.80
Acidity (pH in 1:1 soil to water ratio)	3.6	4.6
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	6.50	6.16
Exchangeable Calcium (cmol kg^{-1} soil)	1.08	0.54
Exchangeable Magnesium (cmol kg^{-1} soil)	1.27	2.34
Exchangeable Potassium (cmol kg^{-1}soil)	0.19	0.15
Exchangeable Sodium (cmol kg^{-1} soil)	0.21	0.15
Exchangeable Acidity (cmol kg^{-1} soil)	3.75	2.98
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	27	17
DTPA extractable Iron (cmol kg^{-1})	3.208	5.531
DTPA extractable Copper (cmol kg^{-1})	5.232	2.986
DTPA extractable Zinc (cmol kg^{-1})	5.36	7.31

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.5.2 Momenga series

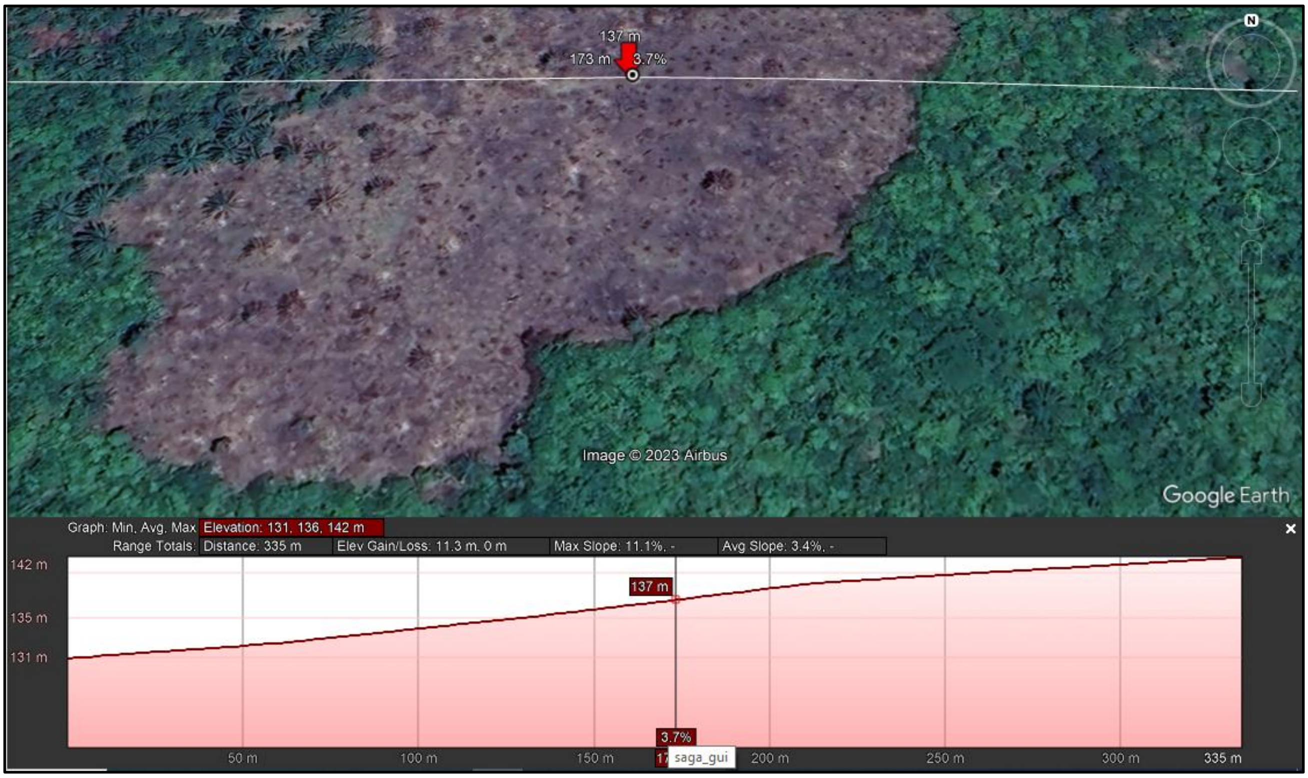

Photo 14. *Typical position of Momenga soil series in Kenema District*

The soils of the Momenga series usually occur on steep escarpment slopes of the uplands, with slopes commonly ranging from 15 to 50 percent. The parent material is gravelly colluvium, usually overlying gravelly residual material, over weathered bedrock (saprolite), usually within a depth of 120 cm. In some cases, hard bedrock may also be present. The colluvial plinthite graveles are rounded, hard, and dense and weighs about 50 % by volume. The residual plinthite gravels, which form in situ, are more irregular, relatively porous, and soft. Quartz veins may occur in the residual material. Quartz gravels may be present in the whole profile, being rounded in the topsoil and more angular in the subsoil. A gravel-free surface layer from gravelly sandy loam to gravelly clay in the upper few cwntimeters and gravelly clay in the subsoil. The silt content of the subsoil often increases because of the presence of weathered bedrock pieces.

The topsoil A_1 horizon is only few centimeters thick, which qualifies it to be classed as ochric epipedon. The topsoil colours range from gray (10YR6/1dry) and gray (10YR5/1 moist). The colours of the subsoil vary from brownish yellow (10YR6/6 dry) to yellowish brown (10YR5/6 moist), with red and brown to white (saprolite) mottles.

Chemically, Momenga soils are chemically poor, with a low nutrient content (Table 22). The organic carbon content is moderate in topsoil horizon and moderate in subsoil horizon. The available phosphorus (Bray P1) is moderate in topsoil horizons and low in subsoil horizons. The pH is high in topsoil horizons and moderate in subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K is low in topsoil horizons and moderate in subsoil horizons, while exchangeable Na is low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co and Zn (cmol kg^{-1}) are high in both topsoil and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the very gently sloping nature of the landscape, runoff is somehow moderate and erosion is a moderate except in cases where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN014, of the *Momenga series* is given in Appendix 14a and 14b.

Table 22. *Key land, morphological and chemical properties of Momenga series*

Soil series name	Momenga	
International soil name	Ferralic Nitrosol	
Slope range	4-6 %	
Soil surface stoniness	Soil surface is partially covered with patches of dried grasses but immediate areas show evidence of fine gravels occurring in patches on the surface	
Typical position in the landscape	*See Plate 5*	
Texture of the topsoil (0 – 20cm)	Gravelly sandy loam	
Texture of the subsoil (at 50cm)	Gravelly sandy clay loam	
Drainage	Moderately well drained to moderately rapid	
Colour of the topsoil:	Gray (2.5Y5/1 dry) and dark gray (2.5Y4/1 moist)	
Colour of the subsoil	Light brownish brown (2.5Y6/2 dry) and grayish brown (2.5Y5/2 moist)	
Soil depth	Deep (>170 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.03	1.09
Available phosphorous (Bray P1 (mg kg^{-1})	9.24	4.85
Acidity (pH in 1:1 soil to water ratio)	4	4.7
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	4.34	4.98
Exchangeable Calcium (cmol kg^{-1} soil)	0.46	1.66
Exchangeable Magnesium (cmol kg^{-1} soil)	2.93	1.27
Exchangeable Potassium (cmol kg^{-1}soil)	0.14	0.24
Exchangeable Sodium (cmol kg^{-1} soil)	0.13	0.28
Exchangeable Acidity (cmol kg^{-1} soil)	0.68	1.53
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	42	15.8
DTPA extractable Iron (cmol kg^{-1})	15.8	5.75
DTPA extractable Copper (cmol kg^{-1})	211	73.9
DTPA extractable Zinc (cmol kg^{-1})	8.35	6.56

NOTE:
Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.1.5.3 Njala sloping series

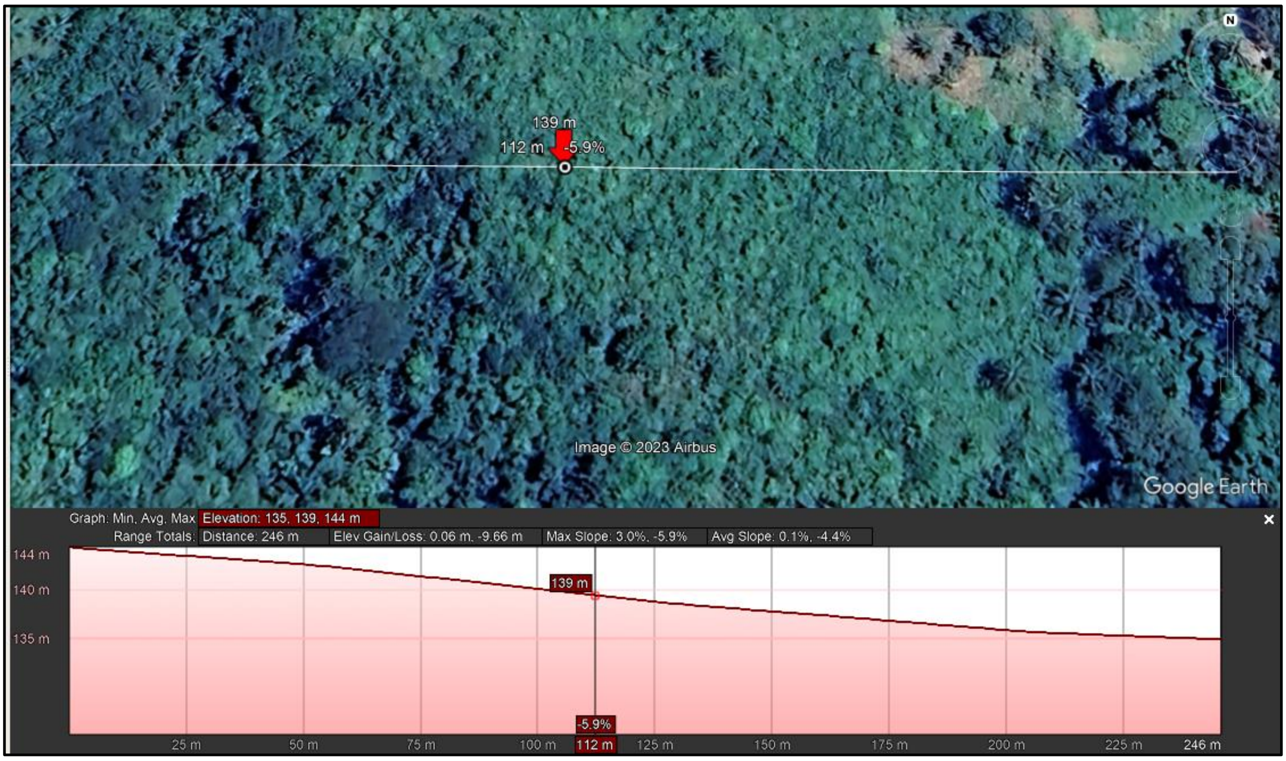

Photo 15. *Typical position of Njala sloping soil series in Kenema District*

Soils of the *Njala sloping series* occur on nearly level ridgetops on gentle slopes (1-3%) and moderate slopes (3-15%) downward toward the drainageways. The parent material is a gravelly colluvium overlying gravelly residual material over weathered bedrock, which occurs at a depth of 100cm and above. The colluvial plinthite gravels are rounded, hard and dense, and dusky red to reddish black. The gravel content of the colluvial surface layer may weigh between 30 and 65% by volume but the thickness of the layer may variy from 50-150 cm. The residual plinthite gravels are more irregular, relatively more porous and soft, and are formed in situ. Colors are brighter red (10R 4/6). The gravel content varies with depth from 25-40% by volume. Quartz veins may be present in the residual material. Quartz gravels may be present in the whole profile, being relatively rounded in the colluvial layers and relatively angular in the residual layers.

A thin gravel-free surface layer of 5-25 cm may either be present or absent, with its thickness often depending on the topography. Textures are usually gravelly clay loam in the surface soil and gravelly clay loam to gravelly clay in the subsoil (Fig. 18) . Topsoil colors are very dark grayish brown to dark yellowish brown (10YR 3/2-4/4) . Subsoil colors are usually yellowish brown to yellow, but strong brown and yellowish-red colors also occur (10YR-7.5YR-5YR 5/8-7/6). Red mottles may or may not be present. The soils are well to moderately well drained and are never waterlogged.

Chemically, Njala sloping soils are very low in plant nutrients (Table 23). The organic carbon content is moderate in topsoil and subsoil horizons. The available phosphorus (Bray P1) is moderate in both topsoil and subsoil horizons. The pH is moderate in both topsoil and subsoil horizons. Effective cation exchange capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1}) is low in both topsoil and subsoil horizons. The exchangeable Ca is low in both topsoil and subsoil horizons, exchangeable Mg is moderate in both topsoil and subsoil horizons, exchangeable K and Na are low in both topsoil and subsoil horizons. Electrical conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio is low in both topsoil and subsoil horizons. The DTPA extractable Fe (cmol kg^{-1}) is low in both topsoil and subsoil horizons, DTPA extractable Co (cmol kg^{-1}) is moderate in topsoil horizon and high in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is high in both topsoil horizon and subsoil horizons.

As revealed by the analytical results, the availability of nutrients to plants may be altered by the high soil pH. It is obvious that with such pH levels, the availability of the major plant nutrients such as nitrogen, phosphorous, potassium, sulfur, calcium, magnesium and also the trace element molybdenum may be reduced and become insufficient during cultivation.

According to Rhodes (1979), phosphorus levels in many agricultural soils of Sierra Leone are far below what is required for optimal production, and with most soils Pujehun district having pH levels that are below pH 5.5, this may further reduce uptake of phosphorus and other nutrients. Liming to raise the pH of acidic soil will increase the availability of these nutrients. In addition, availability of iron, manganese, copper, zinc and aluminium are increased in acidic soils. In Sierra Leone, toxic levels of aluminium and iron has been a topical issue for increasing crop production and productivity. Manganese toxicity is a potential issue for crop production in these acidic soils. However, if appropriate soil management considerations are taken, the concentrations of these exchangeable cations and micronutrients may be prevented from reaching toxic levels.

Because of the gently sloping nature of the landscape, runoff potential is high and hence, erosion is a major challenge especially where the vegetation cover is tampered with. Permeability is rapid.

A detailed description and analytical data for a representative profile, KEN015, of the *Njala sloping series* is given in Appendix 15a and 15b.

Table 23. *Key land, morphological and chemical properties of Njala sloping series*

Soil series name	Njala sloping	
International soil name	Dystric Nitosol	
Slope range	6-8 %	
Soil surface stoniness	Soil surface is partially covered with patches of dried grasses but immediate areas show evidence of fine gravels occurring in patches on the surface	
Typical position in the landscape	*See Plate 015*	
Texture of the topsoil (0 – 20cm)	Gravelly sandy loam	
Texture of the subsoil (at 50cm)	Gravelly sandy clay loam	
Drainage	Well drained to rapid	
Colour of the topsoil:	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist)	
Colour of the subsoil	Yellowish brown (10YR 5/4 dry) and dark yellowish brown (10YR4/4 moist)	
Soil depth	Deep (>150 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.57	1.14
Available phosphorous (Bray P1 (mg kg-^{1})	11.47	8.86
Acidity (pH in 1:1 soil to water ratio)	5.1	5.2
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	3.63	3.45
Exchangeable Calcium (cmol kg^{-1} soil)	1.01	0.63
Exchangeable Magnesium (cmol kg^{-1} soil)	1.94	1.80
Exchangeable Potassium (cmol kg^{-1}soil)	0.18	0.15
Exchangeable Sodium (cmol kg^{-1} soil)	0.2	0.16
Exchangeable Acidity (cmol kg^{-1} soil)	0.30	0.72
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	74	21.5
DTPA extractable Iron (cmol kg^{-1})	5.96	5.81
DTPA extractable (cmol kg^{-1})	4.1	7.1
DTPA extractable Zinc (cmol kg^{-1})	10.74	8.5

NOTE:

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable bases plus exchange Al and H determined under the natural pH of the soil. In general, ECEC values higher than 4 cmol kg^{-1} indicate sufficient cation exchange capacity to prevent serious leaching losses of bases; base saturation calculated on the basis of buffered extractants underestimate the base status of acid soils (Sanchez, 1976).

5.2 Soil classification

Following the field survey activities, the soils of Kono District were classified and mapped on the basis of their representative characteristics, as presented in Table 24. Based on the results show below, it can be noted that soils of the Pendembu series occupy the largest area (1450.2 km^2). This is followed by Tisso (776.2 km^2), Segbwema (536.6 km^2), Kparva (269.4 km^2), Ngelehun (256.2 km^2), Yumbuma (224.2 km^2), Fanima (191.2 km^2), Vaahun (122.4 km^2), Keya (95.5 km^2), Waiima (85.5 km^2), Baoma (81.9 km^2), Momenga (76.8 km^2), Manowa (70.7 km^2) in decreasing order of area of coverage. The least is soils of the Njala sloping series (48.6 km^2).

***Table 24**. Correlation between the FAO WRB and USDA Soil Taxonomy systems of classification*

Map unit (soil series)	FAO World Reference Base Classification System (FAO World Reference Base (FAO, 2022)		USDA Soil Taxonomy Classification System (Keys to Soil Taxonomy 2022)				Area (km^2)
	Level 1	Level 2	Order	Suborder	Great group	Sub group	
Rockland	Leptosol	Dystric Nitosol	Ultisol	Udult	Paleudult	Typic paleudult	100.5
Segbwema	Ferralsol	Ferralic Cambisol	Inceptisol	Tropept	Dystropept	Udoxic dystropept	536.6
Vaahun	Ferralsol	Orthic Ferralsol	Oxisol	Orthox	Haplorthox	Plinthic haplorthox	122.4
Fanima	Ferralsol	Orthic Ferralsol	Oxisol	Orthox	Haplorthox	Plinthic haplorthox	191.2
Waiima	Leptosol	Dystric Nitosol	Ultisol	Udult	Paleudult	Plinthic paleudult	85.5
Baoma	Ferrasol	Orthic Ferralsol	Oxisol	Orthox	Haplorthox	Typic haplorthox	81.9
Pendembu	Leptosol	Dystric Nitosol	Ultisol	Uduls	Paleudlt	Plinthaqiuc Paleudult	1450.2
Kparva	Leptosol	Dystric Nitosol	Ultisol	Udult	Paleudult	Plinthic paleudult	269.4
Tisso	Leptosol	Lithic Dystric Nitosol	Ultisol	Udult	Hapludult	Lithic hapludult	776.2
Ngelehun	Ferralsol	Plinthic Ferralsol	Oxisol	Orthox	Haplorthox	Plinthic haplorthox	256.2
Yumbuma	Leptosol	Dystric Nitosol	Ultisol	Udult	Paleudult	Plinthic paleudult	224.2
Keya	Leptosol	Dystric Nitosol	Ultisol	Udult	Paleudult	Plinthic paleudult	95.5
Manowa	Leptosol	Dystric Nitosol	Ultisol	Udult	Paluedult	Orthoxic palehumult	70.7
Momenga	Leptosol	Ferallic Nitrosol	Inceptisol	Tropept	Dystropept	Plpnthic dystropept	76.8
Njala sloping	Leptosol	Dystric Nitosol	Ultisol	Humult	Palehumult	Orthoxic Palehumult	48.6

5.3 Soil map of Kenema District

The soils of Kono District as indicated in Table 17, were mapped on the basis of their representative characteristics, as presented in Figure 13.

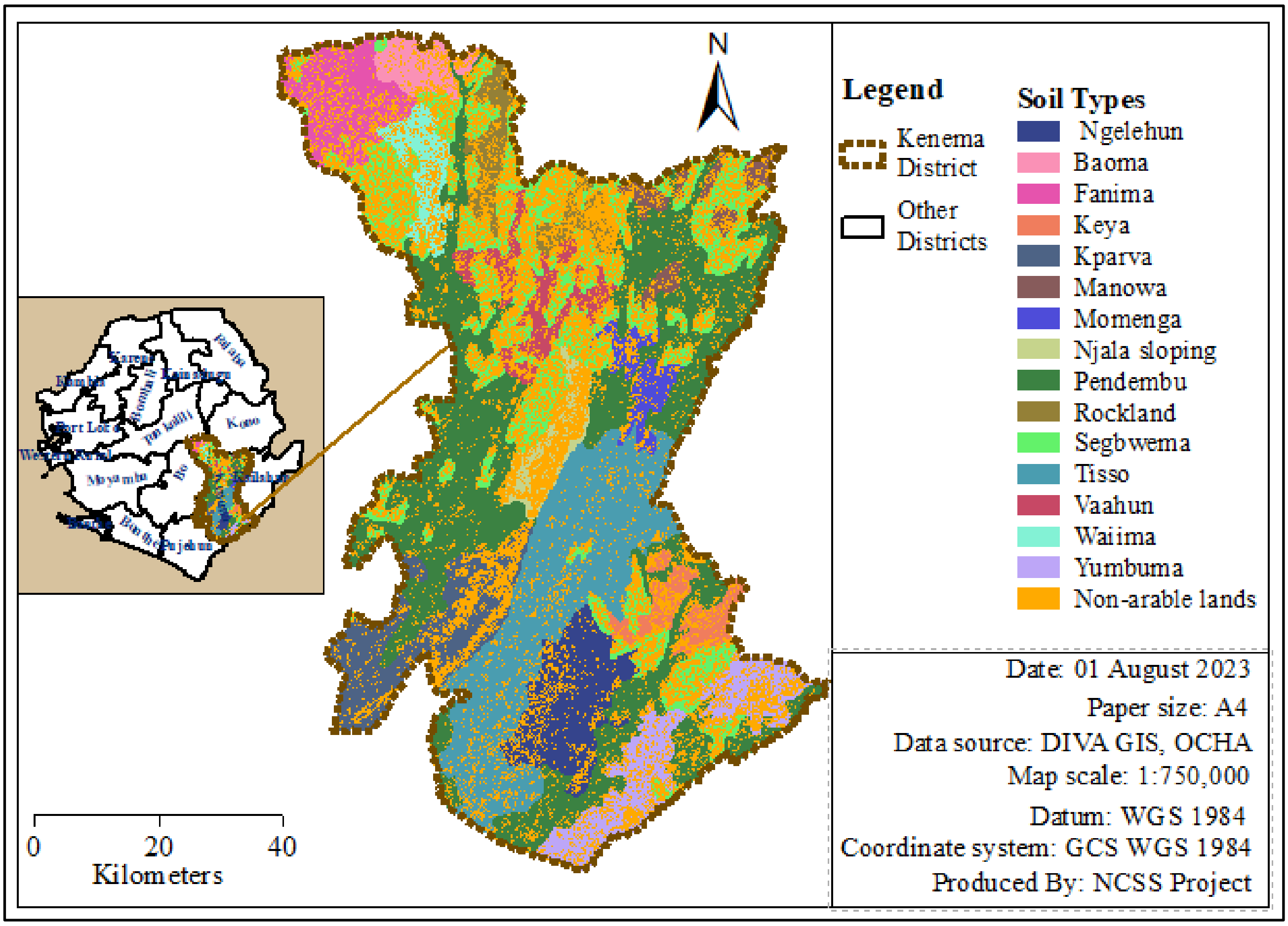

Figure 13. *Soil association map of Kenema district*

6 Opportunities, Challenges and Agricultural Development Potential

This chapter deals with the interpretive aspect of the soil survey after the systematic identification, description, classification and mapping of soils in the Kenema District.

The soils in Kenema District were interpreted for their general potential for agricultural use by firstly classifying them into arable (Class 1-IV) and non-arable (Class V-VIII) classes, with clear statements on the risk of environmental hazard that each soil association bears when subjected to agricultural use.

Among the soil associations classed as arable, a soil suitability evaluation was conducted to determine their relative fitness for meeting the optimal requirement of the MAFS target crops and the agronomic/engineering constraints that have to be resolved by appropriate agronomic /engineering strategies to ensure their sustainable production and productivity. The soil associations with the highest suitability ratings (S1 and S2) for growing the MAFS target crops are recommended for agricultural investment.

To ensure that the premium agricultural soils in the district are used in a sustainable and environmentally friendly manner, proven soil management strategies that have been researched and tested over time in Sierra Leone, are recommended for the attention of farmers and the Government.

6.1 Land capability and implications for agricultural development

The goal of allocating various land capabilities to a land area with varied characteristics is to achieve complete soil conservation. Complete soil conservation implies perfect soil health and zero soil erosion on a sustained basis. This objective is consistent with that of the NCSS project.

The soils identified in Kenema District have been systematically grouped into land capability classes according to those properties that determine their ability to produce crops on a virtually sustainable basis. There are many properties that may limit the use of soils in Kenema District, some are minor and some are major limitations that should be addressed to enhance the sustainable use of these soils.

On the basis of those capability limitations, the soils have been broadly grouped into two major groups, known as (1) arable (or cultivable) and (2) non-arable (or non-cultivable). The arable (or cultivable) lands are those areas within the district that are either highly, moderately or marginally suitable for agriculture. These arable (or cultivable) lands are differentiated into Class I, II, II, IV lands based on four major limitations, including climate (climatic extremities and aberrant weather), soils (water holding capacity and fertility), water (excess water or drainage problems), and erosion (water erosion or wind erosion). Each of the above factors plays a significant role in soil behaviour and management. The non-arable (or non-cultivable) lands are those areas within the district that are not capable of supporting cultivation of crops but can be put to some other uses. Such lands also belong to four classes, namely, Class V, VI, VII, and VIII. These lands are used for growing grasses, forestry and supporting wildlife. Depending on the nature and properties of soils, they may be suitable for one or other uses. The land capability of the various land units is presented in Figure 1.

6.1.1 Arable and non-arable lands in Kenema district

In order to evaluate the capability of land in Kenema district, soil-site characteristics of the fourteen-soil series were matched with the criteria for land capability classification. The results, as presented in Table 25, indicates that 4385.7 km^2 (69 %) of the land area is arable and 1971.5 km^2 (31 %) is non-arable. Arable soils include Segbwema, Vaahun, Fanima, Waiima, Baoma, Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga and Njala sloping soils. These soils are of high agricultural priority and therefore, a high premium should be put on them for the sake of sustainable agricultural development in Sierra Leone.

a. ***Class I lands:*** These are nearly level very good cultivable lands with few minor limitations that require normal soil and crop management practices. They are usually deep and somewhat well drained, and can be used for intense cultivation. They include soils of the Ngelehun and Yumbuma series, which account for about 575.9 km^2 (9.1 %) of the total area. These soils are nearly level with slopes generally within 0-1 %. The soils are deep, fertile, easily workable and are not subjected to damaging overflows. There are hardly any restrictions or limitations for their use, except for risk of rapid decline of soil fertility. Apart from this single limitation, these lands are very good lands which can be safely cultivated by using any farming method to grow any crop, even intensively also.

However, proper crop rotation and green manure use should be followed to maintain soil fertility (Mal, 1995).

b. ***Class II lands:*** Soils in this class are referred to as good cultivable lands, which have slight to moderate limitations that restrict their use (Ghadekar and Pawar, 2009). These soils have gentle slopes, moderate erosion hazard, and are capable of sustaining less intensive cropping systems but have few other limitations that may require moderate conservation practices to prevent their deterioration. They include soils of the Pendembu, Kparva, Tisso, Keya, Manowa, and Momenga series. These soils are limited by one or more factors such as: (a) moderate limitations which reduce choice of crop, (b) gentle slope (1 to 5 %), (c) moderate erosion hazards, (d) inadequate soil depth, (e) less than ideal soil structure and workability, (f) somewhat restricted drainage, (g) require moderate conservation practices to prevent deterioration and h) capable of sustaining less intensive cropping systems. The management practices that may be required for these soils include terracing, strip cropping, contour-tillage, rotation, etc. The result showed that 1118.0 km^2 (17.6 %) is occupied by land capability class II lands. These soils were moderate to rapidly permeable and moderately well-drained with slight limitations of slope, drainage, depth, texture, profile development, soil reaction, organic carbon and base saturation. A sustainable alternate land use option for these lands could be agri-horticulture and agri-silviculture.
c. ***Class III lands:*** Soils in this class are referred to as moderately good cultivable lands, which have severe limitations that restrict their use. These soils are limited by one or more of factors such as: (a) severe limitations which reduce the choice of crops, (b) moderately steep slope (5 to 10 %), (c) high erosion hazards, (d) very slow water permeability, (e) shallow depth and restricted root zone, (f) low water holding capacity, (g) low fertility, (h) moderate alkalinity and salinity and (i) unstable structure. They include soils of Segbwema, Vaahun, Fanima, Baoma, Waiima, and Njala sloping series. These soils were moderate to rapidly permeable and moderately well-drained with moderate limitations of slope, erosion, depth, coarse fragments, profile development, organic carbon and base saturation. For this reason, these soils may require special conservation practices to raise field crops and special management practices are required in addition to the management practices required in Class II lands. According to the results, 2691.8 km^2 (42.3 %) of the district is occupied by land capability class III lands as shown in Table 3. A sustainable alternate land use options for these lands could be agri-horticulture, growing of selected legumes (such as groundnut, cowpeas) and grasses.
a. ***Non-arable:*** These are demarcated as steep slopes and hills, rock outcrops, settlements, roads and water bodies. They account for 1971.5 km^2 (31 %) of the district.

Table 25. *Area covered by soil associations/types in Kenema District*

Land capability group	Soil-physiography	Soil association	Soil series	Area	
				km^2	%
Arable	Soils located on sloping terrains	Rockland-Segbwema-Vaahun	Segbwema, Vaahun	759.5	11.9
	Soils on dissected uplands of high weathered materials	Fanima-Waiima-Baoma	Fanima, Waiima, Baoma	358.6	5.6
	Soils on colluvial footslopes and upper terraces	Pendembu-Kparva-Tisso	Pendembu, Kparva, Tisso	2495.7	39.3
	Soils on colluvial and lower concave slopes	Ngelehun-Yumbuma-Keya	Ngelehun, Yumbuma, Keya	575.9	9.1
	Soils on upland eroded surfaces with gravelly surface and subsoil	Manowa-Momenga-Njala sloping	Manowa, Momenga, Njala sloping	196.1	3.1
Non-arable	Steep slopes and hills, rock outcrops, settlements, roads and water bodies			1971.5	31

The challenges for use of these soils are also outlined in *Table 26* to guide users towards ensuring the sustainable production and productivity of these soils. Land that is not arable may be left for wildlife or protected with afforestation.

Table 26. Land capability indices of soils and their implications for agricultural use in the Kenema district

Soil association	Soil individuals	Capability group	Capability class	Capability subclass/ Risk of hazards
Rockland-Segbwema-Vaahun	Rockland	Non-arable	VI	Very steep, rough terrain, with boulders and rocky outcrops; severe limitation for grazing and forestry
	Segbwema	Arable	III	Marginally suitable for cultivation but have severe limitations which reduce the choice of crops such as moderately steep slope (5 to 10 %), high gravel content, somewhat shallow depth, high erosion hazards, water holding capacity, low fertility, and unstable structure.
	Vaahun	Arable	III	
Fanima-Waiima-Baoma	Fanima	Arable	III	Marginally suitable for cultivation but have moderate limitations of high gravel content, low water holding capacity, and some fertility challenges that may require short- and medium-term soil management programme.
	Waiima	Arable	III	
	Baoma	Arable	III	
Pendembu-Kparva-Tisso	Pendembu	Arable	II	Moderately suitable for cultivation but have moderate limitations of high gravel content, low water holding capacity, and some fertility challenges
	Kparva	Arable	II	
	Tisso	Arable	II	
Ngelehun-Yumbuma-Keya	Ngelehun	Arable	I	Highly suitable for cultivation of arable crops but have few limitations, mainly related with fertility, flash floods during peaks of the rainy season.
	Yumbuma	Arable	I	
	Keya	Arable	II	Moderately suitable for cultivation of arable crops but have few limitations, mainly relating to fertility (f), waterlogging, iron toxicity, and deposition of eroded sand and silt material from upland areas.
Manowa-Momenga-Njala sloping	Manowa	Arable	II	Moderately suitable for cultivation but have severe limitations which reduce the choice of crops such as moderately steep slope (5 to 10 %), high gravel content, high erosion hazards, water holding capacity, low fertility, and unstable structure.
	Momenga	Arable	II	
	Njala sloping	Arable	III	Marginally suitable for cultivation but have severe limitations which reduce the choice of crops such as moderately steep slope (5 to 10 %), high gravel content, high erosion hazards, water holding capacity, low fertility, and unstable structure.

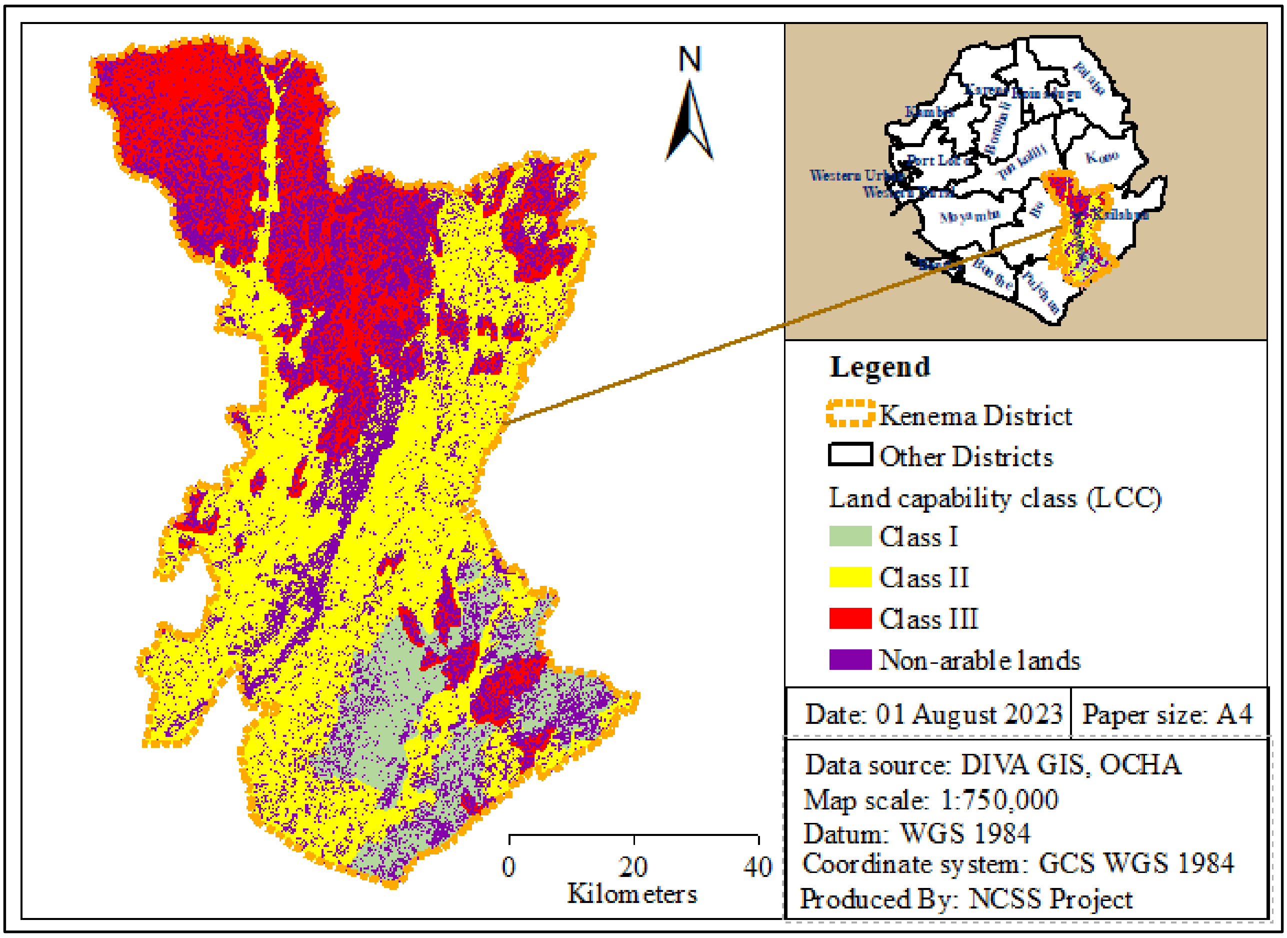

Figure 14. *Land capability of soils in Kenema District*

Soil Suitability and implications for agricultural development

Soil suitability is used to evaluate the best combination of climatic, landscape and soil factors that can meet the optimal growth requirements of specific crops or land utilization type (LUT) along with information on the major constraints that may limit their use and recommendations on how to manage them in a sustainable and ecofriendly manner. This objective is in line with the National Comprehensive Project (NCSS), which sought to update the 40-year Sierra Leone soil survey data to serve as a scientific basis inform agricultural land use planning involving the selection of soils that are most suitable for the optimal production of (1) food crops (2) vegetables (3) tree crops and (4) fruit trees, as the country intensifies its agricultural drive towards boosting national economy and food self-sufficiency.

Suitability classes, produce Land Productivity (LPI) which are grouped into suitability classes in decreasing order of crop productivity and constraints of S1> S2 >S3> N1 >N2. The limitations of the soils to the production of specific crops are coded as f = fertility (pH, CEC, Base saturation), s = soil physical characteristics (texture, bulk density), t = topographic (slope), w = wetness (drainage, flooding), and n= salinity/ alkalinity.

The findings of the land suitability evaluation of soils in Kenema district is discussed below:

6.2.1 Suitability evaluation for rice cultivation

Rice is the main staple food for Sierra Leone and is grown by almost 80% of farmers (STATSL, 2017). Out of the fourteen soil individuals (i.e., soil series) that are arable in the district, Ngelehun, Yumbuma and Keya series ranked the best; being moderately suitable (S2) in their capacity to satisfy the optimal growth requirements and yield of rice in two (rainfed upland rice and irrigated rice cultivation systems) out of four cultivation schemes under low input level of management (Table 30). This is followed by Pendembu, Kparva, and Tisso series for moderate suitability (S2) for rainfed upland rice cultivation (Table 29). The other soil individuals ranked either marginally suitable (S3) or not suitable for rainfed upland rice and irrigated rice cultivation. Overall, the results (Tables 27, 28, 29, 30, and 31) show that soils on isolated hills and steep slopes are not suitable for rainfed bunded rice and natural flooded rice cultivation. The availability of water (low water holding capacity), stoniness, rockiness, and extreme limitations of depth and slope were identified as the main limiting factor for these soils.

6.2.1.1 Soils located on sloping terrains

According to the results presented in Table 27, soils on isolated hills and steep slopes are generally not suitable for rice cultivation. Only soils of Segbwema and Vaahun series are marginally suitable (S3) for rainfed upland rice cultivation.

Table 27. *Suitability of the Rockland-Segbwema-Vaahun soil association for rice cultivation under four farming systems*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Rockland	Rainfed Upland rice				■		t
	Rainfed bunded rice					■	t
	Natural flooded rice				■		t
	Irrigated rice					■	t
Segbwema	Rainfed Upland rice			■			fs
	Rainfed bunded rice					■	ts
	Natural flooded rice					■	ts
	Irrigated rice					■	ts
Vaahun	Rainfed Upland rice			■			fs
	Rainfed bunded rice					■	ts
	Natural flooded rice					■	ts
	Irrigated rice					■	ts

s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.1.2 Soils located on dissected uplands of high weathered materials

According to the results presented in Table 28, soils on dissected uplands of high weathered materials are generally not suitable for rice cultivation. They are only marginally suitable (S3) for rainfed upland rice cultivation.

Table 28. *Suitability of the Fanima-Baoma-Waiima soil association for rice cultivation under four farming systems*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Fanima	Rainfed Upland rice			■			stf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf
Baoma	Rainfed Upland rice			■			stf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf
Waiima	Rainfed Upland rice			■			stf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.1.3 Soils located on colluvial footslopes and upper terraces

According to the results presented in Table 29, majority of soils located on colluvial footslopes and upper terraces are generally not suitable for rice cultivation. However, some soils are moderately suitable (S2) for rainfed upland rice cultivation, and some (Tisso soils) are marginally suitable (S3) for natural flooded rice cultivation.

Table 29. *Suitability of the Pendembu-Kparva-Tisso soil association for rice cultivation under four farming systems*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Rainfed Upland rice		■				sf
	Rainfed bunded rice					■	stf
	Natural flooded rice				■		stf
	Irrigated rice					■	stf
Kparva	Rainfed Upland rice		■				sf
	Rainfed bunded rice					■	stf
	Natural flooded rice				■		stf
	Irrigated rice					■	stf
Tisso	Rainfed Upland rice		■				sf
	Rainfed bunded rice					■	stf
	Natural flooded rice			■			sf
	Irrigated rice					■	stf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.1.4 Soils located on colluvial and lower concave slopes

According to the results presented in Table 30, soils on colluvial and lower concave slopes of the dissected uplands of highly weathered materials are generally suitable for rice cultivation under the four rice cultivation systems. Their suitability ranges from moderate (S2) to marginal (S3), with limitations of fertility.

Table 30. *Suitability of the Ngelehun-Yumbuma-Keya soil association for rice cultivation under four farming systems*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Ngelehun	Rainfed Upland rice		■				fw
	Rainfed bunded rice			■			sfw
	Natural flooded rice			■			sfw
	Irrigated rice		■				fw
Yumbuma	Rainfed Upland rice		■				fw
	Rainfed bunded rice			■			sfw
	Natural flooded rice			■			sfw
	Irrigated rice		■				fw
Keya	Rainfed Upland rice		■				fw
	Rainfed bunded rice			■			sfw
	Natural flooded rice			■			sfw
	Irrigated rice		■				fw

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), w = wetness (drainage, flooding)

6.2.1.5 Soils located on upland eroded surfaces with gravelly surface and subsoil

According to the results presented in Table 31, majority of soils located on upland eroded surfaces with gravelly surface and subsoil are generally not suitable for rainfed bunded rice, natural flooded rice, and irrigated rice cultivation but only moderately suitable (S2) for rainfed upland rice cultivation. The availability of water (low water holding capacity), high gravel content, and some fertility issues were identified as the main limiting factor for these soils.

Table 31. Suitability of the Manowa-Momenga-Njala sloping soil association for rice cultivation under four farming systems

Soil association	MAFS target crops	Suitability class S1	S2	S3	N1	N2	Limitations for management
Manowa	Rainfed Upland rice		■				tf
	Rainfed bunded rice					■	stf
	Natural flooded rice					■	stf
	Irrigated rice					■	stf
Momenga	Rainfed Upland rice		■				tf
	Rainfed bunded rice					■	stf
	Natural flooded rice					■	stf
	Irrigated rice					■	stf
Njala sloping	Rainfed Upland rice		■				tf
	Rainfed bunded rice					■	stf
	Natural flooded rice					■	stf
	Irrigated rice					■	stf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.2 Suitability evaluation for cultivation of other food crops

According to STATSL (2017), cassava, maize, sweet potation, groundnut, and cowpea have also attracted the attention of farmers as major livelihood crops in Sierra Leone. The result of soil suitability evaluation conducted for the cultivation of other food crops including cassava, maize, sweet potato, groundnut, and cowpea reveals that all the fourteen soil individuals that has been classified as arable are also suitable for growing these crops (Tables 32, 33, 34, 35, and 36). The suitability of these soil individuals ranges from highly suitable (S1) to marginally (S3).

62.2.1 Soils located on sloping terrains

A consideration of soil suitability evaluation for soils on isolated hills and steep slopes was done to assess their potential for sustainable cultivation of major field crops such as cassava, maize, sweet potato, groundnut, and cowpea. This was based on the fact that though these terrains seem not to be well-suited for growing of major field crops due to limitations such as steep slopes, gravelly soils, somehow shallow depth, and antecedent soil degradation when these areas are brought under intense cultivation, but at the time of field survey, vast portion of these erosion-prone areas were under agricultural land use, farmers claimed to be their only source of livelihood. From our investigation, we observed that soils of the Segbwema and Vaahun series are moderately suitable (S2) for cassava and groundnut, and marginally suitable (S3) for maize, sweet potato, and cowpea (Table 32).

Table 32. Suitability of the Rockland-Segbwema-Vaahun soil association for cultivation of other food crops

Soil association	MAFS target crops	Suitability class S1	S2	S3	N1	N2	Limitations for management
Rockland	Cassava				■		t
	Maize				■		t
	Sweet potato					■	t
	Groundnut				■		t
	Cowpea					■	t
Segbwema	Cassava		■				tf
	Maize			■			stf
	Sweet potato			■			stf
	Groundnut		■				tf
	Cowpea			■			stf
Vaahun	Cassava		■				tf
	Maize			■			stf
	Sweet potato			■			stf
	Groundnut		■				tf
	Cowpea			■			stf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.2.2 Soils located on dissected uplands of high weathered materials

Based on our evaluation, soils of Fanima, Baoma, and Waiima series are highly suitable (S1) for cassava, moderately suitable (S2) for sweet potato and groundnut, and marginally suitable (S3) for maize and cowpea (Table 33). Major limitations for use of these soil include moderate to strong slope, some amounts of gravels in root zone layer, and fertility problems.

Table 33. *Suitability of the Fanima-Baoma-Waiima soil association for cultivation of other food crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Fanima	Cassava	■					f
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				sf
	Cowpea			■			stf
Baoma	Cassava	■					f
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				sf
	Cowpea			■			stf
Waiima	Cassava	■					f
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				sf
	Cowpea			■			stf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.2.3 Soils located on colluvial footslopes and upper terraces

The suitability evaluation of soils on colluvial footslopes and upper terraces reveals that soils of Pendembu, Kparva, and Tisso series are highly suitable (S1) for cassava, sweet potato and groundnut, and moderately suitable (S2) for maize and cowpea (Table 34). These soils show great potential for supporting the growth of short duration varieties of cassava, maize, sweet potato, groundnut, and cowpeas. However, great attention should be paid to contingency crop planning for aberrant weather conditions that are likely to affect the growth and yield performance of these crops.

Table 34. *Suitability of the Pendembu-Kparva-Tisso soil association for cultivation of other food crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Cassava	■					f
	Maize		■				sf
	Sweet potato	■					f
	Groundnut	■					f
	Cowpea		■				sf
Kparva	Cassava	■					f
	Maize		■				sf
	Sweet potato	■					f
	Groundnut	■					f
	Cowpea		■				sf
Tisso	Cassava	■					f
	Maize		■				sf
	Sweet potato	■					f
	Groundnut	■					f
	Cowpea		■				

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density)

6.2.2.4 Soils located on colluvial and lower concave slopes

Soils located on colluvial and lower concave slopes of the dissected uplands of highly weathered materials have proven sustainable for short duration varieties of major field crops such as cassava, maize, sweet potato, groundnut, and cowpea in some African countries like Nigeria, Ghana, and Kenya, especially during aberrant weather conditions of short-term dry spells and delayed onset of rainy season. Our evaluation of such soils in Kenema district has revealed that soils located on colluvial and lower concave slopes of the dissected uplands of highly weathered materials, been mapped as Ngelehun, Yumbuma, and Keya series are moderately suitable (S2) for maize and sweet potato, and marginally suitable for cassava, groundnut, and cowpea (Table 35).

Table 35. *Suitability of the Ngelehun-Yumbuma-Keya soil association for cultivation of other food crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Ngelehun	Cassava			■			sfw
	Maize		■				fw
	Sweet potato		■				fw
	Groundnut			■			sfw
	Cowpea			■			sfw
Yumbuma	Cassava			■			sfw
	Maize		■				fw
	Sweet potato		■				fw
	Groundnut			■			sfw
	Cowpea			■			sfw
Keya	Cassava			■			sfw
	Maize		■				fw
	Sweet potato		■				fw
	Groundnut			■			sfw
	Cowpea			■			sfw

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), w = wetness (drainage, flooding)

6.2.2.5 Soils located on upland eroded surfaces with gravelly surface and subsoil

Soils found on upland eroded surfaces with gravelly surface and subsoil seem to be widespread in Sierra Leone. According to studies conducted by Odell at al. (1974), these soils account for almost 55% of soils in the country. The result stated in Table 36 shows that soils located on on upland eroded surfaces with gravelly surface and subsoil, been mapped as Manowa, Momenga, and Njala sloping series are moderately suitable (S2) for cassava, maize, sweet potato, groundnut, and cowpea. The potential of these soil individuals for supporting optimum growth of these crops is related to their well-drained nature, which is a major requirement for root and tuber, and leguminous crops.

Table 36. *Suitability of the Manowa-Momenga-Njala sloping soil association for cultivation of other food crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Manowa	Cassava		■				fs
	Maize		■				fs
	Sweet potato		■				fs
	Groundnut		■				fs
	Cowpea		■				fs
Momenga	Cassava		■				fs
	Maize		■				fs
	Sweet potato		■				fs
	Groundnut		■				fs
	Cowpea		■				fs
Njala sloping	Cassava		■				fs
	Maize		■				fs
	Sweet potato		■				fs
	Groundnut		■				fs
	Cowpea		■				fs

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density)

6.2.3 Suitability evaluation for cultivation of vegetable crops

Vegetables provide very important dietary requirements in human nutrition and their role in promoting good growth cannot be underestimated. According to STATSL (2017), about 26% of the country's farming population are into vegetable cultivation. In Kenema district, the same 2015 census report reveals that 3,397 households, which account for 0.3% of country's farming population are engaged in vegetable cultivation, accounting for 4,745 hectares (0.1%) of the land under cultivation and yield of 151,758 kg. Hence, soil suitability evaluation would be of immense relevance for improving the productivity of the vegetable subsector. Based on the results (Table 37, 38, 39, 40, and 41), the suitability of soils for vegetable cultivation ranges from moderately suitable (S2) to currently not-suitable(N1). The details are presented below:

6.2.3.1 Soils located on sloping terrains

Soil suitability evaluation for soils on isolated hills and steep slopes in Kenema district shows that the arable soils of Segbwema and Vaahun series are only marginally suitable (S3) for tomato and currently not-suitable (N1) for onion, cabbage and carrot due to extreme limitations of shallow depth and slope, and moisture availability (Table 37). However, with suitable soil conservation management practices, the currently not-suitable soils can be upgraded to marginally suitable (S3) soils.

Table 37. *Suitability of the Rockland-Segbwema-Vaahun soil association for cultivation vegetable crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Rockland	Onion					■	t
	Tomato					■	t
	Cabbage					■	t
	Carrot					■	t
Segbwema	Onion				■		t
	Tomato			■			st
	Cabbage				■		t
	Carrot				■		t
Vaahun	Onion				■		t
	Tomato			■			st
	Cabbage				■		t
	Carrot				■		t

s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.3.2 Soils located on dissected uplands of high weathered materials

Soils on dissected uplands of high weathered materials show similar suitability status with soils on isolated steep hills and slopes, i.e., marginally suitable (S3) for tomato and cabbage, and currently not-suitable (N1) for onion and carrot (Table 38). Major limitations are associated with shallow depth and slope, and moisture availability. However, with suitable soil conservation management practices, the currently not-suitable soils can be upgraded to marginally suitable (S3) soils, just as for soils on isolated steep hills and slopes.

Table 38. *Suitability of the Fanima-Baoma-Waiima soil association for cultivation of vegetable crops*

Soil association	MAF target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Fanima	Onion				■		t
	Tomato			■			st
	Cabbage			■			st
	Carrot				■		t
Baoma	Onion				■		t
	Tomato			■			st
	Cabbage			■			st
	Carrot				■		t
Waiima	Onion				■		t
	Tomato			■			st
	Cabbage			■			st
	Carrot				■		t

s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.3.3 Soils located on colluvial footslopes and upper terraces

The suitability of soils on colluvial footslopes and upper terraces, i.e., soils of Pendembu, Kparva and Tisso series ranges from moderately suitable (S2) for tomato and carrot, to marginally suitable (S3) for onion and cabbage (Table 39). This is due to major limitations ranging from imperfect to poor drainage, danger of flash floods, and waterlogging, which are major challenges for growing onion and cabbage on sustainable basis. However, growing these crops during the dry season while making use of residual soil moisture would alternatively help to manage and/or reduce shortages in the district.

Table 39. *Suitability of the Pendembu-Kparva-Tisso soil association for cultivation of vegetable crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Onion						sf
	Tomato						f
	Cabbage						sf
	Carrot						f
Kparva	Onion						sf
	Tomato						f
	Cabbage						sf
	Carrot						f
Tisso	Onion						sf
	Tomato						f
	Cabbage						sf
	Carrot						f

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density)

6.2.3.4 Soils located on colluvial and lower concave slopes

Soils on colluvial and lower concave slopes of the dissected uplands of highly weathered materials show similar suitability status with soils on colluvial footslopes and upper terraces, i.e., soils of Pendembu, Kparva and Tisso series and those of soils on upland eroded surfaces with gravelly surface and subsoil, i.e., moderately suitable (S2) for tomato to marginally suitable (S3) for onion, cabbage and carrot (Table 40). Major limitations are associated with waterlogging, flooding, and fertility, which can be overcome by suitable soil conservation management practices.

Table 40. *Suitability of the Ngelehun-Yumbuma-Keya soil association for cultivation of vegetable crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Ngelehun	Onion						fw
	Tomato						f
	Cabbage						fw
	Carrot						fw
Yumbuma	Onion						fw
	Tomato						f
	Cabbage						fw
	Carrot						fw
Keya	Onion						fw
	Tomato						f
	Cabbage						fw
	Carrot						fw

f= fertility (pH, CEC, Base saturation), w = wetness (drainage, flooding)

6.2.3.5 Soils located on upland eroded surfaces with gravelly surface and subsoil

Soils of Manowa, Momenga and Njala sloping series, located on upland eroded surfaces with gravelly surface and subsoil show similar suitability status with soils on colluvial footslopes and upper terraces, i.e., soils of Pendembu, Kparva and Tisso series and those of soils on upland eroded surfaces with gravelly surface and subsoil, i.e., moderately suitable (S2) for tomato and cabbage to marginally suitable (S3) for onion and carrot (Table 41). Major limitations are associated with coarse texture due to gravel and fertility, which can be overcome by suitable soil conservation management practices.

Table 41. Suitability of the Manowa-Momenga-Njala sloping soil association for cultivation of vegetable crops

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Manowa	Onion			■			sf
	Tomato		■				f
	Cabbage		■				f
	Carrot			■			sf
Momenga	Onion			■			sf
	Tomato		■				f
	Cabbage		■				f
	Carrot			■			sf
Njala sloping	Onion			■			sf
	Tomato		■				f
	Cabbage			■			sf
	Carrot			■			sf

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density)

6.2.4 Suitability evaluation for cultivation of tree crops

The tree crop subsector contributes to a major portion of agricultural exports in Sierra Leone. According to STATSL (2017), the main export crops are cocoa, coffee, cola nut and oil palm. In Kenema district, 2015 census report reveals that out of a total of 38,664 agricultural households engaged in tree crop cultivation, 15,944 (i.e., 7.8%) are engaged in cocoa cultivation, 10,752 (i.e., 5.3%) are engaged in coffee cultivation, and 11,556 (i.e., 5.7%) are engaged in oil palm cultivation. In terms of area under cultivation per tree crop, out of a total area of 350,338 hectares under tree crop, cocoa accounts for 58,086 ha, coffee accounts for 34,236 ha, oil palm accounts for 43,126 ha, citrus accounts for 1,104 ha and cashew accounts for 379 ha. This is an indication of how important the tree crop subsector in the national economy development is. Based on the results (Table 42, 43, 44, 45, and 46), the suitability of soils for tree crop cultivation ranges from moderately suitable (S2) to permanently not-suitable (N2). The details are presented below:

6.2.4.1 Soils located on sloping terrains

The suitability of arable soils of Segbwema and Vaahun series, located on isolated hills and steep slopes, ranges from moderately suitable (S2) for cocoa, arabica coffee, and robusta coffee, to marginally suitable (S3) for cashew and oil palm (Table 42). Major limitations are associated with steep slopes, shallow depth, coarse texture due to gravel and fertility, which can be overcome by suitable soil conservation management practices.

Table 42. Suitability of the Rockland-Segbwema-Vaahun soil association for cultivation tree crops

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Rockland	Cocoa			■			tf
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew			■			tf
	Oil palm			■			tf
Segbwema	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew			■			tf
	Oil palm			■			tf
Vaahun	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew			■			tf
	Oil palm			■			tf

f= fertility (pH, CEC, Base saturation), t = topography (slope)

6.2.4.2 Soils located on dissected uplands of high weathered materials

The suitability of arable soils of Fanima, Baoma and Waiima series, located on dissected uplands of high weathered materials, ranges from moderately suitable (S2) for cocoa and cashew, to marginally suitable (S3) for arabica coffee, robusta coffee and oil palm (Table 43). Major limitations are associated with coarse texture due to gravel and fertility, which can be overcome by suitable soil conservation management practices.

Table 43. *Suitability of the Fanima-Baoma-Waiima soil association for cultivation of tree crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Fanima	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf
Baoma	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf
Waiima	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			

f= fertility (pH, CEC, Base saturation), t = topography (slope)

6.2.4.3 Soils located on colluvial footslopes and upper terraces

The suitability of arable soils of Pendembu, Kparva and Tisso series, located on colluvial footslopes and upper terraces indicates that soils are moderately suitable (S2) for cocoa, arabica coffee, robusta coffee, cashew and oil palm (Table 44). Despite this suitability, there might be few limitations of minor concern that are associated with fertility, which can be overcome by suitable soil conservation management practices.

Table 44. *Suitability of the Pendembu-Kparva-Tisso soil association for cultivation of tree crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew		■				f
	Oil palm		■				f
Kparva	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew		■				f
	Oil palm		■				f
Tisso	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew		■				f
	Oil palm		■				f

f= fertility (pH, CEC, Base saturation)

6.2.4.4 Soils located on colluvial and lower concave slopes

The suitability of arable soils of Ngelehun, Yumbuma and Keya series, located on colluvial and lower concave slopes of the dissected uplands of highly weathered materials, ranges from marginally suitable (S3) for cocoa and oil palm, to currently not-suitable (S3) for arabica coffee, robusta coffee and cashew

(Table 45). This is due to major limitations ranging from imperfect to poor drainage, danger of flash floods, and waterlogging, which are major challenges for growing arabica coffee, robusta coffee and cashew on sustainable basis.

Table 45. *Suitability of the Ngelehun-Yumbuma-Keya soil association for cultivation of tree crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Ngelehun	Cocoa			■			fw
	Arabica coffee				■		tfw
	Robusta coffee				■		tfw
	Cashew				■		tfw
	Oil palm			■			fw
Yumbuma	Cocoa			■			fw
	Arabica coffee				■		tfw
	Robusta coffee				■		tfw
	Cashew				■		tfw
	Oil palm			■			fw
Keya	Cocoa			■			fw
	Arabica coffee				■		tfw
	Robusta coffee				■		tfw
	Cashew				■		tfw
	Oil palm			■			fw

f= fertility (pH, CEC, Base saturation), t = topography (slope), w = wetness (drainage, flooding)

6.2.4.5 Soils located on upland eroded surfaces with gravelly surface and subsoil

Similar to soils of Fanima, Baoma and Waiima series, located on dissected uplands of high weathered materials, the suitability of soils of Manowa, Momenga and Njala sloping series ranges from moderately suitable (S2) for cocoa and cashew, to marginally suitable (S3) for arabica coffee, robusta coffee and oil palm (Table 46). Major limitations are associated with coarse texture due to gravel and fertility, which can be overcome by suitable soil conservation management practices.

Table 46. *Suitability of the Manowa-Momenga-Njala sloping soil association for cultivation of tree crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Manowa	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf
Momenga	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf
Njala sloping	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf

f= fertility (pH, CEC, Base saturation), t = topography (slope)

6.2.5 Suitability evaluation for cultivation of fruit crops

Fruit crops such as mango, citrus, banana and pineapple are often referred to as the breakeven for the hunger season in most rural communities in Sierra Leone, especially during the period of June to August, when there is an off-peak moment in the availability of rice, the staple food. These crops also contribute to a major portion of agricultural trade, especially for women in Sierra Leone. This is an indication of how important these crops are in substituting for the staple food. Based on the results (Table 47, 48, 49, 50, and 51), the suitability of soils for fruit crop cultivation ranges from moderately suitable (S2) to permanently not-suitable (N2). The details are presented below:

6.2.5.1 Soils located on sloping terrains

The suitability of arable soils of Segbwema and Vaahun series, located on isolated hills and steep slopes for fruit crops, ranges from marginally suitable (S3) for banana, to currently not-suitable (S3) for mango, citrus and pineapple (Table 47). This is due to major limitations ranging from steep slopes, coarse texture, stoniness, and moisture availability, which are major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 47. *Suitability of the Rockland-Segbwema-Vaahun soil association for cultivation fruit crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Rockland	Mango						st
	Citrus						st
	Pineapple						st
	Banana						st
Segbwema	Mango						sf
	Citrus						sf
	Pineapple						sf
	Banana						f
Vaahun	Mango						sf
	Citrus						sf
	Pineapple						sf
	Banana						f

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density), t = topography (slope)

6.2.5.2 Soils located on dissected uplands of high weathered materials

The suitability of arable soils of Fanima, Baoma and Waiima series, located on dissected uplands of high weathered materials for fruit crops, ranges from moderately suitable (S2) for pineapple and banana, to marginally suitable (S3) for mango and citrus (Table 48). This is due to major limitations ranging from moderate to strong slopes, coarse texture, stoniness, and moisture availability, which are major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 48. *Suitability of the Fanima-Baoma-Waiima soil association for cultivation of fruit crops*

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Fanima	Mango						sf
	Citrus						sf
	Pineapple						f
	Banana						f
Baoma	Mango						sf
	Citrus						sf
	Pineapple						f
	Banana						f
Waiima	Mango						sf
	Citrus						sf
	Pineapple						f
	Banana						f

f= fertility (pH, CEC, Base saturation), s=soil physical characteristics (texture, bulk density)

6.2.5.3 Soils located on colluvial footslopes and upper terraces

The suitability of arable soils of Pendembu, Kparva, and Tisso series, located on colluvial footslopes and upper terraces for fruit crops, shows that these soils are moderately suitable (S2) for mango, citrus, pineapple and banana (Table 49). This is due to major limitations of moisture availability and fertility to some extent, which are major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 49. Suitability of the Pendembu-Kparva-Tisso soil association for cultivation of fruit crops

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Mango		■				f
	Citrus		■				f
	Pineapple		■				f
	Banana		■				f
Kparva	Mango		■				f
	Citrus		■				f
	Pineapple		■				f
	Banana		■				f
Tisso	Mango		■				f
	Citrus		■				f
	Pineapple		■				f
	Banana		■				f

f= fertility (pH, CEC, Base saturation)

6.2.5.4 Soils located on colluvial and lower concave slopes

The suitability of arable soils of Ngelehun, Yumbuma and Keya series, located on colluvial footslopes and upper terraces for fruit crops, shows that these soils are moderately suitable (S2) for banana, to marginal suitable (S3) for mango and citrus, and somewhat permanently not suitable for pineapple (Table 50). This is due to major limitations of moisture availability and fertility to some extent, which are major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 50. Suitability of the Ngelehun-Yumbuma-Keya soil association for cultivation of fruit crops

Soil association	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Ngelehun	Mango			■			fw
	Citrus			■			fw
	Pineapple					■	tfw
	Banana		■				f
Yumbuma	Mango			■			fw
	Citrus			■			fw
	Pineapple					■	tfw
	Banana		■				f
Keya	Mango			■			fw
	Citrus			■			fw
	Pineapple					■	tfw
	Banana			■			fw

f= fertility (pH, CEC, Base saturation), t = topography (slope), w = wetness (drainage, flooding)

6.2.5.5 Soils located on upland eroded surfaces with gravelly surface and subsoil

The suitability of arable soils of Manowa, Momenga and Njala sloping series, located on colluvial footslopes and upper terraces for fruit crops for fruit crops, shows that these soils are moderately suitable (S2) for mango, citrus, pineapple and banana cultivation for soils of Manowa and Momenga, and marginal suitable (S3) for mango and citrus (Table 51). This is due to major limitations of moisture availability and fertility to some extent, which are major challenges for growing these crops on sustainable basis under such environmental conditions.

Table 51. *Suitability of the Manowa-Momenga-Njala sloping soil association for cultivation of fruit crops*

Soil association	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Manowa	Mango						f
	Citrus						f
	Pineapple						f
	Banana						f
Momenga	Mango						f
	Citrus						f
	Pineapple						f
	Banana						f
Njala sloping	Mango						tf
	Citrus						tf
	Pineapple						f
	Banana						tf

f= fertility (pH, CEC, Base saturation) and t = (slope)

7 Soil Fertility Management

The soil tests reported in section 4 indicated low soil fertility status of many soils. It is not surprising therefore that the soil suitability evaluation found that the status of soil fertility is a key factor determining the suitability rating of a soil type for a given crop. Soil fertility management is therefore given special attention in this subsection. The capacity of soils to hold on to nutrient cations (cation exchange capacity), prior to crop uptake and soil acidity (which influences the availability to crops of nutrients in the soil) were often the limiting fertility factors. Soils of Sierra Leone are inherently of low fertility compared to soils of the temperate zone, a consequence of the factors of soil formation. They seem fertile when under bush fallow of several years. On clearing the bush and subjecting the soils to cultivation, their fertility declines due to soil nutrient mining (crop removal not replenished), soil erosion, nutrient leaching, method of land clearing and subsequent tillage. This sub-section of the report deals mainly with locally available technologies for overcoming the soil fertility problems outlined for the mapping units in section 4 of the report. Agronomic evidence for managing soil fertility based on soil tests, leaf analysis and field trials is not available for many of the districts and soils and so the presentation cuts across districts, but mention is made of specific locations when that kind of information is available.

Most of the problems associated with land use in Kenema district are synonymous to those that have already been mentioned by earlier researchers (e.g., Stobbs, 1963; van Vuure and Miedema, 1973; Odell et al., 1974; UNDP/FAO, 1979, Amara and Momoh, 2014, Amara *et al*., 2013 and 2021). While farmers continue to modify farming systems and approaches, problems continue to pose major constraint to sustainability in agricultural production.

Several technologies for managing soil fertility are available in West Africa (Jalloh et al., 2011). They include liming, fertilization, seed priming and micro-fertilization, green manuring, composting, agroforestry, night corralling of livestock, small stock manure production and integrated soil fertility management. Technologies available in Sierra Leone for which there is within-country research-based evidence, that can be exploited as opportunities for overcoming the problem of low soil fertility, especially on the fields of small holder farmers, are outlined here for the groups of soils identified by Odell et al. (1974).

In the discussion of soil fertility management options for soils of Kono district, we observed that soils of Kono district share similar characteristics as those of Kenema and Kailahun districts since most of the soil associations and individuals are repeating. Hence, the soil fertility management options remain the same as those discussed for soils of Kenema and Kailahun districts except otherwise where slight modifications in soil properties probably due to land use were observed.

7.1 Well drained and aerobic soils (i.e. soils located on sloping terrains, dissected uplands of high weathered materials, upland eroded surfaces with gravelly surface and subsoil, and colluvial footslopes and upper terraces such as soils of the Segbwema, Vaahun, Manowa, Momenga, Njala sloping, Fanima, Waiima, Baoma, Pendembu, Kparva and Tisso series)

The well drained and moderately well drained soils on the uplands, and colluvial footslopes and terraces are of low fertility, in terms of pH, plant available nutrients, moisture availability, and storage capacity for nutrient cations. These soils are usually under serious threats of degradation and if this process is allowed to continue, it would create tremendous problems of run-off and soil erosion resulting in further deterioration of such areas, silting up of major reservoirs and floods. It is therefore extremely important to halt this process. The following management practices can be prioritized to improve the status of these soils:

7.1.1 Control of soil acidity

Control of soil acidity accompanied by increased yields of maize and groundnut by liming has been achieved with commercial calcium carbonate (NARC, 2009; NARC, 2010; Rhodes *et al*., 2020), ground oyster shells (Alpha, 1991a) and basic slag (Kamara and Funnah, 1981). Application of organic materials in the form of biomass from Gliricidia sepium (Robert *et al*., 2013) and Biochar made from rice straw (Kamara *et al*., 2015) also raised soil pH and maize and rice biomass. But Gliricidia was less effective than lime. Most of the evidence were obtained from station research conducted on station at Njala, on the Njala soil series and Rokupr. Liming with dolomitic lime (calcium and magnesium carbonate) would be desirable because of the low content of exchangeable magnesium in these acid soils. Residual values of liming on these very acidic soils need careful investigation to best exploit the value of liming.

7.1.2 Fertilizer use

Fertilizers, mainly NPK compound + urea tested by the FAO Fertilizer Programme of 1961-1986, the Sierra Leone Rice Project, based in Rice Research Station, Rokupr, Kambia district, in the 1970's and the Adaptive Crop Research and Extension Project based in Njala University College in the 1980's and implemented on farmers' fields in the Njala, Kenema, Makeni, Rokupr and Kabala zones raised yields of rice and other food crops. A major problem with the 60 kg N + 40 kg P_2O_5 + 40 kg K_2O ha-1 recommendation developed by RARC for rice, applied as 15:15: 15 compounds plus urea in Sierra Leone, is that in this country it is used as a blanket application. The same applies to the fertilizer recommendations developed by NARC, RARC and Njala University for other crops. Recommendations based on soil analysis (Conteh, 2017), especially when calibrated with crop response to fertilizers in the field (Odell *et al*., 1974) is the right way to go for efficient use of fertilizers and protection of the environment. This would permit choice from a range of compound and straight fertilizers for appropriate sites. The approach would however require capacity strengthening in the form of complementing automated wet analysis with very rapid dry laboratory analysis and implementing trials and demonstrations on carefully chosen and characterized sites, making use of NCSS data. Improving fertilizer use efficiency also requires planting on time, accessing quality fertilizer products, correct methods of fertilizers application, use of good quality seeds of high yielding adapted crop varieties and crop protection (Rhodes, 2012).

Concerning the micronutrients, crop deficiencies of boron, copper, molybdenum and zinc occur in soils of Sierra Leone (Sillaanpa, 1982). Application of molybdenum (Haque and Bundu, 1980; Rhodes and Nangju, 1979; Rhodes and Kpaka, 1982) and zinc (RARC, 2012) increased yields of rice and cowpea. The micronutrients in the last three studies were applied as seed coating or seeds primed with nutrient solutions. The trials were on station at Njala and Rokupr. The findings indicate that there is a potential for increasing crop yields in some areas of Sierra Leone by fertilization with micronutrient carriers in one form or the other. Micronutrient containing fertilizers are however not currently available to smallholder farmers in the country. It should be noted also that an additional benefit of organic materials is that they can be sources of micronutrients. For manganese and iron, the issue is more of toxicity. Iron toxicity to rice occurs in inland valley swamps and can be mitigated by good agronomic practices including use of tolerant varieties, liming, early planting, balanced fertilization recycling of crop residues, and water control. On farm trials and demonstrations are required.

7.1.3 Organic materials with or without fertilizers

Less attention has been given to the evaluation of organic materials as plant nutrient sources which because of their low nutrient content must be applied in heavy doses (tons compared to kilograms per hectare). An agroforestry alley cropping system of maize with Gliricidia sepium at an upland site at Senehun, Kamajei, Moyamba district resulted in significant yield increase of the crop (Karim *et al*., 1993); alley cropping has however not been adopted by farmers in Sierra Leone. Application of biomass of Cassia siamea, Gliricidia sepium, Gmelina arborea and compost in combination with NPK reduced the amount of fertilizers required to attain about the same yield of maize on the Njala soil series (Alpha, 1991b). Use of biomass of leguminous trees -Albizia zygia, Senna siamea and Gliricidia sepium with and without fertilization also resulted in improved rice yields at the Upland Samu site of the Rokupr Agricultural Research Centre (RARC, 2008). In both of these studies the amount of NPK + urea required was reduced when applied in combination with organic materials. This use of biomass from growing trees to amend soils is a promising agroforestry system for smallholders referred to as 'cut and carry'. The findings of these trials are of interest in the light of the escalating price of imported fertilizers. With the availability of adapted fast growing N fixing trees that can grow to heights of 2 to 4m producing 7 to 42 t ha- 1 biomass (MAFFS/MFMR, 2007), improving soil fertility with biomass in combination with fertilizers is an opportunity worth exploitation.

Apart from biomass from trees, there are other organic materials which have shown promise. A reduction in the amount of fertilizers needed when applied in combination with palm kernel cake was shown at the Samu upland site (RARC,2011). A residual effect of palm kernel cake (by-product in the processing of palm kernels for oil) applied in the first year on rice yield in the second year of cropping at the Samu upland site was reported (RARC, 2012). Application of biochar has been shown to increase available P, exchangeable cations and cation exchange capacity of a Njala soil series that led to significant increase of rice biomass (Kamara *et al*., 2015). Other researchers (Lahai *et al*., 2014; Feika *et al*., 2018; Margai *et al*., 2021) have reported crop yield increases on the Njala soil series from application of various types of organic materials. In general, annual additions of organic materials to soils or crop residue recycling can over time lead to increase in humus (the colloidal fraction of soil organic matter) and is therefore an opportunity for increasing cation exchange capacity and therefore soil suitability ratings.

7.1.4 Integrated soil fertility management (ISFM)

Njala University, through the Department of Soil Science and the Department of Forestry, participated in a regional capacity building project on Integrated Soil Fertility Management (ISFM) (FED/2013/320-275) (Kamara and Mattia, 2018). The Project was designed to enhance ISFM capacity aimed at promoting practical knowledge and practices of ISFM and encouraging participation and adoption of ISFM by local farmers.

The Project conducted a situation analysis to understand the local knowledge and capacities on ISFM existing in each country. The survey revealed that there existed some local knowledge on integrated soil management but there was inadequate capacity on ISFM in terms of understanding the basic principles and practices of ISFM and lack of trained (ISFM) manpower to provide technical advisory services to farmers and government.

The project trained 33 local smallholder farmers, 2 staffs from large-scale commercial agricultural industries, 53 staff and 52 students of Higher Education Institutions and research institute on the concepts and practices of ISFM and how to implement ISFM on-farm. ISFM “represents a means to overcome the dilemma of poor soil fertility with poor fertilizer access and the lack of knowledge about how to use them, by offering farmers better returns on investment in fertilizers through combination with indigenous agro-minerals and available organic resources” (Sanginga and Woomer, 2009). These conditions appear to be relevant for Kono district. and the rest of the country. The use of organic materials in combination with fertilizers as mentioned in earlier paragraphs constitute elements of ISFM.

7.1.5 Agroforestry and cover cropping

Agroforestry makes maximum use of the land by growing of both trees and agricultural/horticultural crops on the same piece of land, designed to provide multiple products (tree and other crop). Agroforestry also helps return nutrients to the soil such as nitrogen and at the same time protect, conserve, diversify and sustain important economic, environmental, social and natural resources. Agroforestry provides essential products and services that can help relieve the pressure on the natural forest domain. The system also provide food, fodder, fruit, construction materials, medicine, honey etc. Among the several techniques available in the subregion, cocoa agroforestry in the south-east, boundary planting, woodlot, and fruit orchard systems in the north, has all been proven to be soil and water conserving, nutrient replenishing, and economically sustainable in Sierra Leone (Björkemar, 2014).

7.2 Poorly Drained Soils Non-Acid Sulphate (i.e. soils located on colluvial and lower concave slopes such as soils of Ngelehun, Yumbuma and Keya series)

7.2.1 Fertilizer Use

These soils occur along the major streams, in bolilands and inland valley swamps. Rice response in inland valley swamps and bolilands to fertilizers especially N, P, and K have been reported for several years by the Sierra Leone Rice Project, the Adaptive Crop Research and Extension Project, Rice Research Station, and Rokupr Agricultural Research Centre. More recently, balanced application of 40 kg N + 40 kg P_2O_5 + 40 kg K_2O ha^{-1} based on rice response to fertilizers in the Kambia district was recommended (MAFFS/JICA, 2014). Deficiencies of zinc and sulphur were also found in some sites. The report stressed the need for adoption of improved crop cultural practices prior to the use of fertilizers.

These poorly drained soils are characterized by the development of a redox profile; and beneath the oxidized surface zone there exists an anaerobic zone. In this situation, management of nitrogen fertilizers for good uptake by rice and minimization of loss to the atmosphere (contribution to global warming) is critical. Positive response of rice to urea placed at the 20cm depth in non-acid mangrove soils of Rokupr was reported several years ago (Agyen-Sampong, 1981). The International Fertilizer Development Center has recently developed a Urea Super Granule Injector for efficiently placing urea fertilizer in the reduced zone where it is stable (IFDC, 2017). On farm trials and demonstrations in inland valley swamps and associated swamps with soils of different texture will be required to ascertain where it works best.

7.2.2 Organic Materials

Positive effects of the addition of biomass from N fixing trees on the fertility related properties of an acid hydromorphic soil have been shown (Baggie *et al*, 2000). Also, palm kernel cake was shown to increase yield of rice in an inland valley swamp at Rokupr (Johnson *et al*., 2011). However, compared to upland soils, there is less evidence on the use of organic materials as nutrient carriers.

7.3 Economics of fertilizer and organic materials use

The potential for fertilizer or organic material or lime use under commercial production is linked to the yield increases as well as the monetary returns to investments. Economic analysis done in the 1970s of response to 22.4 kg N + 22.4 kg P_2O_5 ha^{-1} fertilization of several annual crops grown in uplands and lowlands showed high value/cost ratios exceeding 2.0 in the FAO Fertilizer Programme (Zschernitz, 1973). Value/cost ratios from use of 40 kg N + 40 kg P_2O_5 + 40 kg K_2O ha^{-1} in the 1980s were lower but did not drop to below 2.0.(Mahapatra and Jalloh, 1979). The 1970s and 1980s were years when fertilizers were subsidized by government of Sierra Leone. The issue of subsidizing fertilizers is controversial. MAFS is currently promoting a voucher scheme, in cooperation with the private sector, to get fertilizers directly to farmers. However, recent data on the economics of fertilizer, organic materials and lime use is limited. Trials are required with new high yielding varieties, on-farm, in which economic analysis of crop response should be performed. The sensitivity analysis of rice response to fertilizers done by MAFFS/ JICA (2014) is a good start.

7.4 District fertilizer needs

Knowledge of the ranges and levels of key plant essential nutrients documented in section 4 for mapping units in each district in conjunction with information on the soil fertility mapping, expected acreages for cropping and target crop yields could be used to roughly estimate fertilizer or other nutrient carrier needs on a district basis. This is appropriate for the scales at which the soil survey was conducted.

7.5 Land Degradation Risks and Soil Conservations

As mentioned earlier, soil loss by erosion especially in the uplands contributes to the decline of soil fertility over time. Estimated soil loss by erosion and nutrient loss in Sierra Leone and their implications are of concern. Thus, Biot *et al*. (1989) predicted significant decline in maize and cowpea yields in the long term for Makeni as a consequence of soil erosion. Sessay and Stocking (1992) estimated soil loss ranging from 4.85 to 15.45 t ha^{-1} y^{-1} in the Makoni catchment of Makeni. Crasswell *et al*. (2004) estimated annual nutrient loss of 48 Kg N + P_2O_5 + K_2O ha^{-1} for Sierra Leone. Amara and Oladele (2014) calculated the soil erodibility (K-factor) values of soils in the Njala area to predict soil loss. They reported that Mokoli silty clay soils has the highest soil erodibility (K-factor) value of 0.57 ton/acre/ha and Momenga gravely clay, the lowest value of 0.26 ton/acre/ha, which indicates that Mokoli silty clay soils are highly vulnerable to erosion than the Momenga gravelly clay soils. Kamara (2023) reported cumulative soil loss on the Njala sloping of 7.49 t ha^{-1} and loss of nutrients from fertilized soils of 34.63 kg N ha^{-1}, 6.95 kg P ha^{-1}, 40.67 kg K ha^{-1} in three cropping phases/seasons. Control of erosion by agronomic practices such as planting fast growing N-fixing trees in slopy areas from which biomass can be obtained for amending cropped plots and mulching/ridging on the Njala sloping have potentials. Sawyerr *et al*. (2019) reported that Arch ridging plus mulching gave high net seasonal returns for sweet potato production over 5 cropping seasons. Promising technologies for the control of soil erosion by inexpensive ways are worthy of testing and demonstrating to farmers on their fields.

7.6 Potential areas for investments

The purpose of a scientific agricultural soil suitability evaluation is to guide planners, and investors as to where the most productive lands (S1 and S2) exist for potential investment. The agricultural constraints and how they can be managed by farmers when the S2 soils are put into use are also indicated. Details of their management have been discussed in section 5.3 to guide the agronomic areas management if the soil should be focused to ensure its sustainable use and prevent environmental degradation. Table 35 summarizes the highly suitable (S1) and moderately suitable (S2) classes of soils recommended for agricultural investment in Kono district.

7.7 Development of a national soil management strategy

The NCSS has been successful in updating the 40-year-old reconnaissance soil survey data (UNDP/FAO, 1979) used for planning Sierra Leone’s agricultural development. Scientific data on the land use, soil associations, soil fertility (including acidity) levels, land capability and soil suitability and their limitations can now be used to inform future agricultural planning in the country. Policy makers in the public and private sectors are now empowered to make evidence-based decisions on soil management and crop production potential areas, at the semi-detailed level, for investment in the production of the MAFS target crops. The staff of the Agricultural Engineering Division of MAFS are now equipped with technical skills and scientific information that will guide the effective management of the soil and related resources, thereby contributing well to the goals of MAFS in increasing agricultural production and productivity in an environmentally sound and sustainable way.

It is recommended that MAFS’s policy takes into consideration the evidence that soils with the highest potential for returns to investment in the Pujehun district are:

1. Set up a MAFS divisional/NU departmental/SLARI programme and other stakeholder Steering Committee to agree on aims and approaches and coordinate the process of strategy development, including public aware ness campaigns to incentivize public participation
2. Review the available data and information needs and agree on the core questions for research and stakeholder consultations. These consultations will include focus group discussions in all the 16 districts of Sierra Leone and key informant interviews. Elaborate a detailed “terms of reference’ for the process and assign departmental/divisional/programme responsibilities.
3. Use the soil data and associated maps produced by the NCSS and carry out additional research and consult with all relevant stakeholders to provide inputs.
4. Formulate the strategy, including vision, and mission statements, aims, guiding principles, action plans and institutional arrangements for implementation.
5. Conduct multi-stakeholder workshops to finalize the strategy and secure the buy-in of all relevant stakeholders including the national government
6. Translate the strategy into action plans and budgets and assign institutional roles and responsibilities for implementation.
7. MAFS hasn’t got a soil department within its organogram. Currently, AED superintend over soil in the ministry. While AED has demonstrated the technical capacity to address soil issues related to irrigation planning and management, however, the technical capacity to address major soil issues related to soil quality, soil productivity and soil fertility, as well as the management and conservation of these fragile resources is limited. We are recommending the establishment of a “Soil Department” to serve as the entering point for Feed Salone Programme. There is need for a detailed soil survey of the entire country but most needfully and urgently in all of the target districts of the Feed Salone Programme. The established soil

department in the ministry would help to facilitate the needed soil surveys that would inform MAFS's planning and decision if the "Feed Salone Programme" is to succeed.

Table 52. *Soils with high suitability (S1 and S2) for agricultural investment areas in rice, other food crops, tree crops, fruit trees and vegetables.*

Agricultural investment areas	**Crop type**	**Soil suitability class/ Soil individual**		**Limitations for management**
		Highly suitable (S1)	**Moderately suitable (S2)**	
Rice production	Rainfed upland rice	NONE	Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping	f (pH, CEC), s (texture)
	Rainfed bunded rice		NONE	t (slope)
	Natural flooded rice			t (slope)
	Irrigated rice		Ngelehun, Yumbuma, Keya	f (pH, w)
Other food crop production	Cassava	Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso,	Segbwema, Vaahun, Manowa, Momenga, Njala sloping	f(pH, CEC), s (texture)
	Maize	NONE	Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping	f (pH, CEC), s (texture)
	Sweet potato	Pendembu, Kparva, Tisso,	Fanima, Baoma, Waiima, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping	f (pH, CEC), s (texture), w (drainage)
	Groundnut	Pendembu, Kparva, Tisso,	Segbwema, Vaahun, Fanima, Baoma, Waiima, Manowa, Momenga, Njala sloping	f (pH, CEC), s (texture)
	Cowpea	NONE	Pendembu, Kparva, Tisso, Manowa, Momenga, Njala sloping	f (pH, CEC)
Tree crop production	Cacao		Segbwema, Vaahun, Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Manowa, Momenga, Njala sloping,	f (pH, CEC)
	Arabica coffee		Segbwema, Vaahun, Pendembu, Kparva, Tisso,	f (pH, CEC), s (texture)
	Robusta coffee			
	Cashew		Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Manowa, Momenga, Njala sloping,	f (pH, CEC), s (texture)
	Oil palm		Pendembu, Kparva, Tisso, Manowa, Momenga	f (pH, CEC)
Fruit crop production	Mango			
	Citrus			
	Pine apple		Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Manowa, Momenga, Njala sloping	f (pH, CEC), s (texture)
	Banana		Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Manowa, Momenga	f (pH, CEC)
Vegetable production	Onion		Pendembu, Kparva, Tisso	f (pH, CEC)
	Tomato		Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping	f (pH, CEC)
	Cabbage		Pendembu, Kparva, Tisso, Manowa, Momenga, Njala sloping	f (pH, CEC), s (texture)
	Carrot		Pendembu, Kparva, Tisso	f (pH, CEC)

f= fertility (pH, CEC, Base saturation), w= wetness (drainage, flooding)

8 Conclusions and recommendations

The NCSS has been successful in updating the 40-year-old reconnaissance soil survey data (UNDP/FAO, 1979) used for planning Sierra Leone's agricultural development. Scientific data on the land use, soil associations, soil fertility (including acidity) levels, land capability and soil suitability and their limitations can now be used to inform future agricultural planning in the country. Policy makers in the public and private sectors are now empowered to make evidence-based decisions on soil management and crop production potential areas, at the semi-detailed level, for investment in the production of the MAFS target crops. The staff of the Agricultural Engineering Division of MAFS are now equipped with technical skills and scientific information that will guide the effective management of the soil and related resources, thereby contributing well to the goals of MAFS in increasing agricultural production and productivity in an environmentally sound and sustainable way.

It is recommended that MAFS's policy takes into consideration the evidence that soils with the highest potential for returns to investment in the Kenema district are:

i. Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping soils of moderate suitability (S2) for Rainfed upland rice;
ii. Ngelehun, Yumbuma, Keya of moderate suitability (S2) for Irrigated rice.
iii. Fanima, Baoma, Waiima, Pendembu, Kparva and Tisso soils of moderate suitability (S2) for Cassava, Sweet Potato and Groundnut.
iv. Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping soils of moderate suitability (S2) for Maize and Cowpea.
v. Segbwema, Vaahun, Pendembu, Kparva and Tisso soils of moderate suitability (S2) for Arabica and Robusta Coffee;
vi. Segbwema, Vaahun, Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Manowa, Momenga, Njala sloping soils of moderate suitability (S2) for Cacao and Cashew.
vii. Pendembu, Kparva, Tisso, Manowa, Momenga soils of moderately suitability (S2) for Oil palm, Mango and Citrus;
viii. Fanima, Baoma, Waiima, Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Manowa, Momenga soils of moderate suitability (S2) for Banana and Pineapple.
ix. Pendembu, Kparva and Tisso soils of moderate suitability (S2) for Onion and Carrot; and
x. Pendembu, Kparva, Tisso, Ngelehun, Yumbuma, Keya, Manowa, Momenga, Njala sloping soils of moderate suitability (S2) for Tomato and Cabbage.

Literature cited

Agyen-Sampong, N. (1981). Highlights of research results. Mangrove Swamp Rice Project. West African Rice Development Association, Rokupr.

Alpha, P. (1991a). Effects of oyster shells on soil acidity on Njala upland soils. Annual Report for 1990/1991, Institute of Agricultural Research, Njala.

Alpha, P. (1991b). Effect of organic manures and recommended fertilizer rates on maize yield. Annual Report for 1990/1991. Institute of Agricultural Research, Njala.

Amara, D.M.K. and Kamara, A. (2011). Land Suitability Appraisals for Crop Production in Three Chiefdoms in Pujehun District of Southern Sierra Leone. Decision Support Manual for Sustainable Crop Production in rural communities. Submitted to Bio-Palm United (Ltd.) SL for implementation of an oil palm out-grower scheme in Pujehun District, Public Private Partnership Project for Sustainable Livelihoods, Sierra Leone. Technical Consultancy Report.

Amara Denis, M.K. and Momoh, E.J.J. (2014). Fertility status, Degradation Rate and Vulnerability Potential of Soils of Sowa Chiefdom in Southern Sierra Leone. *International Journal of Interdisciplinary and Multidisciplinary Studies*, 2(1), pp. 151-162.

Amara Denis, M.K. and Oladele, T.A. (2014). Estimation of Soil Erodibility and Erosivity of Rainfall Patterns in Njala Land Resource Area of Southern Sierra Leone. *Research Journal Agricultural Science*, 5(2), pp. 163-167. DOI: 1463-0810-2013-037.

Amara Denis, M.K., Kamara, A. and Momoh, E.J.J. (2013). Soil Fertility Status of Three Chiefdoms in Pujehun District of Southern Sierra Leone. *Research Journal Agricultural Science*, 4(4), pp. 461-464. DOI: 1334-13-2705-2013-119.

Amara, D.M.K., Ullah, K. and Yushu, Z. (2020). Rainfall Erosivity for Sierra Leone using non-parametric indices. Theoretical and Applied Climatology, 139:221–236 https://doi.org/10.1007/s00704-019-02960-3.

Baggie, I., Zapata, F., Sanginga, N. and Danso, S.K.A. (2000). Ameliorating acid infertile rice soil with organic residues from nitrogen fixing trees. Nutrient Cycling in Agroecosystems 57: 183-190.

Biot, Y., Sessay, M. and Stocking, M. (1989). Assessing the sustainability of agricultural land use in Botswana and Sierra Leone. Land degradation and rehabilitation 1: 263-278.

Björkemar, K. (2014). Agroforestry in Sierra Leone – examining economic potential with carbon sequestration. B.Sc. Thesis, Linnaeus University, Sweeden.

Brady, N.C and Weil, R.R. (2008). The Nature and Properties of Soils. Fourteenth edition. Pearson Education Inc. Published by Pearson Prentice Hall.

Conteh, A.R. (2017). Fertilizer recommendations using soil testing for rice and vegetable production in the inland valley swamps of selected districts of Sierra Leone. Sierra Leone Agricultural Research Institute, Njala.

Crasswell, E.T., Grote, U., Henao, J. and Vlek, P.L.G. (2004). Nutrient flows in agricultural production and international trade: Ecology Policy Issues. ZEF Discussion Paper, No 78 on Development Policy. Center for Development Research, University of Bonn, Bonn.

Dijkerman, J.C. (1969). Soil resources of Sierra Leone, West Africa. African Soils 14: 185-206

Dijkerman, J.C. and Westerveld, D.H. (1969). Reconnaissance soil survey of the lower Sewa floodplain near Torma Bum, Sierra Leone, West Africa. Njala University College. Njala.

Eschweiler, J. A. and Sessay, M. F. (1980). Feasibility study of the Turner's Peninsula Coconut Project: A Semi-detailed Survey of Soils, Vegetation and Land Use for Land Suitability Evaluation". Commissioned by the Commonwealth Secretariat, the Government of Sierra Leone & the African Development Bank. FAO/UNDP-MAFFS, Miscellaneous Report No. 20,

FAO. (2007a). The World's Mangrove. 1980-2005. A thematic Study Prepared in the Framework of Global Forests Resources Assessment 2005. FAO Forestry paper 153. FAO Rome.

FAO. (2007b). Mangroves of Africa 1980–2005: country reports. Forest Resources Assessment Working Paper No. 135, Rome. www.fao.org/forestry/site/mangrove/ statistics.

FAO. (1976). A framework for land evaluation. Soils Bulletin. 32, Food and Agriculture Organization of the United Nations, Rome, Italy. pp 72.

FAO. (2006). Guidelines for Soil Description. Fourth Edition. Rome.

FAO. (2007). Land Evaluation: Toward a version. FAO. Rome, Italy.

FAO. (1998). World Reference Base for Soil Resources. World Soil Resources Reports No 84. FAO, ISRIC-AISS-IBG. pp 88.

Haque, I. and Bundu, H.S. (1980). Effects of inoculation, N and Mo and mulch on soybean in Sierra Leone. Communications in Soil Science and Plant Analysis 11(5): 477-483.

IFDC. (2017). Rapid introduction and market development for urea deep placement technology for lowland transplanted rice- A reference guide. International Fertilizer Development Center, Muscle Shoals.

Jalloh, A., Rhodes, E.R., Kollo, I., Roy-Macauley, H. and Sereme, P. (2011). Nature and management of the soils in West and Central Africa. A review to inform farming systems research and development in the region. Conseil Ouest et Centre Africain pour la Recherche et Development Agricoles/West and Central African Council for Agricultural Research and Development (CORAF/WECARD), Dakar.

Johnson, S.D, Jalloh, A.B. and Harding, S.S. (2011). Evaluation of PKC on rice yield in IVS of Rokupr. Annual Report for 2009/2010, Rokupr.

Kamara, A, Kamara, H.S. and Kamara, M.S. (2015). Effect of rice straw biochar on soil quality and the early growth and biomass yield of rice varieties. Agricultural Sciences 6: 798-806.

Kamara, A. (2023). Assessment of soil erosion and nutrient leaching under maize cropping in Sierra Leone. PhD thesis. Njala University, Njala.

Karim, A.B., Savill, P.S. and Rhodes, E.R (1993). The effect of between row (alley widths) and within row spacings of Gliricidia sepium on alley cropped maize in Sierra Leone. Agroforestry Systems 24:81-93.

Klingbiel, A. A. and Montgomery, P. H. (1961). Land Capability Classification- Agriculture Handbook No. 210. Soil Conservation Service, US Department of Agriculture, Washington, DC, USA.

MAFFS/JICA. (2014). Technical package on rice production. Revised Edition. Ministry of Agriculture Forestry and Food Security/ Japanese International Cooperation Agency, Freetown.

MAFFS/MFRM. (2007). Agriculture sector review and agricultural development strategy. Main Report. Ministry of Agriculture Forestry and Food Security, Ministry of Fisheries and Marine Resources/ Food and Agriculture Organization of the United Nations, Rome.

Mahapatra, I.C. and Jalloh, M. (1979). Soil fertility and fertilizer use for upland rice. Paper presented at the National Seminar on Land and Water Resources Survey and its relation to Agricultural Development in Sierra Leone. 5-9 November, Freetown.

Mal, B.C. (1995). Soil and Water Conservation Engineering. Kalyani Publishers, Ludhiana, India.

NARC. (2009). Annual report for 2008. Njala Agricultural Research Centre, Njala.

NARC. (2010). Effect of lime applications on growth, yield, disease, and pests of groundnut. Annual Report for 2008. Njala Agricultural Research Centre, Njala.

Odell, R.T., Dijkermam, J.C., van Vuure, W., Melsted, S.W., Beavers, A.H., Sutton, P.M, Kurtz, L.T. and Miedema, R. (1974). Characteristics, classification and adaptation of soils in selected areas in Sierra Leone, West Africa. Bulletin 748 Agricultural Experiment Station College of Agriculture, University of Illinois at Urbana Champaign/ Bulletin 4 Njala University College, Freetown.

Ojanuga, A.G. (2008). Land use planning for optimizing agricultural production in Sierra Leone. Mission Report TCP/SIL 3101(A). Food and Agriculture Organization of the United Nations, Rome.

RARC. (2008). Annual report for 2005. Rokupr Agricultural Research Centre, Rokupr.

RARC. (2011). Annual report for 2009/2010. Rokupr Agricultural Research Centre, Rokupr.

RARC. (2012). Annual report for 2010/2011. Rokupr Agricultural Research Centre. Rokupr.

Rhodes, E.R. (2020). Stocktaking of information on agroclimatic regions, agroecological zones, land use/vegetation, soils, soil fertility and land suitability for cropping in Sierra Leone: Main Report, version 1 March 2020. Bosting Agriculture and Food Security Project. Freetown

Rhodes, E.R. (1977). Phosphorus in Sierra Leone soils. Tropical Agriculture 54:77-85.

Rhodes, E.R. (2012). Fertilizer use and handling guide: Profitable Agriculture Series No 1. Sierra Leone Agricultural Research Institute, Freetown.

Rhodes, E.R. and Kpaka, M. (1982). The effects of nitrogen, molybdenum and cultivar on cowpea growth and yield on an Oxisol. Communications in Soil Science and Plant Analysis 13(4):279-283.

Rhodes, E.R. and Nangju, D. (1979). The effects of pelleting cowpea and soybean with fertilizer dusts. Experimental Agriculture 15: 27-32.

Rhodes, E.R., Kamara, A., and Baggie, I. (2020). Review of studies on soil acidity and its management in Sierra Leone: liming and use of organic materials. Occasional Paper. Department of Soil Science, Njala University.

Robert, S.A., Robinson, J.S. and Rhodes, E.R. (2013). Effects of calcium carbonate, prunings of Gliricidia sepium and maize variety on an Ultisol. African Journal of agricultural research 8 (46): 5905-5914.

Sawyerr, P.A., Nabay, O., Yilla, K.M. (2019). Economic evaluation of rain water harvesting and conservation technologies for sweet potato cultivation in Sierra Leone. International Journal of Agricultural Economics 4(3): 94-100.

Sessay, M.F. and Stocking, M. (1992). Financial cost of soil erosion in a small farm intercropping system in Sierra Leone. In: P.G. Haskins and B.M. Murphy (eds). People Protecting their Land. Proceedings of the 7th ISCO Conference. International Soil Conservation Organization, Sydney pp 562-567.

Sillanpaa, M. (1982). Micronutrients and the nutrient status of soils: a global study. Food and Agriculture Organization of the United Nations, Rome. (Which spelling is correct for the author?)

Sys, C., vanRanst, E., Debaveye, J., and Beernaert, F. (1993). Land Evaluation Part III CROP REQUIRMENTS. Agric. Publication No 7, ILRI publication No 22. FAO Publication No 32. General Administration for Development Cooperation. Place du Champ de Mars 5 bte 57-1050 Brussels Belgium.

UNDP/FAO (1979). Agro-ecological atlas of Sierra Leone: a survey and appraisal of climate and crop resources. Land Resources Survey A.G: DP/SIL/73/002 Technical Report No 5. Ministry of agriculture, Forestry and Food Security, Freetown, Sierra Leone.

USDA. (2022). Keys to Soil Taxonomy. United States Department of Agriculture Natural Resources Conservation Service Eleventh Edition, 2010

Zschernitz, K. (1973). Fertilizers in the improvement of shifting cultivation. Regional Seminar on Shifting Cultivation and Soil Conservation in Africa. 2-21 July, Ibadan.

Sys, C., van Ranst, E., Debaveye, J and Beernaert, F. (1993). Land Evaluation. Part 111. Crop Requirement. Agricultural Publication No 7. Place du Champ de Mars 5 bte 57-1050 Brussels – Belgium.

van Vuure, W., Odell, R.T., and Sutton, P.M. (1973). Soil Survey of Njala Area; 1Bulletin No 3; Agronomy Department, Njala University College, University of Sierra Leone in Coop. with MAFFS, Government of Sierra Leone.

Appendices

1a. Soil profile description of profile pit No. KEN001; Rockland series

District: Kenema; **Chiefdom**: Small-Bo; **Village**: Serabu; **GPS location**: 7.82870°/11.32917°; **Elevation**: 127m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain/ Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 8.2%; **Vegetation**: Semi-deciduous trees and shrubs; **Erosion class and intensity**:e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Rice, groundnut, cassava, sesame.

Land System: Blama

Classification : USDA Taxonomy: Typic paleudult **FAO-UNESCO:** Dystric Nitosols

Mapping Unit: KEN001 Gravel-free over gravel soil	**Horizon (cm)**	**Morphological Description**
	Ap (0 – 16)	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist); Sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); non sticky and non-plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, medium, and very few coarse roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
	B (16 – 97)	Brown (10YR4/3 dry) and dark brown (10YR3/3 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); non sticky and non-plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, medium, very few coarse roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
	Bv (97 –163+)	Brown (10YR4/3 dry) and dark brown (10YR3/3 moist); gravelly sandy clay; moderate, coarse, crumbly; loose (dry), friable (moist); non sticky and non-plastic; plenty fine, medium, coarse pores; plenty very fine, fine, medium roots; presence of termites, ants and other insects; clear and way boundary to horizon below.

__1b.__ Analytical laboratory data of profile pit No. KEN001; Rockland series

Horizon (cm)	**Unit**	**0-16**	**16-97**	**97-163**
Sand	%	76.80	76.80	68.80
Silt	%	2.36	0.36	4.36
Clay	%	20.84	22.84	26.84
Organic Carbon	%	2.07	0.68	0.84
Bray P1	mg/kg soil	15.11	12.25	11.52
pH 1:1 soil : water ratio		4.50	4.50	4.60
pH 1:1 M KCl ratio		3.60	3.60	3.70
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	4.50	2.60	3.74
Exchangeable calcium	mg/kg soil	1.07	0.01	2.09
Exchangeable magnesium	mg/kg soil	2.20	1.41	0.25
Exchangeable potassium	mg/kg soil	0.19	0.10	0.27
Exchangeable sodium	mg/kg soil	0.21	0.07	0.34
Exchangeable acidity	cmol/kg soil	0.83	1.01	0.79
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	8.00	5.00	3.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	4.30	3.668	0.00
DTPA extractable copper (mg kg^{-1})	mg/kg soil	4.70	3.90	3.80
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	9.54	4.77	0.07

2a. Soil profile description of profile pit No. KEN002; Segbwema series

District: Kenema; **Chiefdom**: Nongowa; **Village**: Potehun; **GPS location**: 7.95373°/11.06921°; **Elevation**: 190m; **Physiography**: Undulating plain; **Landform/facet**: Interfluve crest; **Parent Material**: Weathered Residium; **Landscape position**: Summit/ crest; **Slope**: 6.3%; **Vegetation**: Tree crops; **Erosion class and intensity**:e1, slight; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 180cm; **Moisture:** Surface is dry up to 92cm but moist beyond this layer; **Landuse**: Plantation agroforestry; **Major crops grown**: Coffee, cocoa, kola nut, citrus, avogadro, mangoes and banana.

Land System: Bo

Classification : USDA Taxonomy: Udoxic dystropept **FAO-UNESCO:** Ferralic Cambisol

Mapping Unit: KEN002
Gravel-free soil

Horizon (cm)	Morphological Description
Ah (0 – 34)	Yellowish brown (10YR5/4 dry) and dark yellowish brown (10YR4/4 moist); sandy clay loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and few coarse pores; common very fine, plenty fine, few medium, and very few coarse roots; presence of open boreholes, earthworms, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bt1 (34 – 115)	Yellowish brown (10YR 4/6 dry) and yellowish brown (10YR3/6 moist); sandy clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and few coarse pores; common very fine, plenty fine, and few medium roots; presence of open boreholes, termites, ants and other insects; gradual and wavy boundary to horizon below.
Bt2 (115 – 152+)	Yellowish brown (10YR5/6 dry) and dark yellowish brown (10YR4/6 moist); sandy clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and very few coarse pores; common very fine and fine, few medium roots; presence of open boreholes, earthworms, termites, ants and other insects; gradual and irregular boundary to horizon above.

2b. Analytical laboratory data of profile pit No. KEN002; Segbwema series

Horizon (cm)	Unit	0-34	34-115	115-152
Sand	%	74.80	68.80	64.80
Silt	%	2.36	2.36	4.36
Clay	%	22.84	28.84	30.84
Organic Carbon	%	1.83	1.04	0.60
Bray P1	mg/kg soil	15.92	13.57	11.81
pH 1:1 soil : water ratio		3.60	4.00	4.10
pH 1:1 M KCl ratio		3.30	3.40	3.50
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	2.83	7.23	3.68
Exchangeable calcium	mg/kg soil	0.26	2.24	1.49
Exchangeable magnesium	mg/kg soil	0.46	1.42	0.4
Exchangeable potassium	mg/kg soil	0.12	0.28	0.22
Exchangeable sodium	mg/kg soil	0.11	0.36	0.26
Exchangeable acidity	cmol/kg soil	1.88	2.93	1.31
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	21.00	6.00	6.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	5.24	4.94	1.95
DTPA extractable copper (mg kg^{-1})	mg/kg soil	411.20	4.10	4.99
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	21.48	6.56	5.36

3a. Soil profile description of profile pit No. KEN003; Vaahun series

District: Kenema; **Chiefdom**: Nongowa; **Village**: Potehun; **GPS location**: 7.96125°/11.07010°; **Elevation**: 180m; **Physiography**: Undulating plain; L**andform/facet**: Dissected plain; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 6.5 %; **Vegetation**: Tree crops; **Erosion class and intensity**:e1, slight; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 150cm; **Moisture:** Surface is dry up to 86cm but moist beyond this layer; **Landuse**: Plantation agroforestry; **Major crops grown**: Coffee, cocoa, kola nut, citrus, avogadro, mangoes and banana.

Land System: Kailahun

Classification : USDA Taxonomy: Plinthic haplorthox **FAO-UNESCO:** Orthic Ferralsol

Mapping Unit: KEN003 Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ah (0 – 32)	Reddish gray (5YR5/2 dry) and dark reddish gray (5YR4/2 moist); sandy loam; moderate, coarse, crumbly; slightly hard (dry), friable (moist); non sticky and non-plastic; common very fine, fine and medium, and few coarse pores; common very fine, plenty fine, few medium, and coarse roots; presence of earthworms, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bv1 (32 – 64)	Yellowish red (5YR 5/6 dry) and yellowish red (5YR4/6 moist); very gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and plenty coarse pores; common very fine, plenty fine, and few medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Bv2 (64 – 117+)	Reddish brown (5YR5/4 dry) and reddish brown (5YR4/4 moist); very gravelly sandy clay; strong, medium, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and few coarse pores; common very fine, plenty fine, few medium, very few coarse roots; presence of earthworms, termites, ants and other insects; presence of a boulder at 117+cm; gradual and irregular boundary to horizon below.

3b. Analytical laboratory data of profile pit No. KEN003; Vaahun series

Horizon (cm)	Unit	0-32	32-64	64-117
Sand	%	72.80	64.80	66.80
Silt	%	4.36	5.08	5.08
Clay	%	22.84	30.12	28.12
Organic Carbon	%	0.84	0.44	0.28
Bray P1	mg/kg soil	15.77	11.23	6.68
pH 1:1 soil : water ratio		4.50	5.30	5.40
pH 1:1 M KCl ratio		3.50	3.60	3.60
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	5.04	3.61	3.68
Exchangeable calcium	mg/kg soil	2.83	1.86	2.05
Exchangeable magnesium	mg/kg soil	0.36	0.06	0.38
Exchangeable potassium	mg/kg soil	0.33	0.25	0.27
Exchangeable sodium	mg/kg soil	0.43	0.31	0.34
Exchangeable acidity	cmol/kg soil	1.09	1.13	0.64
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	11.00	3.00	57.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	2.728	3.048	2.42
DTPA extractable copper (mg kg^{-1})	mg/kg soil	5.216	6.00	6.22
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	4.77	5.96	4.17

__4a.__ Soil profile description of profile pit No. KEN004; Fanima series

District: Kenema; **Chiefdom**: Small-Bo; **Village**: Fabaina; **GPS location**: 7.87786°/11.26380°; **Elevation**: 252m; **Physiography**: Interior plain; La**ndform/facet**: Interfluve crest; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 2.5 %; **Vegetation**: Deciduous and semi-deciduous trees and shrubs; **Erosion class and intensity**:e3, severe; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 400cm; **Moisture:** Profile is dry throughout; **Landuse**: Bush regrowth under fallow shifting cultivation; **Major crops grown**: None.

Land System: Blama

Classification : USDA Taxonomy: Plinthic haplorthox **FAO-UNESCO:** Orthic Ferralsol

Mapping Unit: KEN004 Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ah (0 – 29)	Weak red (7.5R5/3dry) and weak red (7.5R4/3 moist); sandy loam; moderate, fine, crumbly; loose (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium pores; plenty very fine and fine roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bt (29 – 126)	Red (7.5R5/6 dry) and red (7.5R4/6 moist); gravelly sandy clay; moderate, coarse, crumbly; loose (dry), friable (moist); not sticky and not plastic; few fine and plenty medium and coarse pores; few very fine and fine roots; presence of plinthite stones and boulders, termites, ants and other insects; clear and wavy boundary to horizon above.

4b. Analytical laboratory data of profile pit No. KEN004; Fanima series

Horizon (cm)	**Unit**	**0-29**	**29-126**
Sand	%	74.80	74.80
Silt	%	11.08	9.08
Clay	%	14.12	16.12
Organic Carbon	%	2.96	0.20
Bray P1	mg/kg soil	15.48	7.70
pH 1:1 soil : water ratio		4.20	4.60
pH 1:1 M KCl ratio		3.40	3.30
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	6.66	4.27
Exchangeable calcium	mg/kg soil	2.91	2.27
Exchangeable magnesium	mg/kg soil	1.77	0.22
Exchangeable potassium	mg/kg soil	0.34	0.29
Exchangeable sodium	mg/kg soil	0.44	0.36
Exchangeable acidity	cmol/kg soil	1.20	1.13
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	10.00	5.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	5.25	4.46
DTPA extractable copper (mg kg^{-1})	mg/kg soil	0.10	5.89
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	14.68	4.77

5a. Soil profile description of profile pit No. KEN005; Waiima series

District: Kenema; **Chiefdom**: Small-Bo; **Village**: Serabu; **GPS location**: 7.85756°/11.28506°; **Elevation**: 106m; **Physiography**: Undulating plain; La**ndform/facet**: Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 5.8%; **Vegetation**: Plantation forestry; **Erosion class and intensity**:e3, severe; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 150cm; **Moisture:** Profile is dry up to 67cm but slightly moist beyond this layer; **Landuse**: Plantation; **Major crops grown**: Oil palm.

Land System: Blama

Classification : USDA Taxonomy: Plinthic paleudult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KEN005
Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ah (0 – 27)	Light brown (7.5YR6/4 dry) and brown (7.5YR5/4 moist); loamy sand; moderate, fine, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium pores; plenty very fine, fine, very few coarse roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bv1 (27 – 56)	Strong brown (7.5YR5/6 dry) and brown (7.5YR4/4 moist); gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty fine, medium, coarse pores; plenty very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Bv2 (56 – 77)	Strong brown (7.5YR5/6 dry) and brown (7.5YR4/4 moist); very gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; few fine and plenty medium and coarse pores; common very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Cr (77 – 157+)	Strong brown (7.5YR5/6 dry) and brown (7.5YR4/4 moist); gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; few fine and plenty medium and coarse pores; very few very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.

5b. Analytical laboratory data of profile pit No. KEN005; Waiima series

Horizon (cm)	Unit	0-27	27-56	56-77	77-157+
Sand	%	70.80	74.80	80.80	80.80
Silt	%	4.36	2.36	4.36	2.36
Clay	%	24.84	22.84	14.84	16.84
Organic Carbon	%	1.71	0.64	0.56	0.40
Bray P1	mg/kg soil	14.97	14.45	16.14	13.79
pH 1:1 soil : water ratio		4.20	4.40	4.50	4.70
pH 1:1 M KCl ratio		3.60	3.50	3.50	3.60
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	2.40	1.84	3.17	2.80
Exchangeable calcium	mg/kg soil	0.52	0.08	0.18	0.17
Exchangeable magnesium	mg/kg soil	0.44	0.25	1.69	1.48
Exchangeable potassium	mg/kg soil	0.14	0.11	0.11	0.11
Exchangeable sodium	mg/kg soil	0.14	0.09	0.10	0.10
Exchangeable acidity	cmol/kg soil	1.16	1.31	1.09	0.94
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	57.00	4.00	2.00	4.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	4.14	5.40	2.73	0.00
DTPA extractable copper (mg kg^{-1})	mg/kg soil	3.99	4.21	4.32	3.76
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	4.77	8.95	4.77	0.77

6a. Soil profile description of profile pit No. KEN006; Baoma series

District: Kenema; **Chiefdom**: Small-Bo; **Village**: Serabu; **GPS location**: 7.87080°/11.27171°; **Elevation**: 131m; **Physiography**: Undulating plain; La**ndform/facet**: Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 6.6 %; **Vegetation**: Semi-deciduous trees and shrubs; **Erosion class and intensity**:e2, moderate; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 150cm; **Moisture:** Profile is dry throughout; **Landuse**: Bush regrowth under fallow shifting cultivation; **Major crops grown**: None.

Land System: Blama

Classification : USDA Taxonomy: Typic haplorthox **FAO-UNESCO:** Orthic Ferralsol

Mapping Unit: KEN006 Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ah (0 – 27)	Brown (10YR5/3dry) and brown (10YR4/3 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine and fine pores; plenty very fine and fine roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bt (27 – 49)	Yellowish brown (10YR5/6 dry) and dark yellowish brown (10YR4/6 moist); very gravelly sandy clay; strong, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; few fine and plenty medium and coarse pores; few very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Cr (49 – 152+)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); very gravelly sandy clay; strong, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; very few fine and plenty medium and coarse pores; very few very fine and fine roots; presence of plinthite glaebules having red colour 7.5YR5/8 moist (covering about 50% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon above.

6b. *Analytical laboratory data of profile pit No. KEN006; Baoma series*

Horizon (cm)	**Unit**	**0-27**	**27-49**	**56-152+**
Sand	%	72.80	58.80	54.80
Silt	%	7.08	5.08	3.08
Clay	%	20.12	36.12	42.12
Organic Carbon	%	2.75	1.71	0.88
Bray P1	mg/kg soil	11.96	6.46	5.06
pH 1:1 soil : water ratio		4.40	4.30	4.50
pH 1:1 M KCl ratio		3.30	3.20	3.30
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	5.58	6.53	5.83
Exchangeable calcium	mg/kg soil	3.17	2.76	2.20
Exchangeable magnesium	mg/kg soil	0.45	0.41	0.23
Exchangeable potassium	mg/kg soil	0.36	0.32	0.28
Exchangeable sodium	mg/kg soil	0.32	0.26	0.19
Exchangeable acidity	cmol/kg soil	1.28	2.78	2.93
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	7.00	9.00	21.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	3.20	3.83	1.31
DTPA extractable copper (mg kg^{-1})	mg/kg soil	610.0	32.03	7.00
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	12.53	4.17	10.74

7a. Soil profile description of profile pit No. KEN007; Pendembu series

District: Kenema; **Chiefdom**: Small-Bo; **Village**: Soko Town; **GPS location**: 7.86232°/11.22747°; **Elevation**: 140m; **Physiography**: Interior plain; La**ndform/facet**: Dissected plain; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 3 %; **Vegetation**: semi-deciduous dwarf shrubs; **Erosion class and intensity**:e2, moderate; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 150cm; **Moisture:** Profile is dry up to 86cm but moist beyond this layer; **Landuse**: Pegged area that has been acquired for construction of dwelling house; **Major crops grown**: None.

Land System: Kangari

Classification : USDA Taxonomy: Plinthaqiuc Paleudult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KEN024 Gravel-free soil (PLATE 007)	**Horizon (cm)**	**Morphological Description**
	Ah (0 – 31)	Light gray (2.5Y7/1dry) and gray (2.5Y6/1 moist); sandy loam; moderate, fine, crumbly/ angular and sub-angular blocky; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine and fine pores; plenty very fine and fine roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
	Bt1 (31 – 70)	Yellowish brown (10YR 5/4 dry) to yellow (2.5Y 7/6 moist); silty clay; moderate, fine, angular and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine, fine and medium pores; few very fine and fine roots; presence of termites, ants and other insects; clear and gradual boundary to horizon below.
	Bt2 (70 – 136)	Yellow (2.5Y7/6 dry) and olive yellow (2.5Y6/6 moist); silty clay; moderate, fine, angular and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine and medium pores; few very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
	Cg (136 – 174+)	Light yellowish brown (2.5Y6/4 dry) and light olive brown (2.5Y5/4 moist); silty clay; moderate, fine, angular and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine and medium pores; few very fine and fine roots; presence of faintly developed soft mottles having reddish yellow colour 7.5YR6/8 to 7.5YR6/8 moist (covering about 10-15% of soil mass), termites, ants and other insects; clear and gradual boundary to horizon above.

7b. Analytical laboratory data of profile pit No. KEN007; Pendembu series

Horizon (cm)	Unit	0-31	31-70	70-136	136-174+
Sand	%	80.80	70.80	66.80	84.80
Silt	%	2.36	4.36	2.36	2.36
Clay	%	16.84	24.84	30.84	12.84
Organic Carbon	%	1.56	1.28	0.56	0.48
Bray P1	mg/kg soil	21.50	16.29	18.27	12.69
pH 1:1 soil : water ratio		4.90	4.30	4.10	4.20
pH 1:1 M KCl ratio		4.10	3.40	3.30	3.40
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	9.44	6.87	6.85	4.23
Exchangeable calcium	mg/kg soil	6.05	3.73	1.94	1.64
Exchangeable magnesium	mg/kg soil	1.85	0.95	2.15	0.17
Exchangeable potassium	mg/kg soil	0.59	0.40	0.26	0.23
Exchangeable sodium	mg/kg soil	0.84	0.55	0.32	0.28
Exchangeable acidity	cmol/kg soil	0.11	1.24	2.18	1.91
Electrical conductivity(salinity) in 1:5 soil water ratio	μS/cm	13.00	3.00	7.00	9.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	4.46	4.93	1.94	0.84
DTPA extractable copper (mg kg^{-1})	mg/kg soil	7.79	7.34	4.32	5.22
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	11.34	17.3	10.74	10.14

__8a.__ Soil profile description of profile pit No. KEN008; Kparva series

District: Kenema; **Chiefdom**: Niawa; **Village**: Bondayillahun; **GPS location**: 7.78544°/11.36391°; **Elevation**: 107m; **Physiography**: Interior plain; La**ndform/facet**: Boliland/ toe slope; **Parent Material**: Weathered Residium; **Landscape position**: toe slope; **Slope**: 2 %; **Vegetation**: Rice fallow land; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Poorly/ imperfectly drained and slow permeability; **Ground water depth**: Above 60cm; **Moisture:** Profile is moist throughout; **Landuse**: Arable cropping; **Major crops grown**: Rice.

Land System: Blama

Classification : USDA Taxonomy: Plinthic paleudult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KEN008
Gravel-free soil

Horizon (cm)	Morphological Description
Aeg (0 – 61)	Light gray (2.5Y7/1 dry) and dark gray (2.5Y6/1 moist); silty clay loam; moderate, fine, angular and sub-angular blocky; very hard (dry), very firm (moist); very sticky and very plastic; plenty very fine and fine pores; plenty very fine, fine, few medium roots; presence of earthworms, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bwg (61 – 96)	Light gray (2.5Y7/2 dry) and dark gray (2.5Y6/2 moist); silty clay loam; moderate, fine, angular and sub-angular blocky; very hard (dry), very firm (moist); very sticky and very plastic; plenty very fine and fine pores; plenty very fine, fine, few medium roots; presence of earthworms, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Cg (96 – 143+)	Light yellowish brown (2.5Y6/3 dry) and light olive brown (2.5Y5/3 moist); silty clay; moderate, fine, angular and sub-angular blocky; very hard (dry), very firm (moist); very sticky and very plastic; plenty very fine, fine, and medium pores; plenty very fine and fine roots; presence of faintly developed soft mottles having reddish yellow colour 7.5YR6/6 moist (covering about 40-50% of soil mass), earthworms, ants and other insects; clear and wavy boundary to horizon below.

8b. *Analytical laboratory data of profile pit No. KEN008; Kparva series*

Horizon (cm)	**Unit**	**0-61**	**61-96**	**96-143+**
Sand	%	74.80	58.80	54.80
Silt	%	5.08	5.08	5.08
Clay	%	20.12	36.12	40.12
Organic Carbon	%	2.71	0.04	0.52
Bray P1	mg/kg soil	8.14	4.70	4.77
pH 1:1 soil : water ratio		4.20	4.50	50
pH 1:1 M KCl ratio		3.30	3.40	3.50
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	6.68	4.25	2.32
Exchangeable calcium	mg/kg soil	2.61	1.94	0.81
Exchangeable magnesium	mg/kg soil	0.58	0.09	0.01
Exchangeable potassium	mg/kg soil	0.31	0.26	0.17
Exchangeable sodium	mg/kg soil	0.25	0.16	0.02
Exchangeable acidity	cmol/kg soil	2.93	1.80	1.31
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	6.00	6.00	11.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	3.04	2.26	1.32
DTPA extractable copper (mg kg^{-1})	mg/kg soil	4.32	1.86	1.86
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	10.74	6.56	0.00

9a. Soil profile description of profile pit No. KEN009; Tisso series

District: Kenema; **Chiefdom**: Niawa; **Village**: Bondayillahun; **GPS location**: 7.78600°/11.36385°; **Elevation**: 110m; **Physiography**: Undulating plain; La**ndform/facet**: River flood plain; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 2.3 %; **Vegetation**: Semi-deciduous dwarf shrubs; **Erosion class and intensity**:e1, slight; **Drainage and permeability:** Moderately well drained and moderately slow; **Ground water depth**: Above 100cm; **Moisture:** Surface is dry up to 45cm but moist beyond this layer; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Rice, sesame, and groundnut.

Land System: Blama

Classification : USDA Taxonomy: Lithic hapludult **FAO-UNESCO:** Lithic Dystric Nitosol

Mapping Unit: KEN009 Gravel-free soil underlain by hard bedrock of sedimentary origin

Horizon (cm)	Morphological Description
Aeg (0 – 61)	Gray (2.5Y5/1 dry) and dark gray (2.5Y4/1 moist); sandy loam; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, few medium roots; presence of termites, millipedes, ants and other insects, occurrence of stones believed to have been deposited by colluvial processes; clear and wavy boundary to horizon below.
Btg (61 – 96)	Yellow (2.5Y7/6 dry) and olive yellow (2.5Y6/6 moist); silty clay; moderate, fine, angular and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, few medium roots; presence of faintly developed soft mottles having reddish yellow colour 7.5YR6/8 moist (covering about 40-50% of soil mass), earthworms, termites, ants and other insects; clear and wavy boundary to horizon below.
Cg (96 – 143+)	Yellowish brown (2.5Y6/8 dry) and dark yellowish brown (2.5Y5/6 moist); clay; moderate, coarse, angular and sub-angular blocky; very hard (dry), firm (moist); very sticky and very plastic; few very fine, fine and plenty medium, and coarse pores; common very fine, plenty fine, and few medium roots; presence of prominent mottles having strong brown colour 7.5YR4/6 moist (covering about 40-50% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon above.

9b. *Analytical laboratory data of profile pit No. KEN009; Tisso series*

Horizon (cm)	**Unit**	**0-61**	**61-96**	**96-143+**
Sand	%	74.80	68.80	70.80
Silt	%	7.08	5.08	3.08
Clay	%	18.12	26.12	26.12
Organic Carbon	%	1.67	0.76	0.28
Bray P1	mg/kg soil	13.65	7.19	5.87
pH 1:1 soil : water ratio		3.50	4.20	4.40
pH 1:1 M KCl ratio		3.30	3.40	3.50
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	6.80	5.58	5.32
Exchangeable calcium	mg/kg soil	2.09	2.09	2.57
Exchangeable magnesium	mg/kg soil	2.27	1.84	0.92
Exchangeable potassium	mg/kg soil	0.27	0.27	0.31
Exchangeable sodium	mg/kg soil	0.18	0.18	0.24
Exchangeable acidity	cmol/kg soil	1.99	1.20	1.28
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	3.00	14.00	5.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	5.41	2.74	0.85
DTPA extractable copper (mg kg^{-1})	mg/kg soil	1.20	0.10	4.10
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	10.14	21.48	6.86

__10a.__ Soil profile description of profile pit No. KEN010; Ngelehun series

District: Kenema; **Chiefdom**: Niawa; **Village**: Gbandi; **GPS location**: 7.77025°/11.33735°; **Elevation**: 140m; **Physiography**: Undulating plain; La**ndform/facet**: Alluvial plain; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 2.3%; **Vegetation**: Forest regrowth with deciduous and semi-deciduous trees and shrubs; **Erosion class and intensity**:e1, slight; **Drainage and permeability:** Poorly/ imperfectly drained and slow; **Ground water depth**: Above 125cm; **Moisture:** Profile is moist throughout; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Rice, sesame, maize, and groundnut.

Land System: Bo

Classification : USDA Taxonomy: Plinthic Ferralsol **FAO-UNESCO:** Plinthic haplorthox

Mapping Unit: KEN010 Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ah (0 – 30)	Gray (2.5Y5/1 dry) and dark gray (2.5Y4/1 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); non sticky and non-plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, few medium, and very few coarse roots; presence of earthworms, few burrows, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Btg1 (30 – 59)	Light brownish brown (2.5Y6/2 dry) and grayish brown (2.5Y5/2 moist); sandy clay loam; strong, fine, crumbly and sub-angular blocky; slightly hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine, fine, and medium pores; plenty very fine, fine, medium roots; presence of worm casts, termites, ants and other insects; clear and wavy boundary to horizon above.
Btg2 (59 – 138)	Pale brown (2.5Y7/3 dry) and light yellowish brown (2.5Y6/3 moist); sandy clay; strong, fine, angular and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, medium pores; plenty very fine and fine, few medium roots; presence of faintly developed soft mottles having reddish yellow colour 7.5YR6/8 to 7.5YR6/8 moist (covering about 15-30% of soil mass), burrows vesicular in shape and network, termites, ants and other insects; clear and wavy boundary to horizon above.
Cssg (138 – 164+)	Pale brown (2.5Y7/4 dry) and light yellowish brown (2.5Y6/4 moist); sandy clay; strong, coarse, angular and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, medium, few coarse pores; plenty very fine and fine, few medium roots; presence of prominent mottles (almost becoming plinthite glaebules) having strong brown colour 7.5YR5/8 to 7.5YR4/6 moist (covering about 15-40% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon above.

10b. *Analytical laboratory data of profile pit No. KEN010; Ngelehun series*

Horizon (cm)	**Unit**	**0-30**	**30-59**	**59-138**	**138-164+**
Sand	%	72.80	70.80	70.80	66.80
Silt	%	7.08	3.08	5.08	3.08
Clay	%	20.12	26.12	24.12	30.12
Organic Carbon	%	1.00	0.68	0.88	0.56
Bray P1	mg/kg soil	15.63	9.83	14.53	10.27
pH 1:1 soil : water ratio		4.70	4.60	4.50	4.70
pH 1:1 M KCl ratio		3.40	3.30	3.30	3.30
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	5.77	6.30	4.96	7.23
Exchangeable calcium	mg/kg soil	3.02	2.42	2.38	3.13
Exchangeable magnesium	mg/kg soil	0.70	1.56	0.53	1.89
Exchangeable potassium	mg/kg soil	0.35	0.30	0.29	0.36
Exchangeable sodium	mg/kg soil	0.46	0.22	0.22	0.31
Exchangeable acidity	cmol/kg soil	1.24	1.80	1.54	1.54
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	4.00	2.00	4.00	8.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	3.2	3.04	2.41	1.31
DTPA extractable copper (mg kg^{-1})	mg/kg soil	6.22	3.99	4.21	4.99
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	9.54	7.75	8.95	27.46

__11a.__ Soil profile description of profile pit No. KEN011; Yumbuma series

District: Kenema; **Chiefdom**: Small-Bo; **Village**: Serabu; **GPS location**: 7.8815°/11.28560°; **Elevation**: 112m; **Physiography**: Undulating plain; **Landform/facet**: Boliland/ Alluvial plain; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 2 %; **Vegetation**: Semi-deciduous dwarf shrubs; **Erosion class and intensity**:e0, Nil; **Drainage and permeability:** Imperfectly/ poorly drained and slow; **Ground water depth**: Below 120cm; **Moisture:** Profile is moist throughout; **Landuse**: Lowland rice cultivation and vegetable cropping; **Major crops grown**: Rice, sweet potato, chili, sour-sour.

Land System: Blama

Classification : USDA Taxonomy: Plinthic paleudult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KEN011 Gravel-free soil	**Horizon (cm)**	**Morphological Description**
	Ag (0 – 22)	Light gray (2.5Y7/2 dry) and light brownish gray (2.5Y6/2 moist); silty sand; strong, fine, angular and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, and medium pores; plenty very fine and fine roots; presence of earthworms and worm casts, vesicular burrows, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
	Btg (22 – 72)	Pale brown (2.5Y7/3 dry) and light yellowish brown (2.5Y6/3 moist); silty clay; strong, fine, angular and sub-angular blocky; very hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, and medium pores; plenty very fine and fine roots; presence of faintly developed soft mottles having reddish yellow colour 7.5YR6/8 to 7.5YR6/8 moist (covering about 2-5% of soil mass), earthworms and vesicular burrows, termites, ants and other insects; clear and wavy boundary to horizon below.
	Bssk (72 – 101)	Olive yellow (2.5Y6/6 dry) and light olive yellow (2.5Y5/6 moist); clay; strong, fine, angular and sub-angular blocky; extremely hard (dry), very firm (moist); very sticky and very plastic; plenty very fine and fine pores; plenty very fine and fine roots; presence of faintly developed soft mottles having reddish yellow colour 7.5YR6/8 to 7.5YR6/8 moist (covering about 15-20% of soil mass), slickensides/ pressure faces, earthworms and worm casts, termites, ants and other insects; clear and wavy boundary to horizon below.
	Cssk (101 – 152+)	Olive yellow (2.5Y6/6 dry) and light olive yellow (2.5Y5/6 moist); clay; strong, fine, angular and sub-angular blocky; extremely hard (dry), very firm (moist); very sticky and very plastic; plenty very fine and fine pores; plenty very fine and fine roots; presence of faintly developed soft mottles having reddish yellow colour 7.5YR6/8 to 7.5YR6/8 moist (covering about 30-40% of soil mass), slickensides/ pressure faces, earthworms, termites, ants and other insects; clear and wavy boundary to horizon below.

11b. *Analytical laboratory data of profile pit No. KEN011; Yumbuma series*

Horizon (cm)	**Unit**	**0-22**	**22-72**	**72-101**	**101-152+**
Sand	%	74.80	70.80	70.80	68.80
Silt	%	7.08	5.08	3.08	5.08
Clay	%	18.12	24.12	26.12	26.12
Organic Carbon	%	1.44	1.04	0.56	5.74
Bray P1	mg/kg soil	15.55	13.79	15.26	5.21
pH 1:1 soil : water ratio		4.50	4.50	4.60	4.90
pH 1:1 M KCl ratio		3.40	3.40	3.40	3.40
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	8.50	2.15	4.05	4.50
Exchangeable calcium	mg/kg soil	3.97	0.34	1.86	1.56
Exchangeable magnesium	mg/kg soil	2.60	0.52	0.36	1.29
Exchangeable potassium	mg/kg soil	0.42	0.13	0.25	0.23
Exchangeable sodium	mg/kg soil	0.42	0.00	0.15	0.11
Exchangeable acidity	cmol/kg soil	1.09	1.16	1.43	1.31
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	5.00	3.00	13.00	3.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	1.31	1.78	1.31	1.27
DTPA extractable copper (mg kg^{-1})	mg/kg soil	4.77	3.99	4.32	5.44
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	21.48	7.16	5.36	7.16

12a. Soil profile description of profile pit No. KEN012; Keya series

District: Kenema; **Chiefdom**: Small-Bo; **Village**: Serabu; **GPS location**: 7.86751°/11.27911°; **Elevation**: 128m; **Physiography**: Undulating plain; La**ndform/facet**: Interfluve lower slope; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 2 %; **Vegetation**: Semi-deciduous dwarf shrubs; **Erosion class and intensity**:e0, Nil; **Drainage and permeability:** Imperfectly/ poorly drained and slow; **Ground water depth**: Below 100cm; **Moisture:** Profile is moist throughout; **Landuse**: Fallow land under tree cropping; **Major crops grown**: Oil palm.

Land System: Blama

Classification : USDA Taxonomy: Plinthic paleudult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KEN012 Gravel-free soil underlain by a hard bedrock

Horizon (cm)	Morphological Description
Aeg (0 – 30)	Gray (5Y6/1dry) and olive gray (5Y5/1 moist); sandy clay loam; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; plenty very fine and fine pores; plenty very fine and fine roots; presence of earthworms and worm casts, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bg (30 – 94+)	Light gray (5Y7/1dry) and gray (5Y6/1 moist); sandy clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), firm (moist); sticky and plastic; plenty very fine and fine pores; common very fine and fine roots; presence of earthworms and worm casts, termites, ants and other insects; clear and gradual boundary to horizon below.
Cg (94 – 117+)	Light gray (5Y7/1dry) and gray (5Y6/1 moist); gravelly sandy clay; moderate, medium, angular and sub-angular blocky; slightly hard (dry), firm (moist); sticky and plastic; plenty very fine and fine pores; few very fine and fine roots; presence of earthworms and worm casts, termites, ants and other insects; clear and gradual boundary to horizon above.

12b. Analytical laboratory data of profile pit No. KEN012; Keya series

Horizon (cm)	**Unit**	**0-30**	**30-94**	**94-117+**
Sand	%	76.80	70.80	68.80
Silt	%	3.08	3.08	3.08
Clay	%	20.12	26.12	28.12
Organic Carbon	%	2.00	1.20	0.84
Bray P1	mg/kg soil	10.95	8.66	7.47
pH 1:1 soil : water ratio		4.20	4.40	4.80
pH 1:1 M KCl ratio		3.40	3.40	3.50
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	8.37	8.87	3.26
Exchangeable calcium	mg/kg soil	1.64	1.90	0.05
Exchangeable magnesium	mg/kg soil	2.99	2.84	0.48
Exchangeable potassium	mg/kg soil	0.23	0.25	0.10
Exchangeable sodium	mg/kg soil	0.28	0.32	0.08
Exchangeable acidity	cmol/kg soil	3.23	3.56	2.55
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	21.00	4.00	9.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	3.21	1.79	1.32
DTPA extractable copper (mg kg^{-1})	mg/kg soil	9.63	5.31	5.95
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	4.76	1.08	1.26

__13a.__ Soil profile description of profile pit No. KEN013; Manowa series

District: Kenema; **Chiefdom**: Kandu Leppiama; **Village**: Nafamie; **GPS location**: 7.98967°/11.333361°; **Elevation**: 135m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 4 %; **Vegetation**: Bush regrowth with grasses; **Erosion class and intensity**:e3, severe; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 160cm; **Moisture:** Profile is dry throughout; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Pineapple.

Land System: Blama

Classification : USDA Taxonomy: Orthoxic palehumult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KEN013
Gravelly soil

Horizon (cm)	Morphological Description
Ap (0 – 36)	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist); gravelly sandy loam; moderate, coarse, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty fine, medium, coarse pores; plenty very fine and fine roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bv1 (36 – 65)	Yellowish brown (10YR 5/4 dry) and dark yellowish brown (10YR4/4 moist); gravelly sandy clay loam; moderate, coarse, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium, very few coarse pores; plenty very fine, fine, few medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Bv2 (69 – 151+)	Yellowish brown (10YR 5/6 dry) and dark yellowish brown (10YR4/6 moist); gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; few very fine, fine and plenty medium, and coarse pores; common very fine, plenty fine, and few medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.

***13b.** Analytical laboratory data of profile pit No. KEN013; Manowa series*

Horizon (cm)	**Unit**	**0-36**	**36-65**	**65-151+**
Sand	%	82.80	78.80	78.80
Silt	%	1.08	3.08	1.08
Clay	%	16.12	18.12	20.12
Organic Carbon	%	1.36	0.68	0.20
Bray P1	mg/kg soil	13.76	15.39	20.94
pH 1:1 soil : water ratio		3.60	4.20	4.60
pH 1:1 M KCl ratio		3.40	3.50	3.50
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	6.50	7.09	4.26
Exchangeable calcium	mg/kg soil	1.08	0.97	0.08
Exchangeable magnesium	mg/kg soil	1.27	2.85	1.32
Exchangeable potassium	mg/kg soil	0.19	0.18	0.11
Exchangeable sodium	mg/kg soil	0.21	0.20	0.09
Exchangeable acidity	cmol/kg soil	3.75	2.89	2.66
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	27.00	29.00	7.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	3.21	10.14	4.77
DTPA extractable copper (mg kg^{-1})	mg/kg soil	5.23	2.42	3.65
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	5.36	7.16	12.53

14a. Soil profile description of profile pit No. KEN014; Momenga series

District: Kenema; **Chiefdom**: Small-Bo; **Village**: Serabu; **GPS location**: 7.86579°/11.28124°; **Elevation**: 127m; **Physiography**: Undulating plain; La**ndform/facet**: Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 4.1 %; **Vegetation**: Semi-deciduous trees and shrubs; **Erosion class and intensity**:e3, severe; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 150cm; **Moisture:** Profile is dry throughout; **Landuse**: Farmbush under fallow shifting cultivation; **Major crops grown**: None on present land but a cassava farm adjacent.

Land System: Blama

Classification : USDA Taxonomy: Plpnthic dystropept **FAO-UNESCO:** Ferallic Nitrosol

Mapping Unit: KEN014
Gravelly soil

Horizon (cm)	Morphological Description
Ap (0 – 31)	Gray (10YR6/1dry) and gray (10YR5/1 moist); loamy sand; moderate, fine, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium pores; plenty very fine and fine roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bv (31 – 67)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); gravelly sandy clay loam; moderate, coarse, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty fine, medium, coarse pores; common very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Btv (67 – 152+)	Brownish yellow (10YR6/8 dry) and yellowish brown (10YR5/6 moist); very gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; few fine and plenty medium and coarse pores; few very fine and fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon above.

14b. *Analytical laboratory data of profile pit No. KEN014; Momenga series*

Horizon (cm)	**Unit**	**0-31**	**31-67**	**67-152+**
Sand	%	70.80	70.80	66.80
Silt	%	7.08	5.08	5.08
Clay	%	22.12	24.12	28.12
Organic Carbon	%	2.03	1.56	1.04
Bray P1	mg/kg soil	9.24	6.88	4.66
pH 1:1 soil : water ratio		4.00	4.70	4.60
pH 1:1 M KCl ratio		3.50	3.60	3.60
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	4.34	8.70	6.54
Exchangeable calcium	mg/kg soil	0.46	2.42	2.95
Exchangeable magnesium	mg/kg soil	2.93	2.56	0.32
Exchangeable potassium	mg/kg soil	0.14	0.3	0.34
Exchangeable sodium	mg/kg soil	0.13	0.38	0.45
Exchangeable acidity	cmol/kg soil	0.68	3.04	2.48
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	42.00	15.00	11.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	15.80	4.90	1.90
DTPA extractable copper (mg kg^{-1})	mg/kg soil	211.00	2.00	150.00
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	8.35	5.36	5.36

15a. Soil profile description of profile pit No. KEN015; Njala sloping series

District: Kenema; **Chiefdom**: Kandu Leppiama; **Village**: Nafamie; **GPS location**: 7.99034°/11.33392°; **Elevation**: 141m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain; **Parent Material**: Weathered Residium; **Landscape position**: Summit/ crest; **Slope**: 4 %; **Vegetation**: Bush regrowth with grasses; **Erosion class and intensity**:e3, severe; **Drainage and permeability:** Well drained and rapid; **Ground water depth**: Above 160cm; **Moisture:** Profile is dry throughout; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Pineapple.

Land System: Blama

Classification : USDA Taxonomy: Orthoxic Palehumult **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KEN015
Gravelly soil

Horizon (cm)	Morphological Description
Ap (0 – 35)	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist); gravelly sandy loam; moderate, coarse, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; few fine, medium, plenty coarse pores; plenty very fine, fine and few medium roots; presence of termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bv1 (35 – 69)	Yellowish brown (10YR 5/4 dry) and dark yellowish brown (10YR4/4 moist); gravelly sandy clay loam; moderate, coarse, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium, very few coarse pores; plenty very fine, fine, few medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Bv2 (69 – 151+)	Yellowish brown (10YR 5/6 dry) and dark yellowish brown (10YR4/6 moist); gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; few very fine, fine and plenty medium, and coarse pores; common very fine, plenty fine, and few medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.

15b. *Analytical laboratory data of profile pit No. KEN015; Momenga series*

Horizon (cm)	**Unit**	**0-35**	**35-69**	**69-151+**
Sand	%	84.80	78.80	74.80
Silt	%	5.08	1.08	1.08
Clay	%	10.12	20.12	24.12
Organic Carbon	%	2.57	0.88	0.68
Bray P1	mg/kg soil	11.47	13.39	0.00
pH 1:1 soil : water ratio		5.10	5.00	5.80
pH 1:1 M KCl ratio		4.30	4.20	4.20
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	3.63	4.28	2.65
Exchangeable calcium	mg/kg soil	1.01	0.51	0.33
Exchangeable magnesium	mg/kg soil	1.94	3.15	1.69
Exchangeable potassium	mg/kg soil	0.18	0.14	0.13
Exchangeable sodium	mg/kg soil	0.20	0.14	0.12
Exchangeable acidity	cmol/kg soil	0.30	0.34	0.38
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	74.00	5.00	4.00
DTPA extractable iron (mg kg^{-1})	mg/kg soil	5.96	4.77	6.56
DTPA extractable copper (mg kg^{-1})	mg/kg soil	4.10	3.65	2.65
DTPA extractable zinc (mg kg^{-1})	mg/kg soil	10.74	10.74	6.56