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 Kailahun district, which is in the Eastern Region, and borders Kenema district to the northwest and southwest, the Republic of Liberia to the southeast and northwest, and Kono district to the north. Its capital and largest city is Kailahun, which is the least populated district in the eastern region. The district is comprised of 14 chiefdoms including Dea, Jahn, Jawie, Kissi Kama, Kissi Teng, Kissi Tongi, Kpeje Bongre, Luawa, Malema, Mandu, Njaluahun, Penguia, Upper Bambara and Yawei chiefdoms. The economy of the district is largely based on farming and trade.

The climate is tropical with two pronounced seasons: the rainy season from May to October and dry season from November to April. Rainfall is highest in the coastal areas, with annual rainfall ranging from 3350 mm in Kissi Kama, Kissi Teng and Kissi Tongi chiefdoms in the northeast to 3820 mm in Jawei and Njaluahun chiefdoms 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 granite/greenstone complex comprising of a series of iron and magnesium-rich rocks metamorphosed to the amphibolite facies (Sula Group) over a quartz-rich basement of granitic composition (Williams, 1978). The grade of metamorphism in the basement tends to increase towards the Sula Group boundary giving rise to local occurrences of Nimini Hills and Kambui Hills Groups and the Mano-Moa granulite formation. So-called Younger granite was intruded after the most intense period of deformation at about 2.7 ma ago and occurs around the margins of the Sula Group.

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 indicate that 2984.5 km^2 (71.9 %) of the land area is arable and 1166.7 km^2 (28.1 %) is non-arable. Four land capability classes were identified and mapped, ranging from soils suited for cultivation with moderate limitations or risks of damage from floods to soils that have severe limitations that restrict their use to grazing and forestry. Malema-Manowa-Gbeika soil association, belonging to land capability class (LCC) III, which are located on upland eroded surfaces occupy the largest area (2879.7 km^2), followed by Pendembu-Moa soil association (70.1 km^2) which soil belonging to LCC I and are located on bottomland swamps and stream terraces, Misila-Gombi-Mayengbema soil association (31.1 km^2), belonging to LCC II, which are soils located on colluvial footslopes and upper river tributary terraces and the least is the Madina-Bandajuma soil association (3.6 km^2), belonging to LCC IV, which are soils located on sloping terrains.

Soil suitability analysis indicates that high soil acidity, low cation exchange capacity (CEC), steep and moderate slopes, high gravel content, low water-holding capacity, coarse texture, and poor drainage (in some cases) are the key limiting factors in over 90 percent of cases that render the soils somehow unsuitable for the optimal production of the target crops under improved farmer management systems. Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa soils are moderately suitable (S2) for rainfed upland rice; Pendembu and Moa soils are moderately suitable (S2) for natural flooded and irrigated rice. For other food crops, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema soils are highly suitable (S1) for cassava, and Misila, Gombi, Mayengbema are high suitable (S1) for sweet potato, while Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa soils are moderately suitable (S2) for cassava, maize, sweet potato, groundnut and cowpea. For tree crops, Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema soils are moderately suitable (S2) for cocoa, Arabica coffee, Robusta coffee, cashew and oil palm while for fruit tree, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa soils are moderately suitable (S2) for mango, citrus, pineapple and banana. For vegetables, Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa soils are moderately suitable (S2) for onion, tomato, cabbage and carrot.

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.

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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 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 (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) from a reconnaissance land resources survey, 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 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).

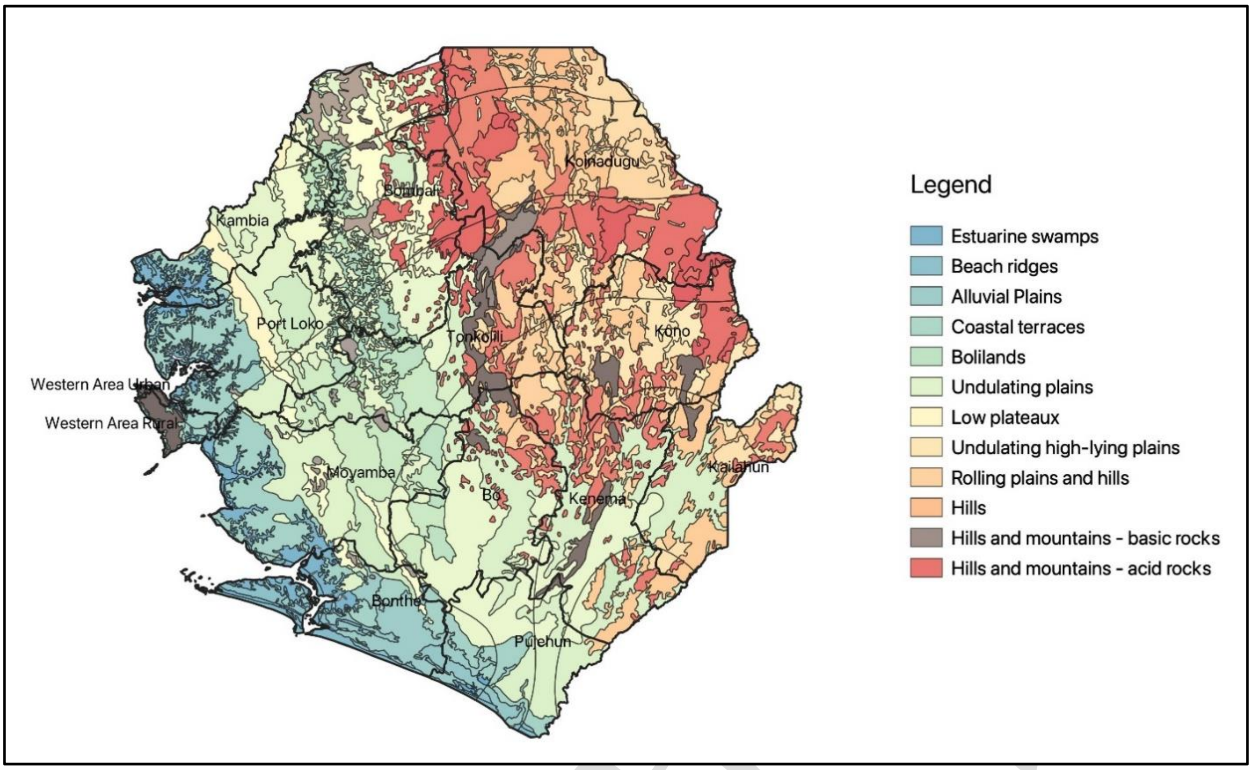

Figure 1. Land systems map of Sierra Leone (UNDP/FAO, 1979)

Table 1. *Land regions, sub regions and systems of Sierra Leone presented and described in the 1979 Reconnaissance Survey of Sierra Leone*

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 – spanning from well drained shallow soils on hill tops down 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.

Kailahun 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, colluvial footslopes and upper river tributary terraces, and bottomland swamps and stream terraces from which 10 major soil series occurred including Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu and Moa series. The semi-detailed soil survey work of Veldkamp (1980), Sutton et al (1980) and Odell et al (1974) 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 Policy and Plans, Sierra Leone Soils, and the National Comprehensive Soil Survey

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 MAF 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.

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2 How to use this report

This section explains to readers how the soil survey report of the Kailahun 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.

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3 Geographical context

3.1 Location

Kailahun District is located on Longitude 10.255W to 11.085W and Latitude 7.575N to 8.525N in the Eastern Province of Sierra Leone. It is bordered by Kenema district to the northwest and southwest, the Republic of Liberia to the southeast and northwest, and Kono district to the north. Its capital and largest city is Kailahun, which is the least populated district in the eastern region with a population of 550,432 (STATSL, 2022). Other major towns in the district include Madina, Koindu, Pendembu and Daru. The district has an area of 6,053 km^2 and is comprised of 14 chiefdoms including Dea, Jahn, Jawie, Kissi Kama, Kissi Teng, Kissi Tongi, Kpeje Bongre, Luawa, Malema, Mandu, Njaluahun, Penguia, Upper Bambara and Yawei chiefdoms (Figure 2). The economy of the district is largely based on farming and trade.

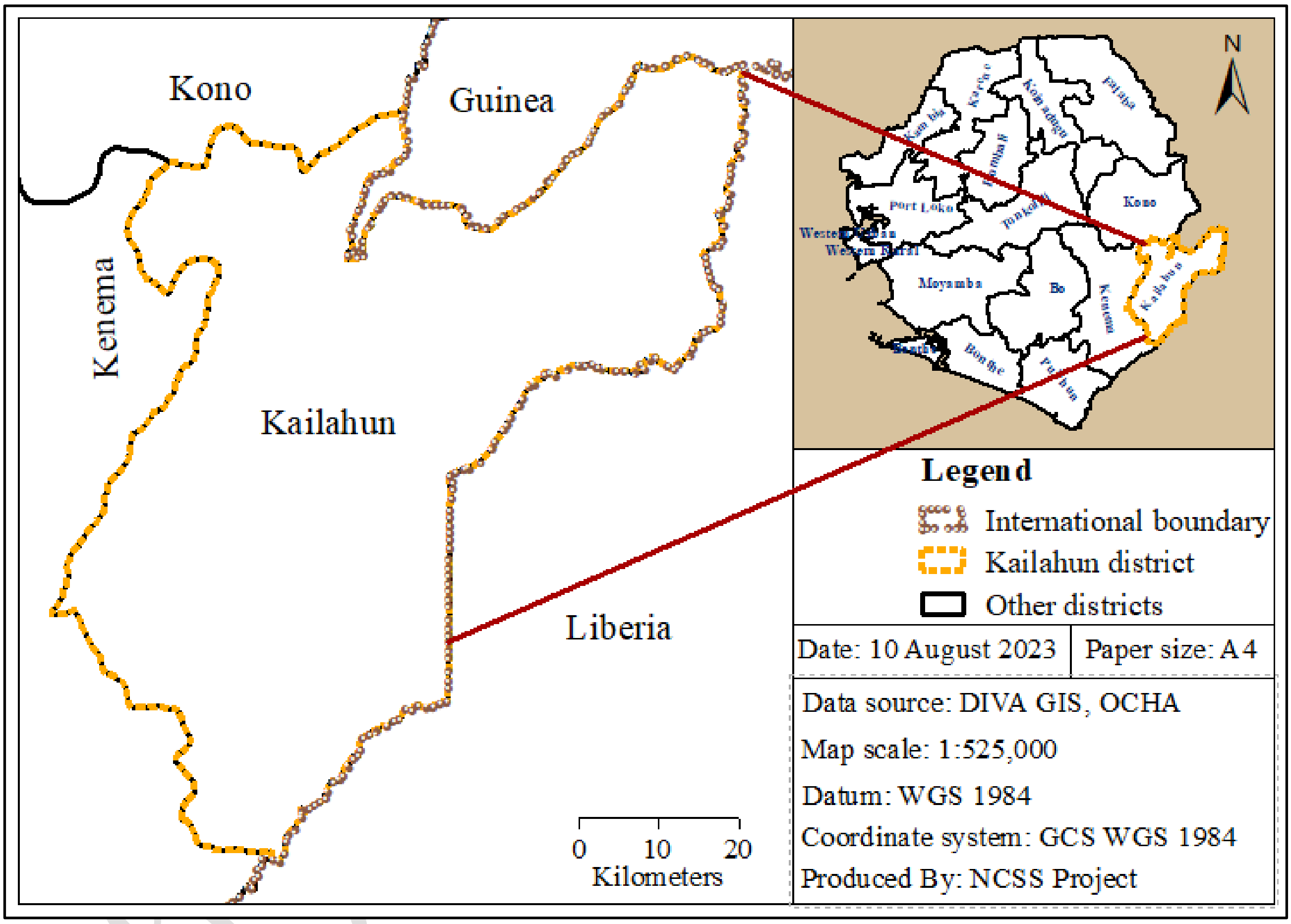

Figure 2. *Location map of Kailahun District*

3.2 Climate

The climate is tropical with two distinct seasons, namely rainy season (May to October) and dry season (November to April). The annual rainfall ranges from 3350 mm in Kissi Kama, Kissi Teng and Kissi Tongi chiefdoms neighboring Guinea in the southeast to 3820 mm in Jawei and Njaluahun chiefdoms 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 31.4°C to 32.25°C during the year but may rise to a maximum of 34°C especially in March, the driest month (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.

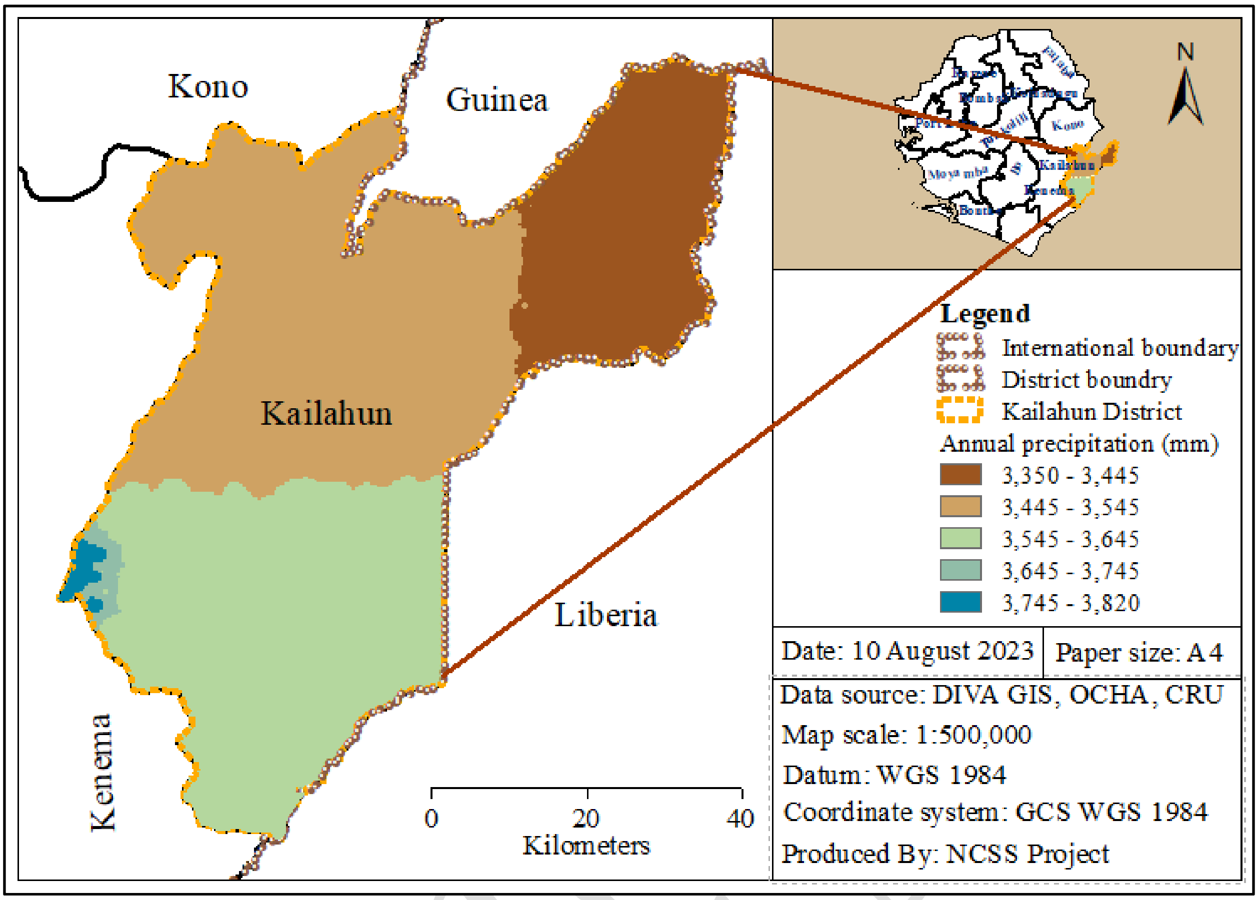

Figure 3. *Annual Rainfall distribution in Kailahun District (2021)*

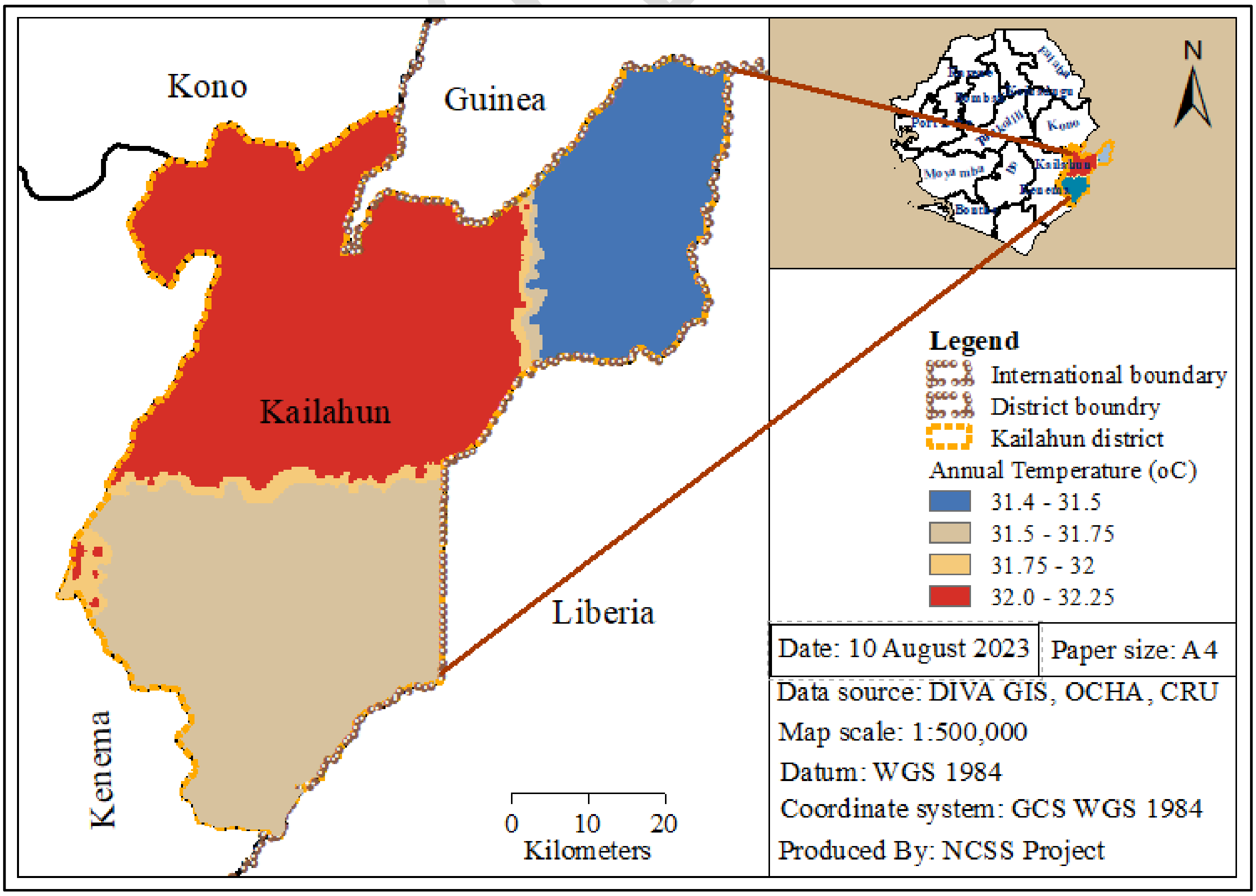

Figure 4. *Annual Temperature distribution in Kailahun District (2021)*

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

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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

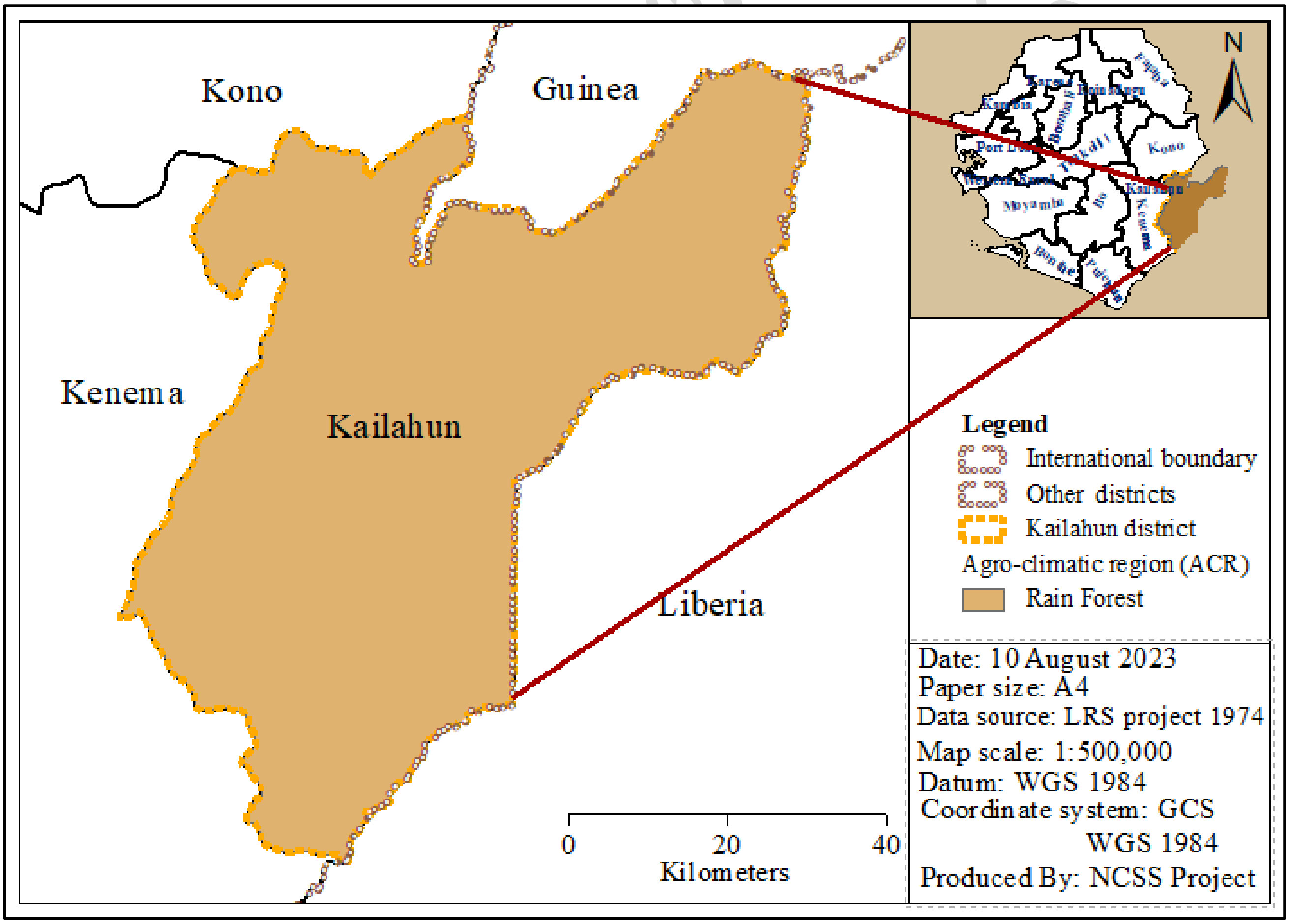

***Figure 5.** Agro-climatic regions of Kailahun District (Adapted from UNDP/FAO 1979)*

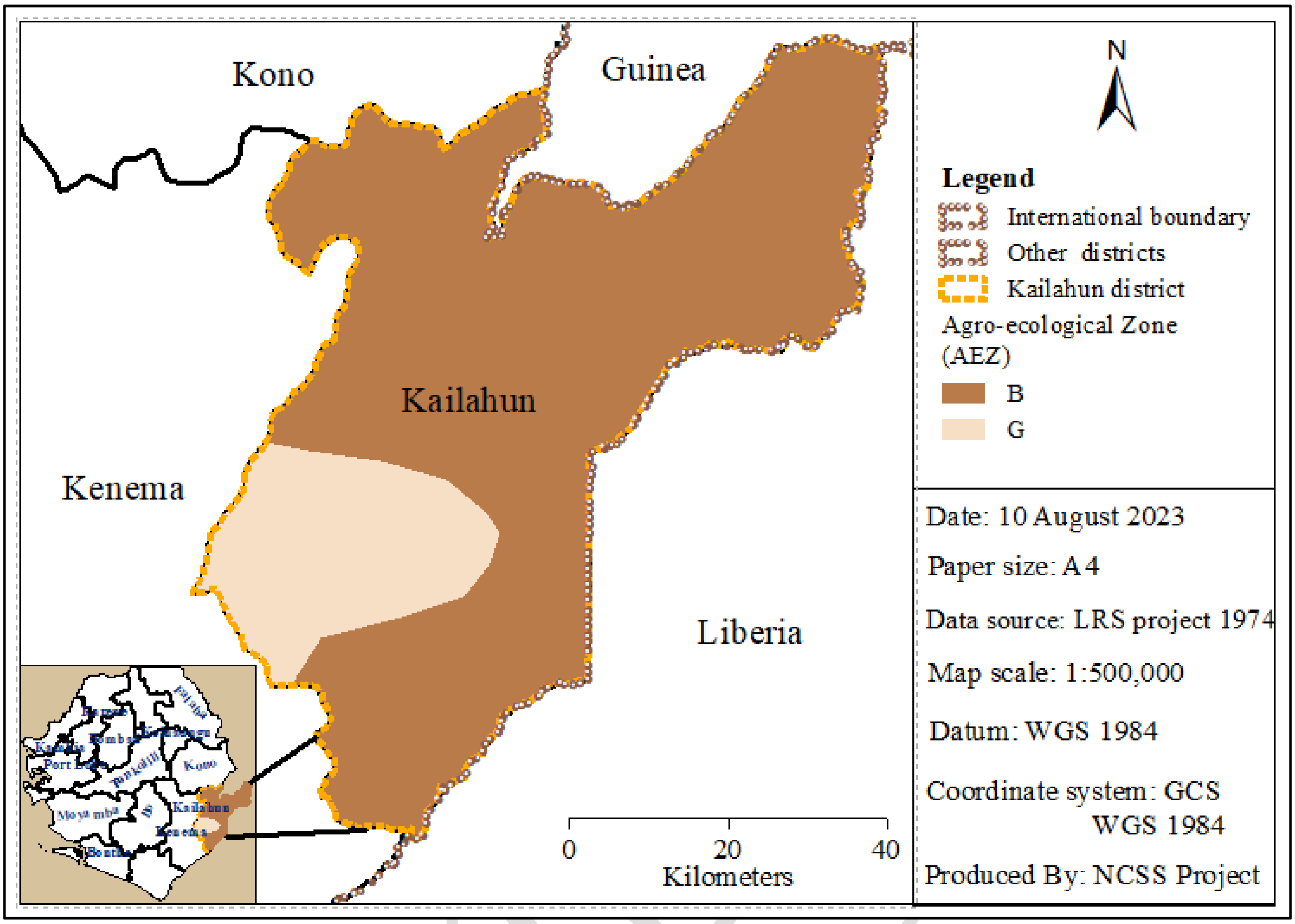

Figure 6. *Agro-ecological zones of Kailahun District (Adapted from Verheye 1987)*

3.3 Geology

The geology is an Assemblage of granite/greenstone complex comprising of a series of iron and magnesium-rich rocks metamorphosed to the amphibolite facies (Sula Group) over a quartz-rich basement of granitic composition (Williams, 1978). The grade of metamorphism in the basement tends to increase towards the Sula Group boundary giving rise to local occurrences of granulite (Mano-Moa formation). So-called Younger granite was intruded after the most intense period of deformation at about 2.7 ma ago and occurs around the margins of the Sula Group. To the northeast of the district, the geology is underlain by the Nimini Hills Group, and to the southwest of the district, by the Kambui Hills Group and Mano-Moa Granulites., Further details on the geology of the district are given in Table 5 and Figure 7.

Table 5. *Geology of Kailahun District (Adapted from UNDP/FAO 1979)*

Geology	Area (km^2)
Unknown mineral	25.8
Branded iron formation	2.9
Dolerite dykes	4.7
Kamboi group (Lower)	24.6
Kamboi group (Upper)	0.6
Leonean Anorthosite and Metagabbro	2.4
Leonean granite	3957.3
Leonean Migmatites and hybrid rocks	18.0
Marampa group (Lower)	4.6

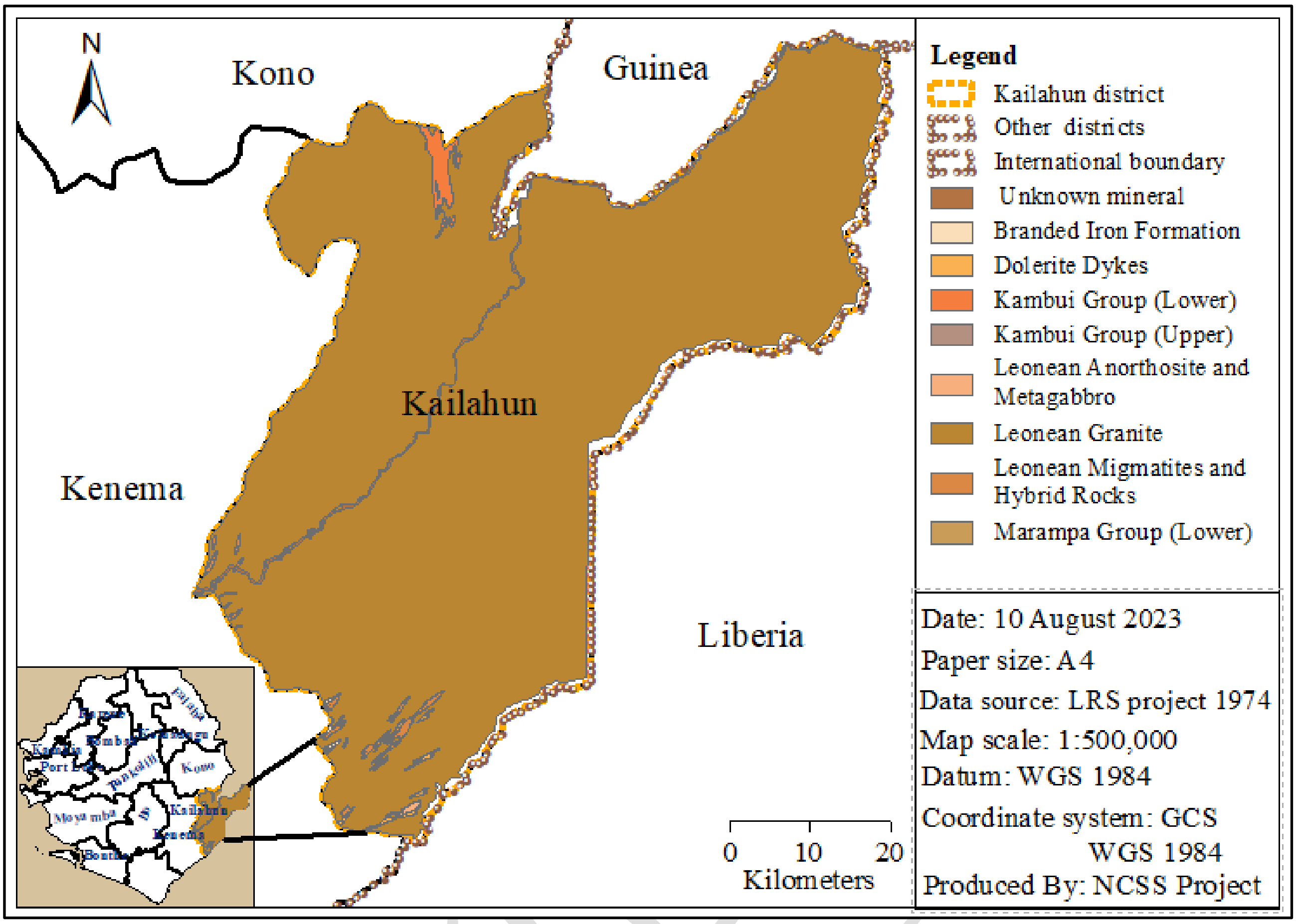

Figure 7. *Geology of Kailahun District*

3.4 Land systems

The district is comprised of 7 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 (Christian 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 6.

Table 6. Characteristics of land systems of Kailahun District (Adapted from UNDP/FAO 1979)

Land region	Subregion	Land system	Name	Code	Area (km^2)
Interior plains	Undulating plains	Dissected plains with isolated small hills and common terraces	Blama	15	1239.4
		Intricately dissected hills with isolated small hills	Bo	18	177.8
Plateaux	Undulating high-lying plateaux	Intricately dissected plains with isolated rocky hills and narrow wooded valleys	Wadu	26	267.4
		Strongly dissected plains with isolated hills	Kailahun	28	541.8
	Rolling plains and hills	Variably dissected association of plains and rocky hills	Sandaru	32	1416.3
Hills and Mountains	On basic and ultra-basic rocks	Dissected escarpment and hill ranges	Kangari	38	74.4
	On acid rocks	Complex of rocky hills	Kulufaga	41	460.9

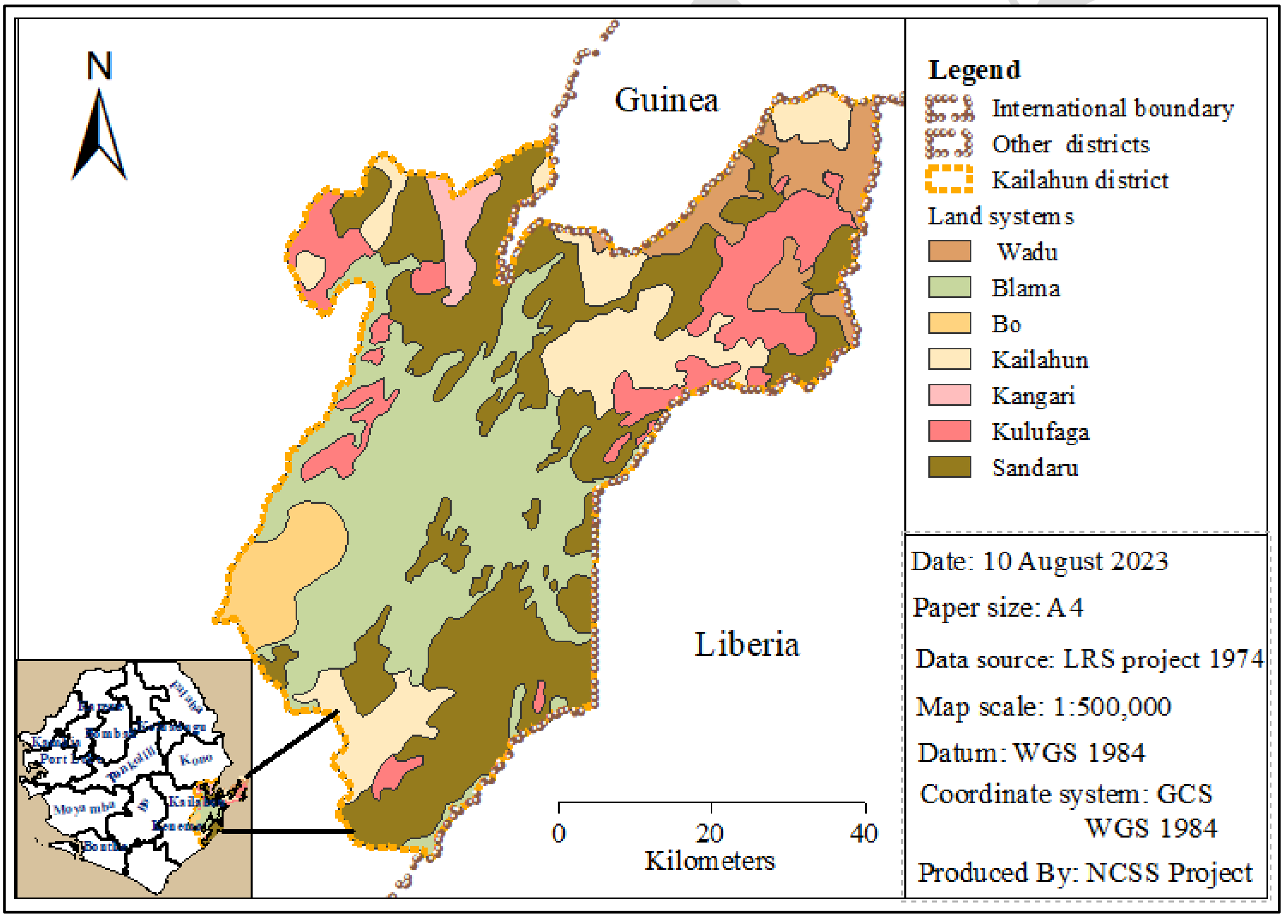

***Figure 8.** Land systems of Kailahun District (Adapted from UNDP/FAO 1979)*

3.5 Hydrology

The major rivers in the district include Moa, Male and Moro, and major streams include Seya, Magbole, Komboya, Waseng, Weiyura, Mogbai, Leye, Polewa, Pateya, Wanyema, Womoi, Mahimbe, Muawa, Gaya, etc. (Figure 9). These form a network of convergence in the southwest with its head flowing tributaries from northeast and southeastern peripherals. The Moa River contributes the major portion to the district's hydrology.

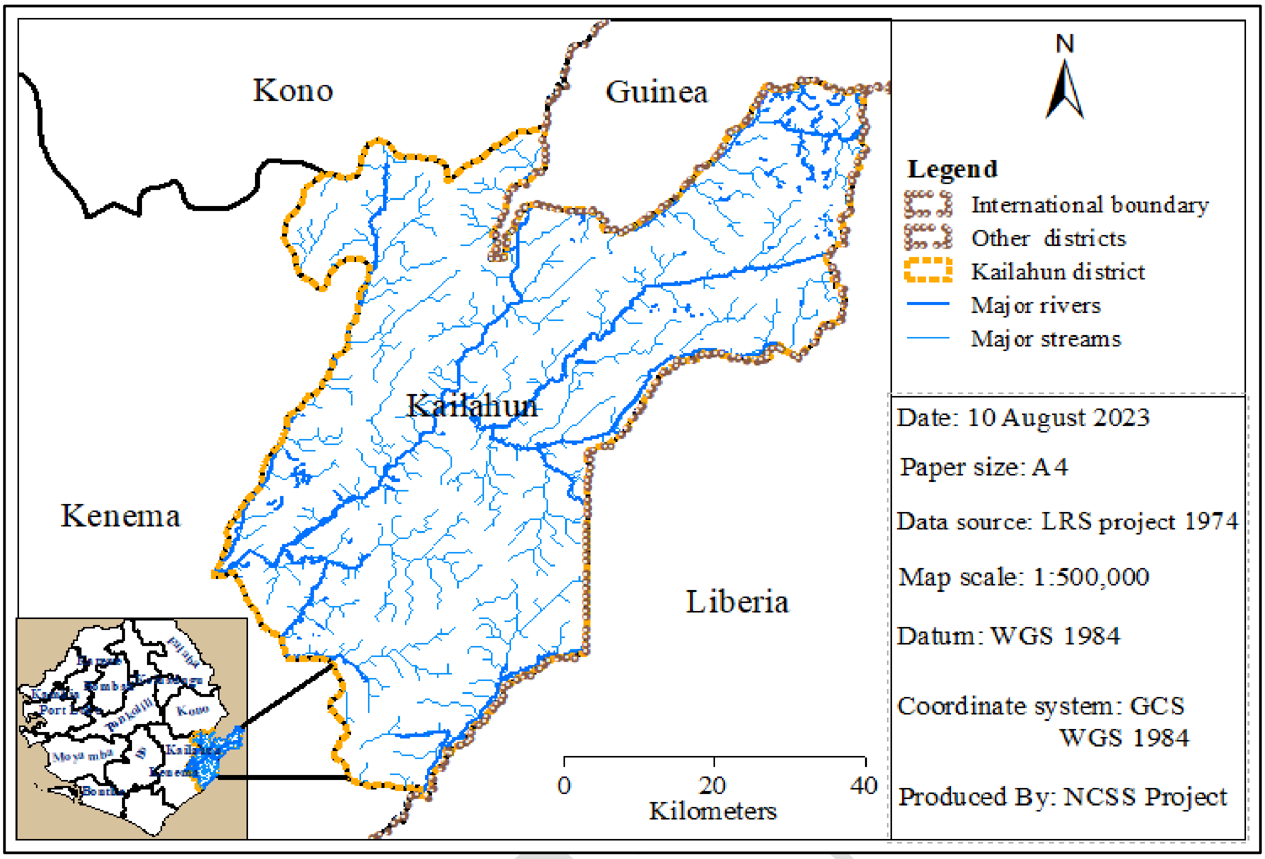

Figure 9. *Hydrology of Kailahun District*

3.6 Main soil associations

The soils of Kailahun 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. The soils have been generally grouped into five (5) representative soil types (UNDP/FAO, 1979), 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 five main associations (Figure 10 and Table 8), namely, 1) Gravelly ferralitic soils over weathered granitic basement or colluvial gravel on southern interior and plateau plains; 2) Gravelly nodular ferralitic soils over weathered granitic basement on northern interior and plateau plains; 3) Stony and gravelly ferralitic soils over weathered granitic basement or colluvial gravel on low to moderate relief hills; 4) stony and gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from predominantly acid rocks; and 5) Very gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from basic and ultrabasic rocks (Table 7 and Figure 10).

Table 7. *Main soil types and associations of Kailahun District (Adapted from UNDP/FAO 1979)*

Description of soil association	Area (km^2)
Gravelly ferralitic soils over weathered granitic basement or colluvial gravel on southern interior and plateau plains	1692.6
Gravelly nodular ferralitic soils over weathered granitic basement on northern interior and plateau plains	87.7
Stony and gravelly ferralitic soils over weathered granitic basement or colluvial gravel on low to moderate relief hills	2086.8
Stony and gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from predominantly acid rocks	216.3
Very gravelly ferralitic soils with shallow soils on moderate to high relief hills formed from basic and ultrabasic rocks	86.6

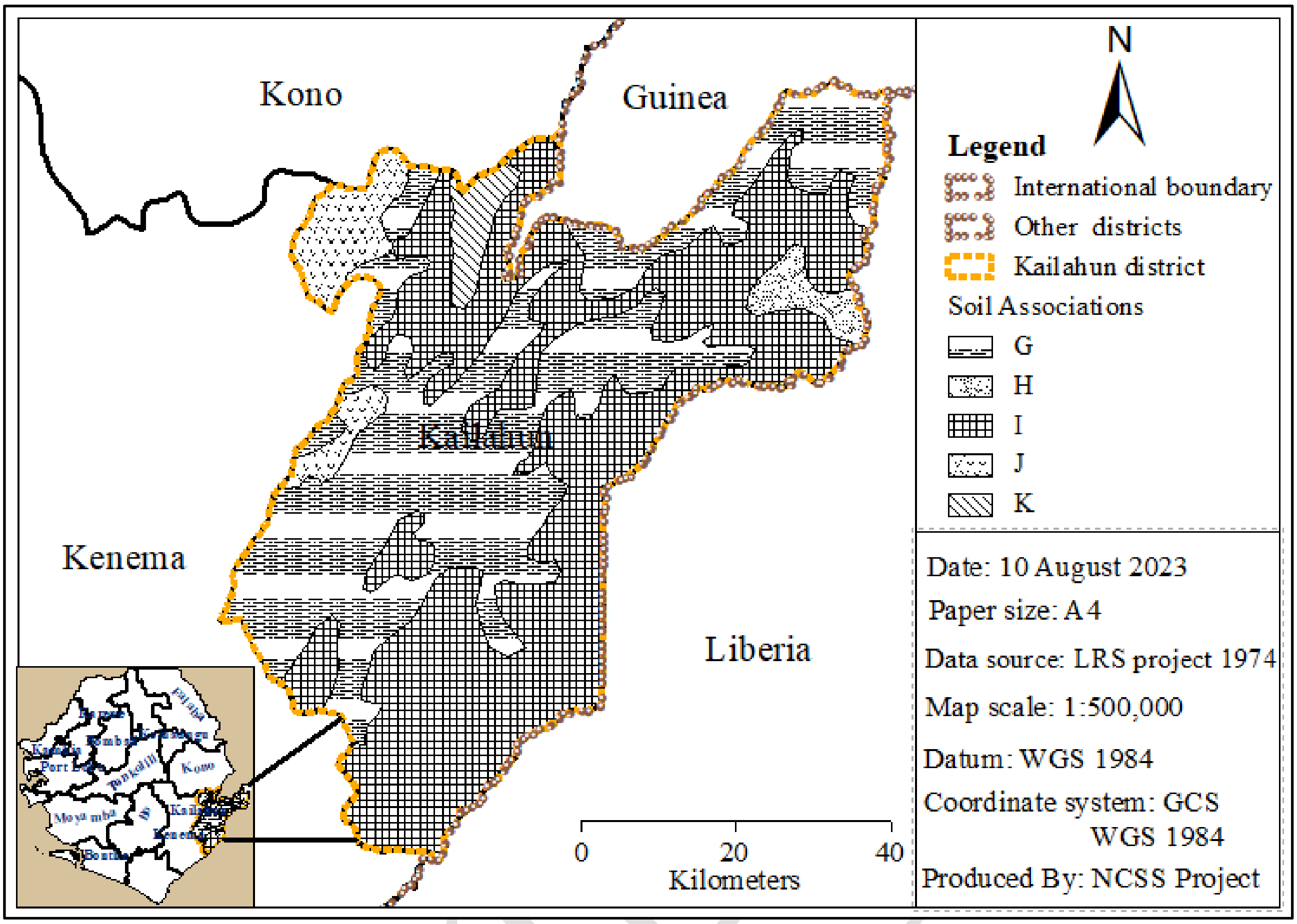

Figure 10. *Main soil association of Kailahun District (Adapted from UNDP/FAO 1979)*

3.7 Vegetation and land use

Seven major vegetation/ land use/ land cover types have been identified in the district (FAO, 2007), among which are closed high forest, secondary forest, forest regrowth, rock outcrop, oil palm plantation, upland crops and upland grassland (Table 8 and Figure 11). The closed high forest composed mainly of primary and mature secondary moist evergreen and moist semi-deciduous forest, with trees usually over 30 m tall. The secondary forest is an elongated generally narrow strip of dense secondary and immature forest cover with widths that vary from place to place along the banks of major streams and rivers, containing trees ranging from 10-30 m tall. The forest regrowth vegetation is derived from the shifting cultivation pattern of farming that is common in the country. This type of vegetation/ land use/ land cover usually contain thicket in several stages of growth but may have trees that are up to 10 m tall. The upland grassland vegetation is generally composed of tall grasses, mainly Pennisetum purpurenum (a tall grass specie commonly referred to as elephant grass). At some points, upland grassland vegetation may contain native oil palm trees that are scattered all over and sometimes, low grasses up to 0.8 m tall on laterite sheets. The rock outcrops are bare rocks, often with giant sedges growing on their surfaces. The upland crop vegetation is mainly farmland, usually having a mixture of crop trees as well as tree crops, whereas the oil palm plantation is a regular stand of oil palm trees, sometimes having a single stand of either native palms or Tenera spp. or a mixture of both.

Table 8. Vegetation and land cover types of Kailahun District (Adapted from UNDP/FAO 1979 and FAO, 2007)

Vegetation	Area	
	km^2	%
Closed high forest	559.7	13.2
Forest regrowth	2569.7	60.7
Secondary forest	742.6	17.6
Rock outcrop	68.1	1.6
Oil palm plantation	8.8	0.2
Upland crops	202.5	4.8
Upland grassland	78.6	1.9

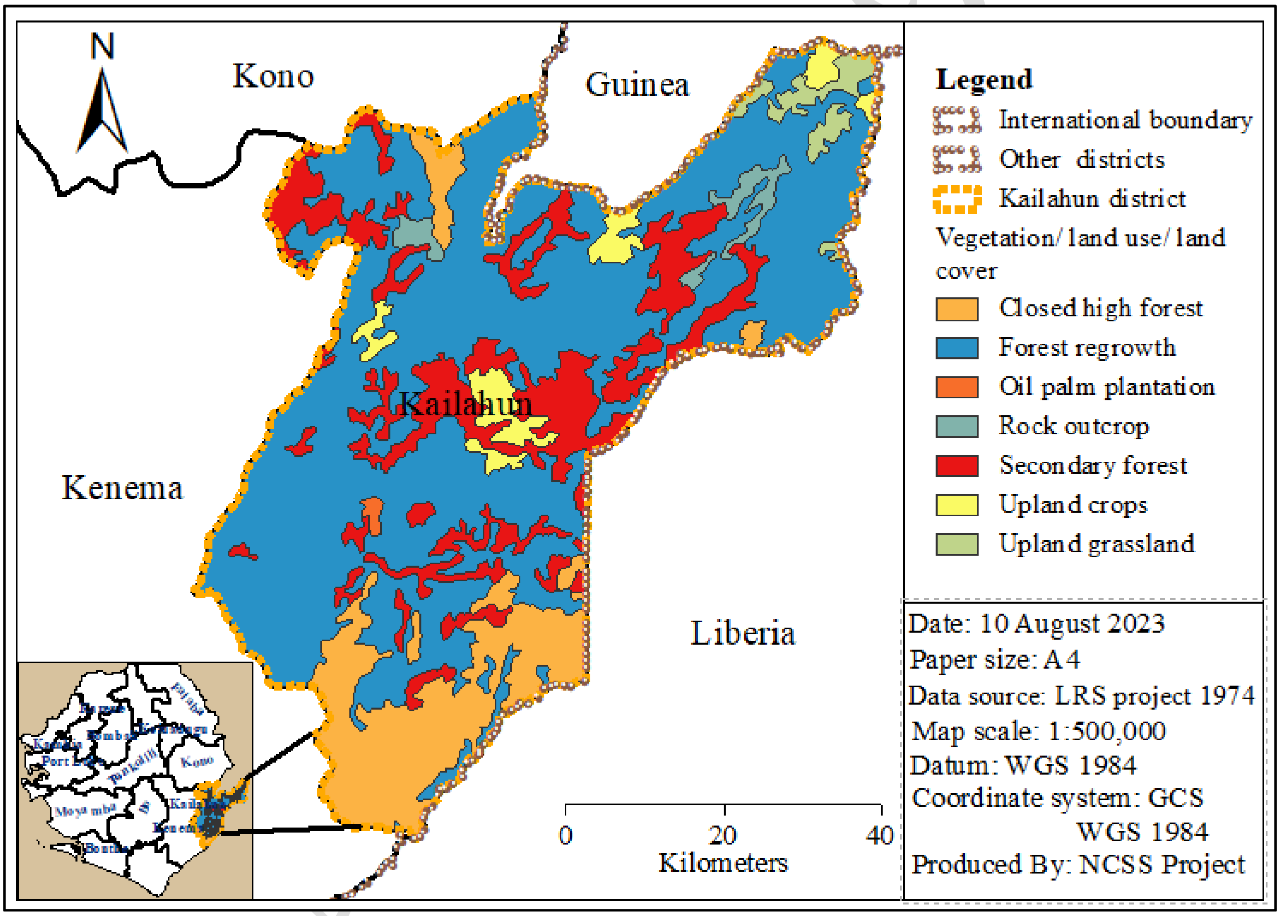

***Figure 11.** Vegetation and land use of Kailahun district (FAO, 2007)*

3.8 Socio-economy

Kailahun district is the only district is Sierra Leone where they regard the soil as their bank. Hence, the livelihoods are largely dependent on agriculture, mainly 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 are currently less prevalent in the district.

3.9 Environmental hazards

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

DRAFT 2

4 Soil Survey Methodology

4.1 The planning phase of the field 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.

4.2 How the Field Soil 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. 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.

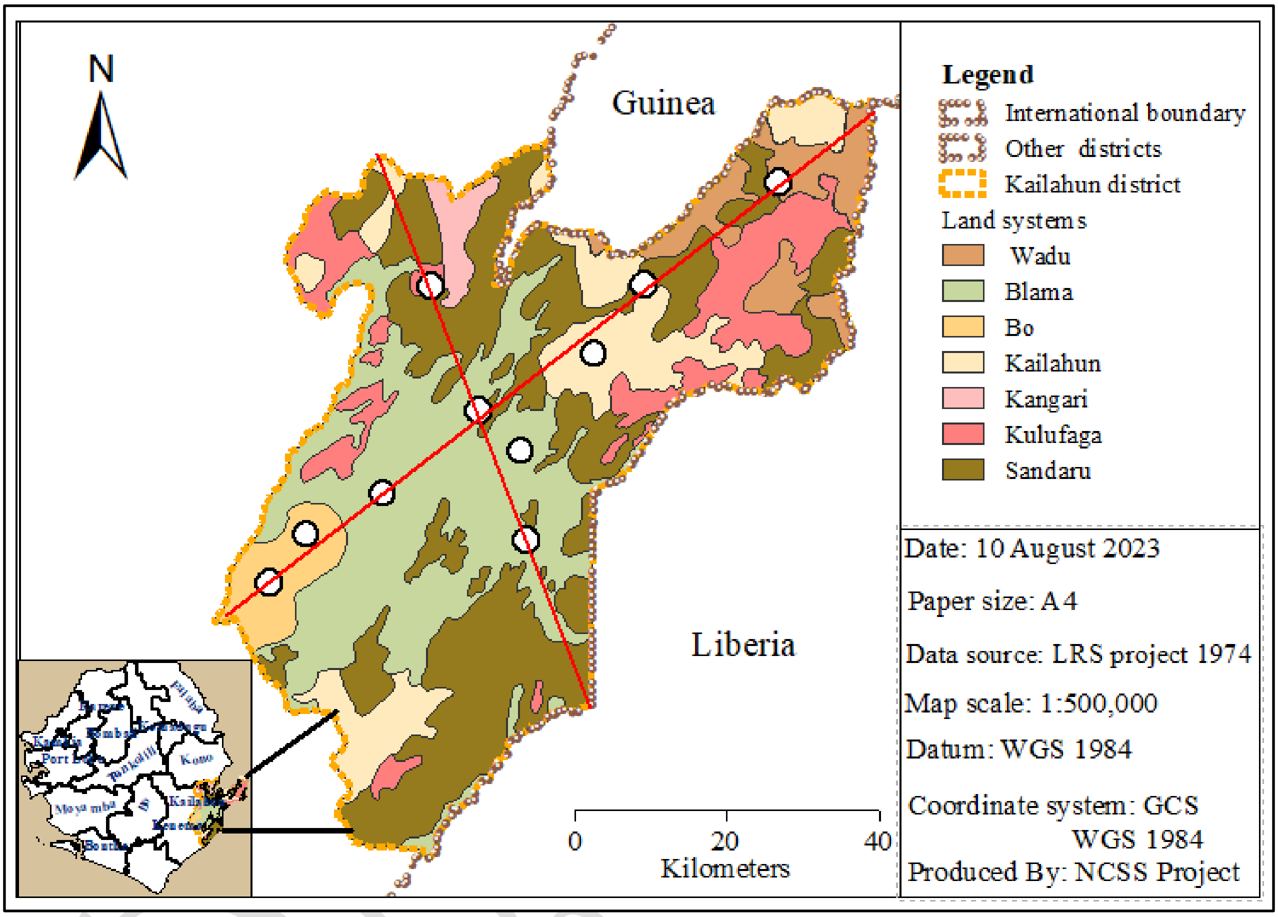

Figure 12. *Transect lines running through soil profile locations in preparation for a free-soil survey (adapted from Brady and Weil, 2008)*

District: Kailahun; **Chiefdom**: Yawei; **Village**: Madina; **GPS location**: 8.269791°/10.834464°; **Elevation**: 473m; **Physiography**: Undulating plain; **Landform/facet**: Dissected plain/ Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Crest; **Slope**: 10.2%; **Vegetation**: Semi-deciduous dwarf shrubs; **Erosion class and intensity**: e2, moderate; **Drainage and permeability**: Well drained and rapid; **Landuse**: Tree crop plantation; **Major crops grown**: Cocoa and coffee.

Land System:

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

Mapping Unit: KAI001 Gravel-free soil	**Horizon (cm)**	**Morphological Description**
	Ap (0 – 40)	Pale brown (10YR6/3 dry) and brown (10YR5/3 moist); sandy clay loam; 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 smooth boundary to horizon below.
	Bt1 (40 – 80)	Light yellowish brown (10YR6/4 dry) and yellowish brown (10YR5/4 moist); silty clay; moderate, fine, angular and sub-angular blocky; slightly hard (dry), friable (moist); sticky and plastic; plenty very fine, fine and very few medium pores; plenty very fine and fine roots; presence of few open boreholes, termites, ants and other insects; clear and gradual boundary to horizon below.
	Bt2 (80 – 153)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); silty clay loam; moderate, fine, angular 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 open boreholes, termites, ants and other insects; clear and wavy boundary to horizon below.
	C (153 – 202+)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); silty clay; moderate, fine, angular and sub-angular blocky; slightly hard (dry), friable (moist); sticky and plastic; plenty very fine and fine pores; few very fine and very few fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon above.

Figure 13*. A benchmark soil, first described in Madina, Yawei Chiefdom, Kailahun District to compare and represent all pedons described as the Madina 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 Kailahun District was 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 9.

Table 9. *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/PARSAL 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 Kailahun District

5.1 Description of Soils of Kailahun district

5.1.1 Soils located on sloping terrains

Map unit 1: Madina-Bandajuma soil association

5.1.1.1 Madina series

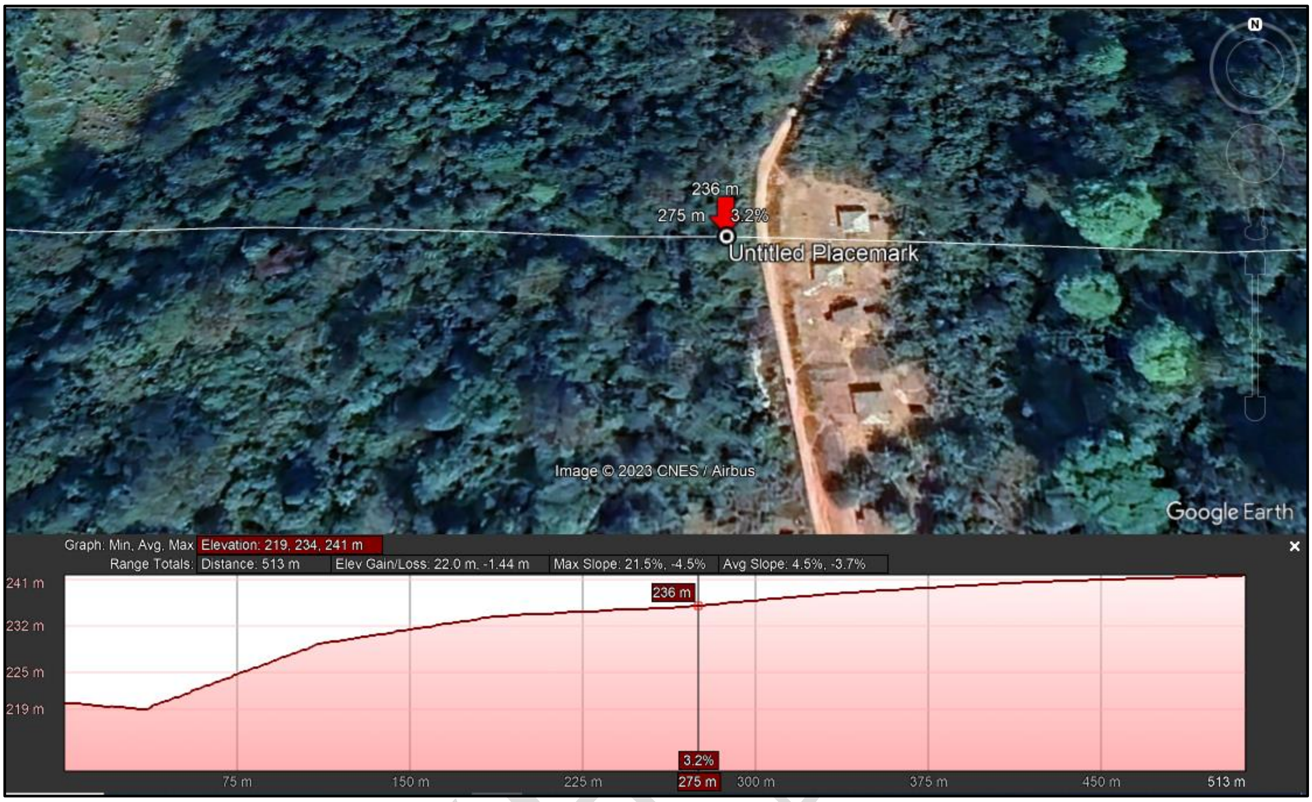

***Photo 1.** Typical position of Madina soil series in Kailahun District.*

Madina soils occur on moderately steep to steep slopes and are of limited extent in the district. These soils have developed on fine-grained granodiorite that 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. The pale brown (10YR6/3 dry) and brown (10YR5/3 moist) colours of the A1 horizon qualifies as an ochric epipedon. Subsoil colors are typically light yellowish brown (10YR6/4 dry) and yellowish brown (10YR5/4 moist). Madina soils are well drained and are never waterlogged at the surface (Table 10).

Plant nutrients levels are low in Madina soils. The organic carbon content is moderate in both topsoil and subsoil horizons. 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 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 (Weaver and Summers 2013). 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 is rapid and erosion is a serious hazard. Permeability is rapid. A detailed description and analytical data for a representative profile of the *Madina series*, KAI001, are given in Appendices 1a and 1b.

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

Soil series name	Madina
Common local names used for this soil	NA
International soil name	Ferralic Cambisol
Slope range	10.2 %
Soil surface stoniness	NA
Typical position in the landscape	*See Photo 2*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Very gravelly sandy clay
Drainage	Well drained to rapid
Colour of the topsoil:	Pale brown (10YR6/3 dry) and brown (10YR5/3 moist)
Colour of the subsoil	Yellowish brown (10YR6/4 dry) and yellowish brown (10YR5/4 moist)
Soil depth	Deep (>150 cm)
Nature of obstruction	NA

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.89	1.06
Available phosphorous (Bray P1 (mg kg^{-1})	5.30	2.05
Acidity (pH in 1:1 soil to water ratio)	4.40	4.48
Effective Cation Exchange Capacity (ECEC) (sum of exchangeable cations) cmol kg^{-1})	3.90	4.03
Exchangeable Calcium (cmol kg^{-1} soil)	2.01	2.02
Exchangeable Magnesium (cmol kg^{-1} soil)	0.36	0.43
Exchangeable Potassium (cmol kg^{-1}soil)	0.22	0.22
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.22	0.22
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.09	1.13
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	6.00	5.75
DTPA extractable Iron (cmol kg^{-1})	2.66	37.16
DTPA extractable Copper (cmol kg^{-1})	3.58	2.58
DTPA extractable Zinc	6.00	6.93

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).

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5.1.1.2 Bandajuma series

Photo 2. *Typical position of Bandajuma soil series in Kailahun District.*

The soils of the Bandajuma series usually occur on steep escarpment slopes of the uplands, with slopes commonly ranging from 15 to 50 percent. The develop from gravelly colluvium over clayey residuum from siltstone, sandstone, or shale. These soils are of limited extent in the surveyed area.

In these soils, the textures are typically gravelly sandy loam in the A and C horizons and gravelly sandy clay in the B horizon. The upper layers of these soils are dominated by detrital hardened plinthite gravel. The reddish brown (5YR5/3 dry) and (5YR4/3 moist) colours of the A1 horizon qualifies as an ochric epipedon. Subsoil colors are typically yellowish red (5YR 4/6 dry) and (5Y/R4/6 moist). Bandajuma soils are well drained and are never waterlogged at the surface (Table 11).

Levels of plant nutrients are low in Bandajuma soils. 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 topsoil horizon 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 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 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 (Weaver and Summers 2013). 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 is rapid and erosion is a serious hazard. Permeability is rapid. A detailed description and analytical data for a representative profile of the *Bandajuma series*, KAI002, are given in Appendices 2a and 2b.

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

Soil series name	Bandajuma
Common local names used for this soil	NA
International soil name	Dystric Nitosol
Slope range	8.5 %
Soil surface stoniness	Soil surface is partially covered with patches of fine and medium gravels
Typical position in the landscape	*See Photo 2*
Texture of the topsoil (0 – 20cm)	Gravelly sandy loam
Texture of the subsoil (at 50cm)	Gravelly sandy clay
Drainage	Moderately well drained to moderately rapid
Colour of the topsoil:	Reddish brown (5YR5/3 dry) and (5YR4/3 moist)
Colour of the subsoil	Yellowish red (5YR 4/6 dry) and (5Y/R4/6 moist)
Soil depth	Deep (>150 cm)
Nature of obstruction	NA

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.00	1.28
Available phosphorous (Bray P1 (mg kg^{-1})	9.99	5.80
Acidity (pH in 1:1 soil to water ratio)	4.40	4.57
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	6.84	4.94
Exchangeable Calcium (cmol kg^{-1} soil)	0.78	0.30
Exchangeable Magnesium (cmol kg^{-1} soil)	1.75	1.16
Exchangeable Potassium (cmol kg^{-1}soil)	0.16	0.12
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.17	0.11
Exchangeable Acidity (cmol+ kg^{-1} soil)	3.98	3.24
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	5.00	3.67
DTPA extractable Iron (cmol kg^{-1})	1.31	1.47
DTPA extractable Copper (cmol kg^{-1})	7.43	8.35
DTPA extractable Zinc (cmol kg^{-1})	53.8	43.66

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 located on upland erosion surfaces

Map unit 2: Malema-Manowa-Gbeika soil association

These are upland soils located on old erosion surfaces of highly weathered materials, containing 35-75% of hardened plinthite gravel, and fine earth fraction (< 2.0 mm) that is usually sandy clay loam or sandy clay. These soils are low in available water-holding capacity and low in plant nutrients.

5.1.2.1 Malema series

Photo 3. *Typical position of Malema soil series in Kailahun District.*

Malema soils are very gravelly and usually dominated by clayey reworked materials. They occur on nearly level ridgetops (with slopes ranging from 1-3 on gentle slopes and 3-15 % on moderate slopes). The parent material is a gravelly colluvium overlying gravelly residual material over weathered bedrock, which is always found at a depth of more than 100 cm. The colluvial plinthite gravels are rounded, hard and dense, and dusky red to reddish black. The gravel content of the colluvial surface layer usually varies from 35-60 % by volume; with a layer thickness of 60-12 cm. The residual plinthite gravels are more irregular, relatively more porous and softer, and are formed in situ, which varies in colour from bright red (10R 4/6) to dark red (10R 3/4). The gravel content usually decreases with depth from 25 % in the topsoil horizon to 50 % in the subsoil horizon. The textures are usually gravelly clay loam in the surface soil and gravelly clay loam to gravelly clay in the subsoil. The topsoil colors are pale brown (10YR6/3 dry) and brown (10YR5/3 moist), while the subsoil colors are usually light yellowish brown (10YR6/4 dry) and yellowish brown (10YR5/4 moist). In most cases, red mottles may or may not be present. The soils are well to moderately well drained and are never waterlogged.

In these soils, plant nutrient levels are low (Table 12). The organic carbon content is moderate in both topsoil and 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 is low in both topsoil and subsoil horizons, exchangeable Mg is high in topsoil horizon and moderate in subsoil horizon, exchangeable K is moderate in topsoil horizon 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 (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 (Weaver and Summers 2013). 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 is rapid and erosion is a serious hazard. Permeability is rapid. A detailed description and analytical data for a representative profile of the *Malema series*, KAI003, are given in Appendices 3a and 3b.

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

Soil series name	Malema
International soil name	Orthic Ferralsol
Slope range	7.8 %
Soil surface stoniness	NA
Typical position in the landscape	*See Photo 3*
Texture of the topsoil (0 – 20cm)	Gravelly clay loam
Texture of the subsoil (at 50cm)	Gravelly clay loam
Drainage	Well drained to rapid
Colour of the topsoil:	Pale brown (10YR6/3 dry) and brown (10YR5/3 moist)
Colour of the subsoil	Light yellowish brown (10YR6/4 dry) and yellowish brown (10YR5/4 moist)
Soil depth	Deep (>150 cm)
Nature of obstruction	NA

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	2.36	1.14
Available phosphorous (Bray P1 (mg kg^{-1})	10.21	8.34
Acidity (pH in 1:1 soil to water ratio)	4.30	4.40
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	9.54	5.80
Exchangeable Calcium (cmol kg^{-1} soil)	1.77	0.95
Exchangeable Magnesium (cmol kg^{-1} soil)	5.58	2.29
Exchangeable Potassium (cmol kg^{-1}soil)	0.24	0.18
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.22	0.16
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.73	2.23
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	11.00	6.00
DTPA extractable Iron (cmol kg^{-1})	5.24	3.47
DTPA extractable Copper (cmol kg^{-1})	4.472	7.47
DTPA extractable Zinc (cmol kg-1)	40.70	27.18

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 Manowa series

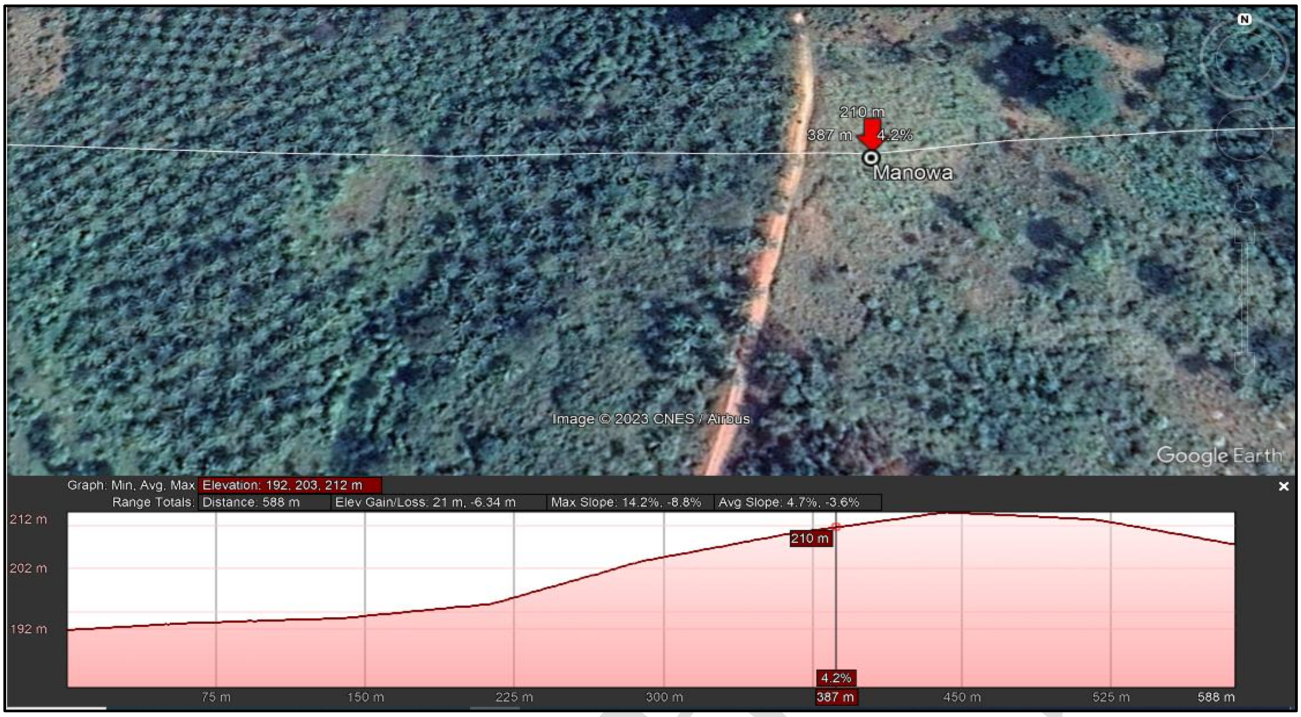

Photo 4. *Typical position of Manowa soil series in Kailahun District.*

These are very gravelly soils containing about 60 % gravel, usually with clayey reworked materials, that are often associated with Malema soils. Manowa soils usually occur on convex summits and convex upper slopes. The gravels are predominantly dark-coated, dense, hardened plinthite glaebules. The fine earth fractions (< 2.0 mm) in these soils are usually sandy clay loam in the topsoil A1 horizon, sandy clay in the upper subsoil, and clay in the lower subsoil.

The topsoil colors are dark gray (10YR4/1 dry) and very dark gray (10YR3/1 moist), while the subsoil colors are usually dark greyish brown (10YR 4/2 dry) and brown (10Y/R4/3 moist). In most cases, red mottles may or may not be present. The soils are well to moderately well drained and are never waterlogged.

Manowa soils are very low 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 moderate in in topsoil horizon and low subsoil horizon. 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 in topsoil horizon and moderate subsoil horizon, 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, while 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 (Weaver and Summers 2013). 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 is rapid and erosion is a serious hazard. Permeability is rapid. A detailed description and analytical data for a representative profile of the *Manowa series*, KAI004, is given in Appendices 4a and 4b.

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

Soil series name	Manowa	
Common local names used for this soil	NA	
International soil name	Dystric Nitosol	
Slope range	4.2 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Photo 4*	
Texture of the topsoil (0 – 20cm)	Sandy clay loam	
Texture of the subsoil (at 50cm)	Sandy clay	
Drainage	Moderately well drained to rapid	
Colour of the topsoil:	Dark gray (10YR4/1 dry) and very dark gray (10YR3/1 moist)	
Colour of the subsoil	Dark greyish brown (10YR 4/2 dry) and brown (10Y/R4/3 moist)	
Soil depth	Deep (>140 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.68	1.03
Available phosphorous (Bray P1 (mg kg-^{1})	12.14	5.13
Acidity (pH in 1:1 soil to water ratio)	4.60	4.70
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	7.37	7.67
Exchangeable Calcium (cmol kg^{-1} soil)	4.03	3.60
Exchangeable Magnesium (cmol kg^{-1} soil)	0.71	1.32
Exchangeable Potassium (cmol kg^{-1}soil)	0.43	0.39
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.51	0.46
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.69	1.90
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	36.00	71.00
DTPA extractable Iron (cmol kg^{-1})	4.46	3.04
DTPA extractable Copper (cmol kg^{-1})	11.15	6.54
DTPA extractable Zinc (cmol kg^{-1})	61.69	38.72

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 Gbeika series

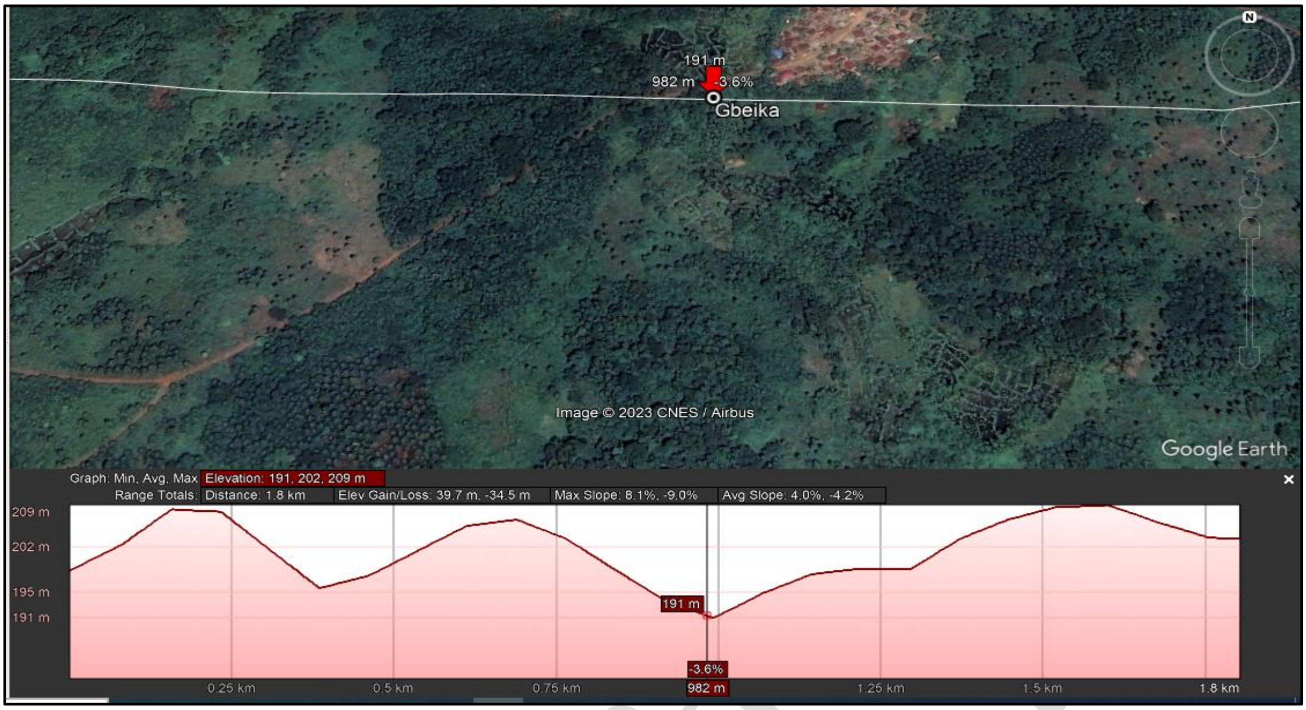

Photo 5. *Typical position of Gbeika soil series in Kailahun District.*

Gbeika soils are similar to those of Malema and Manowa soils, which are very gravelly and usually containing clayey reworked materials. 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 usually high in weathered rock fragment. 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 dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist), whereas the subsoil colours are usually dark yellowish brown (10YR 5/6 dry) and dark yellowish brown (10YR4/6 moist). The thickness and colour of the surface horizon qualify these soils for the umbric epipedon. These soils are well drained and never waterlogged.

Gbeika soils are very low in plant nutrients (Table 14). The organic carbon content is moderate in topsoil horizon and low in subsoil horizon. The available phosphorus (Bray P1) is moderate in topsoil horizon and low in subsoil horizon. 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 high in both topsoil and subsoil horizons, 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 (Weaver and Summers 2013). 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 moderate and erosion is moderate. Permeability is rapid. A detailed description and analytical result of a representative profile of *Gbeika series*, KAI005, is given in Appendices 5a and 5b.

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

Soil series name	Gbeika
Common local names used for this soil	NA
International soil name	Dystric Nitosol
Slope range	3.6 %
Soil surface stoniness	NA
Typical position in the landscape	*See Photo 5*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	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	Dark yellowish brown (10YR 5/6 dry) and dark yellowish brown (10YR4/6 moist)
Soil depth	Deep (>150 cm)
Nature of obstruction	NA

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.44	0.80
Available phosphorous (Bray P1 (mg kg^{-1})	18.06	1.04
Acidity (pH in 1:1 soil to water ratio)	4.70	4.50
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	5.93	4.84
Exchangeable Calcium (cmol kg^{-1} soil)	0.31	1.15
Exchangeable Magnesium (cmol kg^{-1} soil)	2.91	1.52
Exchangeable Potassium (cmol kg^{-1}soil)	0.12	0.19
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.11	0.22
Exchangeable Acidity (cmol+ kg^{-1} soil)	2.48	1.76
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	11.00	84.00
DTPA extractable Iron (cmol kg^{-1})	1.47	1.11
DTPA extractable Zinc (cmol kg^{-1})	8.35	4.99
DTPA extractable Copper (cmol kg^{-1})	730.00	24.56

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).

5.1.3 Soils located on colluvial footslopes and upper river tributary terraces

On the colluvial footslopes and upper tributary terraces, soils such as Misila, Gombi, and Mayengbema occur. Downslope from the upland, the upper gravel-free layer becomes progressively thicker. On the upland footslopes and highest terrace are the Misila soils, which have 20-60 cm of gravel-free material over a gravelly subsoil. At lower elevations are Gombi soils, which have 40-120 cm of gravel-free material over a gravelly lower subsoil. At the lowest end of the toposequence, are the Mayengbema soils.

Map unit 3: Misila-Gombi-Mayengbema soil association

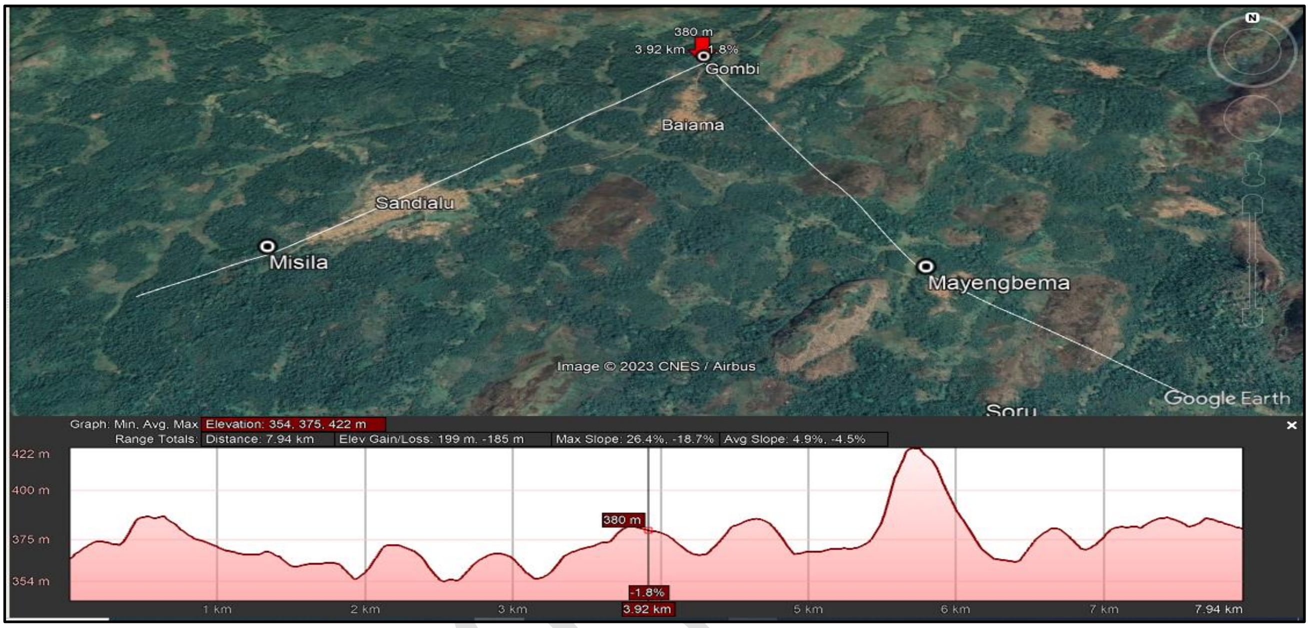

Photo 6. *Typical position of Madina and Bandajuma soil in Kailahun District.*

5.1.3.1 Misila series

Soils of the Misila series occur on concave colluvial footslopes of 2-8 % slopes and the upper river tributary terraces. The parent material is a gravel-free colluvium, overlying gravelly colluvium, over gravelly residual material, over weathered bedrock. The thickness of the gravel-free colluvium is usually 20 to 60 cm. The underlying subsoil layer is usually dominated by 35-50 % colluvial plinthite glaebules that are rounded, hard and dense, and dusky red to reddish black. The residual plinthite glaebules, formed in situ, are more irregular and relatively more porous and softer. The topsoil textures are sandy loam, while the subsoil textures are gravelly clay loam to gravelly sandy clay loam. These soils have an ochric epipedon and a thin A1 horizon that is less than 25 cm thick. The topsoil colours are gray (10YR5/1dry) and dark gray (10YR4/1 moist), and subsoil colours is pale brown (10YR6/3 dry) and brown (10YR5/3 moist). In some cases where moisture remains high for most parts of the year, the subsoil may look yellowish-grey (2.5Y 7/6), which after being indurated for long periods normally results in the formation of prominent reddish (2.5YR 4/8) mottles. The soils are moderately well drained and are seldom waterlogged.

Misila soils are very low in plant nutrients (Table 15). The organic carbon content is moderate in topsoil horizon and low in subsoil horizon. The available phosphorus (Bray P1) is low in both topsoil and subsoil horizons. The pH is high in topsoil horizon and moderate subsoil horizon. 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 high in topsoil horizon and moderate in subsoil horizon, 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 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 (Weaver and Summers 2013). 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 is rapid and erosion is a serious hazard. Permeability is rapid. A detail description and analytical data for a representative profile of the *Misila series*, KAI006, is given in Appendices 6a and 6b.

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

Soil series name	Misila
Common local names used for this soil	NA
International soil name	Haplic Plinthosol
Slope range	4.1 %
Soil surface stoniness	NA
Typical position in the landscape	*See Photo 6*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Very gravelly sandy clay
Drainage	Well drained to rapid
Colour of the topsoil:	Gray (10YR5/1dry) and dark gray (10YR4/1 moist)
Colour of the subsoil	Pale brown (10YR6/3 dry) and brown (10YR5/3 moist)
Soil depth	Deep (>150 cm)
Nature of obstruction	Paralithic lateritic layer

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.73	0.91
Available phosphorous (Bray P1 (mg kg^{-1})	4.49	2.87
Acidity (pH in 1:1 soil to water ratio)	4.40	4.70
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	4.15	4.74
Exchangeable Calcium (cmol kg^{-1} soil)	2.60	3.07
Exchangeable Magnesium (cmol kg^{-1} soil)	0.41	0.56
Exchangeable Potassium (cmol kg^{-1}soil)	0.28	0.32
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.30	0.37
Exchangeable Acidity (cmol+ kg^{-1} soil)	0.56	0.41
Electrical Conductivity (salinity) (μS cm^{-1}) in 1: 5 soil to water ratio	10.00	6.00
DTPA extractable Iron (cmol kg^{-1})	514.51	358.65
DTPA extractable Zinc (cmol kg^{-1})	5.38	4.70
DTPA extractable Copper (cmol kg^{-1})	4.29	6.35

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 Gombi series

These are soil mostly occurring on the concave colluvial footslopes that have slopes ranging from 2-5 % and upper terraces of the Moa River and its tributaries. The parent material is gravel-free colluvium or alluvium, over gravelly colluvium, over residual weathered material from the bedrock. The thickness of the gravel-free upper layer often varies from 50-120 cm. However, their gravelly colluvial layer is thinner than their counterpart soils and often has a characteristic stone line of 25 cm thickness. They have plinthite glaebules that are rounded, hard and dense, with gravel content ranging from 25-65 % by volume. In these soils, the residual materials are soft, often irregular, and tend to have more porous glaebules decrease with depth.

The topsoil textures are sandy loam to loam but as the depth gradually increases, these textures become sandy clay loam in the upper subsoil and gravelly clay loam in the lower subsoil. These soils have an ochric epipedon and a thin A1 horizon, whose thickness is often less than 25 cm. The topsoil colours are reddish gray (5YR5/2 dry) and dark reddish gray (5YR4/2 moist) while the subsoils are reddish brown (5YR5/6 dry) and reddish brown (5YR4/6 moist). Prominent red mottles (2.5YR 4/8) are usually present at depths of 50 cm or more. Gombi soils are moderately well to imperfectly drained, and can be waterlogged at the surface and even submerged for a few weeks.

Chemically, Gombi soils are very low in plant nutrients (Table 16). The organic carbon content is moderate in topsoil horizon and low 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 topsoil horizon and moderate in subsoil horizon, 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 high in topsoil horizon and moderate in subsoil horizon, DTPA extractable Co (cmol kg^{-1}) is high in topsoil horizon and moderate in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is low in topsoil horizon and high 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 (Weaver and Summers 2013). 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 is rapid and erosion is a serious hazard. Permeability is rapid. A detailed description and analytical data for a representative profile of the *Gombi series*, KAI007, are given in Appendices 7a and 7b.

Table 16. Key land, morphological and chemical properties of Gombi series		
Soil series name	Gombi	
Common local names used for this soil	NA	
International soil name	Haplic Plinthosol	
Slope range	1.8 %	
Soil surface stoniness	NA	
Typical position in the landscape	*See Plate 6*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Sandy clay loam	
Drainage	Well drained to rapid	
Colour of the topsoil:	Reddish gray (5YR5/2 dry) and dark reddish gray (5YR4/2 moist)	
Colour of the subsoil	Reddish brown (5YR5/6 dry) and reddish brown (5YR4/6 moist)	
Soil depth	Deep (>150 cm)	
Nature of obstruction	NA	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.77	0.97
Available phosphorous (Bray P1 (mg kg^{-1})	4.04	3.86
Acidity (pH in 1:1 soil to water ratio)	4.50	4.50
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	6.47	4.89
Exchangeable Calcium (cmol kg^{-1} soil)	4.32	2.85
Exchangeable Magnesium (cmol kg^{-1} soil)	0.64	0.35
Exchangeable Potassium (cmol kg^{-1}soil)	0.44	0.30
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.54	0.34
Exchangeable Acidity (cmol+ kg^{-1} soil)	0.53	1.05
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	12.00	7.00
DTPA extractable Iron (cmol kg^{-1})	545.31	347.44
DTPA extractable Zinc (cmol kg^{-1})	1.768	6.17
DTPA extractable Copper (cmol kg^{-1})	7.38	4.32

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 Mayengbema series

These are poorly drained soils occurring in the drainageways or inland swamps that dissect the higher topographies of the district. Usually, Mayengbema soils are found in the upper reaches of the drainageways; closer to the Moa, Male and Moro, and major streams including seya, Magbole, Komboya, Waseng, Weiyura, Mogbai, Leye, Polewa, Pateya, Wanyema, Womoi, Mahimbe, Muawa, Gaya, etc. The terrain is nearly level to depressional, with concave slopes of 1-3 %.

The soils have a parent material that is gravel-free colluvium or alluvium, over a gravelly colluvium, over residual material derived from the parent rock. The thickness of the gravel-free layer is about 50-100 cm. The gravelly colluvial layer varies in thickness and can be compared with that of the Gombi soils. In many cases, the gravel content may vary from 20- 60 % by volume, with quartz being an important component of the gravels.

Textures are loam to fine sandy loam in the topsoil, clay loam in the upper subsoil, and gravelly clay loam in the lower subsoil. The silt content often increases in the lower subsoil, especially where saprolite is present. Clay coatings are present in the subsoil, which is argillic. The thickness of the topsoil Al horizon 20 to 40 cm, so that both ochric and umbric epipedons are included their classification. The topsoil colors are very dark gray (10YR 3/1 dry) to dark grayish brown (10YR 4/2 moist), while the subsoil colors range from yellowish brown (10YR 5/4 dry) to gray (10YR 5/1). Depending on the depth, colour variability may be prominent especially at depth of 100 cm and beyond, i.e., the colour may change to light gray (10YR 6/1-7/1). At a depth of 50-75 cm, prominent red mottles (2.5YR 4/6-4/8) may be visible.

Chemically, Mayengbema soils are very low in plant nutrients (Table 17). The organic carbon content is moderate in topsoil horizon and low in subsoil horizon. The available phosphorus (Bray P1) is moderate in topsoil horizon and low in subsoil horizon. 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 are 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 topsoil horizon and moderate in subsoil horizon, DTPA extractable Co (cmol kg^{-1}) is high in both topsoil and subsoil horizons, 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 (Weaver and Summers 2013). 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 moderate and erosion is moderate. Permeability is rapid.

A detailed description and analytical data for a representative profile of the *Mayengbema series*, KAI008, are given in Appendices 8a and 8b.

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

Soil series name	Mayengbema		
Common local names used for this soil	NA		
International soil name	Lithic Leptosol		
Slope range	9.8 %		
Soil surface stoniness	NA		
Typical position in the landscape	*See Plate 6*		
Texture of the topsoil (0 – 20cm)	Sandy loam		
Texture of the subsoil (at 50cm)	Sandy clay loam		
Drainage	Well drained to rapid		
Colour of the topsoil:	Very dark gray (10YR 3/1 dry) to dark grayish brown (10YR 4/2 moist)		
Colour of the subsoil	Yellowish brown (10YR 5/4 dry) to gray (10YR 5/1 moist)		
Soil depth	Deep (>150 cm)		
Nature of obstruction	NA		
Soil Property		Soil Depth (cm)	
		0 – 20	50
Organic Carbon (%)		1.50	0.83
Available phosphorous (Bray P1 (mg kg^{-1})		12.03	5.54
Acidity (pH in 1:1 soil to water ratio)		4.30	4.30
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})		5.62	5.38
Exchangeable Calcium (cmol kg^{-1} soil)		3.77	3.41
Exchangeable Magnesium (cmol kg^{-1} soil)		0.40	0.42
Exchangeable Potassium (cmol kg^{-1}soil)		0.39	0.36
Exchangeable Sodium (cmol+ kg^{-1} soil)		0.46	0.41
Exchangeable Acidity (cmol+ kg^{-1} soil)		0.60	0.78
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio		18.00	13.00
DTPA extractable Iron (cmol kg^{-1})		4.39	100.55
DTPA extractable Zinc (cmol kg^{-1})		5.31	4.47
DTPA extractable Copper (cmol kg^{-1})		6.52	6.81

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 bottomland swamps and stream terraces

Map unit 4: Pendembu-Moa soil association

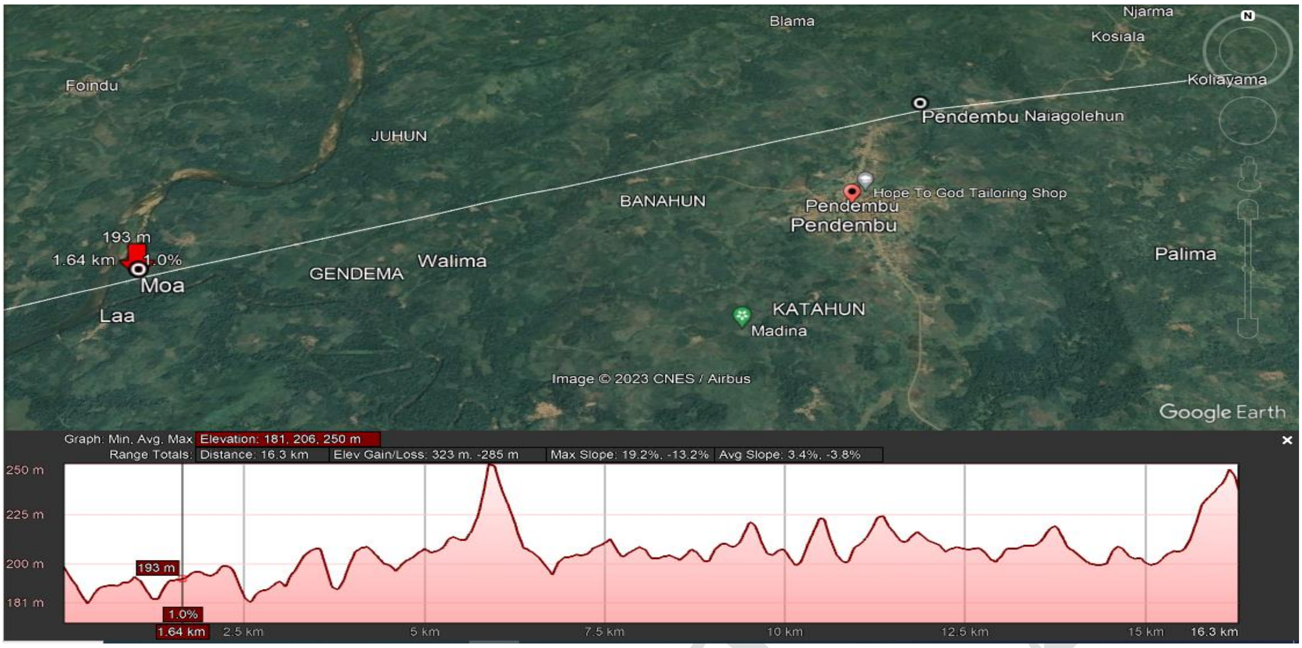

Photo 7. *Typical position of Pendembu-Moa soil association in Kailahun District*.

Along the valley bottoms and banks of many of the larger streams, clayey alluvial soils of the Pendembu and Moa series occur. These soils develop from fine-loamy colluvium and alluvium parent material, on a landscape that is nearly level and occur slightly above the streams. These are the most productive soils in the area and are often used for rainfed upland rice, natural flooded rice and cocoa production.

5.1.4.1 Pendembu series

Pendembu soils occur along the banks of many of the larger streams and convex slopes adjoining swamp terraces. The parent material is gravel-free colluvium or alluvium over soft and hard ironstone gravels. The gravel-free colluvium or alluvium is usually 0-50 cm thick over the gravelly subsoil. The topsoil textures are usually sandy loam to sandy clay loam, changing to gravelly sandy loam or gravelly sandy clay loam in the subsoil. The gravel content in the subsoil is usually more than 40 % by volume, and are composed mainly of hardened quartz and ironstone materials. The colours of the topsoil range from dark brown (10YR 3/3 dry) and dark yellowish brown (10Y/R4/3 moist) and that of the subsoil ranges from yellowish brown (10YR 5/6 dry) to brownish yellow (10Y/R6/8 moist). The topsoil A1 horizon is ≥ 25 cm, which qualifies for umbric horizon classification.

Pendembu soils are imperfectly drained and one major limitation of these soils is waterlogging during the first few weeks of the rainy season. In some cases, the water table may stand tall in the profile for a much longer period than expected. Despite this limitation of waterlogging, the chemical and nutrient status of the Pendembu soils (Table 18) is much better than most of the well-drained soils in the district. The organic carbon content is high 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 topsoil horizon and moderate in subsoil horizon. 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 and 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 topsoil horizon and moderate in subsoil horizon, DTPA extractable Cu (cmol kg^{-1}) is high in topsoil horizon and low in subsoil horizon, while the DTPA extractable Zn (cmol kg^{-1}) is moderate 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 (Weaver and Summers 2013). 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 nearly level nature of the landscape, flooding is a serious hazard due to the continuous inundation by rainfall. Permeability is moderately slow. A detailed description and analytical data for a representative profile of the *Pendembu series*, KAI009, are given in Appendices 9a and 9b.

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

Soil series name	Pendembu	
International soil name	Humic Nitosol	
Slope range	4.1 %	
Soil surface stoniness	Soil surface is partially covered with patches of fine and medium gravels	
Typical position in the landscape	*See Plate 7*	
Texture of the topsoil (0 – 20cm)	Sandy loam	
Texture of the subsoil (at 50cm)	Sandy clay loam	
Drainage	Moderately well drained to moderately rapid	
Colour of the topsoil:	Dark brown (10YR 3/3 dry) and dark yellowish brown (10Y/R4/3 moist)	
Colour of the subsoil	Yellowish brown (10YR 5/6 dry) to brownish yellow (10Y/R6/8 moist)	
Soil depth	Deep (>148 cm)	
Nature of obstruction	Impenetrable lateritic gravel and stone line together with weathered rock at 85cm and above	
Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	3.08	1.48
Available phosphorous (Bray P1 (mg kg^{-1})	1.80	1.02
Acidity (pH in 1:1 soil to water ratio)	4.30	4.80
Effective Cation Exchange Capacity (ECEC) (sum of cations) cmol kg^{-1})	6.57	3.49
Exchangeable Calcium (cmol kg^{-1} soil)	4.17	2.20
Exchangeable Magnesium (cmol kg^{-1} soil)	0.96	0.49
Exchangeable Potassium (cmol kg^{-1}soil)	0.43	0.22
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.52	0.28
Exchangeable Acidity (cmol+ kg^{-1} soil)	0.49	0.30
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	19.00	54.8
DTPA extractable Iron (cmol kg^{-1})	43.63	200.58
DTPA extractable Zinc (cmol kg^{-1})	3.34	2.24
DTPA extractable Copper (cmol kg^{-1})	14.08	7.12

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 Moa series

Moa soils develop from clayey alluvium that is approximately 40-50 % clay and 20 % silt; the remainder being mostly fine sand. These soils usually have dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist) A1 horizon that is usually thin (ochric epipedon). The colours in the upper B horizon are brown (10YR 4/3dry) and grayish brown (10YR4/2 moist). The colors of the lower B horizon are variable but are often brownish yellow (10YR 6/8) with distinct mottles, sometimes having variable colours. Moa soils are considered to be moderately well drained with the upper part of the profile being better drained and the lower part more poorly drained. They may be flooded for brief periods of 1 to 15 days during the rains.

Chemically, Moa soils are very low in plant nutrients (Table 19). The organic carbon content is moderate in both topsoil and subsoil horizons. The available phosphorus (Bray P1) is high in topsoil horizon and moderate in subsoil horizon. The pH is high in topsoil horizon and moderate in subsoil horizon. 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 high 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 moderate 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 (Weaver and Summers 2013). 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 nearly level nature of the landscape, flooding is a serious hazard due to the continuous inundation by rainfall. Permeability is moderately slow.

A detailed description and analytical data for a representative profile of the *Moa series*, KAI010, are given in Appendices 10a and 10b.

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

Soil series name	Moa
International soil name	Ferralic Cambisol
Slope range	1.1 %
Soil surface stoniness	N/A
Typical position in the landscape	*See Plate 7*
Texture of the topsoil (0 – 20cm)	Sandy loam
Texture of the subsoil (at 50cm)	Sandy clay loam
Drainage	Moderately well drained to moderately rapid
Colour of the topsoil:	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist)
Colour of the subsoil	Brown (10YR 4/3dry) and grayish brown (10YR4/2 moist)
Soil depth	Deep (>150 cm)
Nature of obstruction	NA

Soil Property	Soil Depth (cm)	
	0 – 20	50
Organic Carbon (%)	1.70	1.23
Available phosphorous (Bray P1 (mg kg^{-1})	17.90	11.24
Acidity (pH in 1:1 soil to water ratio)	4.10	4.70
Effective Cation Exchange Capacity (sum of cations) cmol kg^{-1})	8.13	4.51
Exchangeable Calcium (cmol kg^{-1} soil)	5.01	2.81
Exchangeable Magnesium (cmol kg^{-1} soil)	1.16	0.76
Exchangeable Potassium (cmol kg^{-1}soil)	0.18	0.10
Exchangeable Sodium (cmol+ kg^{-1} soil)	0.09	0.07
Exchangeable Acidity (cmol+ kg^{-1} soil)	1.69	0.78
Electrical Conductivity (salinity) (µS cm^{-1}) in 1: 5 soil to water ratio	30.00	45.00
DTPA extractable Iron (cmol kg^{-1})	64.18	89.37
DTPA extractable Zinc (cmol kg^{-1})	32.39	31.01
DTPA extractable Copper (cmol kg^{-1})	2.34	51.55

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 Kailahun District were classified and mapped on the basis of their representative characteristics, as presented in Table 20. Based on the results show below, it can be noted that soils of the Malema series occupy the largest area (1013.2 km^2). This is followed by Manowa (935.6 km^2), Gbeika (930.9 km^2), Pendembu (43.1 km^2), Moa (27.0 km^2), Misila (11.8 km^2), Mayengbema (10.1 km^2), Gombi (9.8 km^2) and Madina (2.2 km^2) in decreasing order of area of coverage. The least is soils of the Bandajuma series (1.4 km^2).

***Table 20**. 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	
Madina	Ferrasol	Ferralic Cambisol	Inceptisol	Tropept	dystropept	Udoxic Dystropept	2.2
Bandajuma	Nitosol	Dystric Nitosol	Inceptisol	Tropept	Dystropept	Plpnthic Dystropept	1.4
Malema	Ferrasol	Orthic Ferrasol	Oxisol	Orthox	Haplorthox	Plinthic Haplorthox	1013.2
Manowa	Nitosol	Dystric Nitosol	Ultisol	Udult	Paluedult	Orthoxic Dalehumult	935.6
Gbeika	Nitosol	Dystric Nitosol	Ultisol	Udult	Paleudult	Typic Paleudult	930.9
Misila	Plinthosol	Haplic plinthosol	Ultisol	Udult	Paleudult	Plinthic Paleudult	11.2
Gombi	Plinthosol	Haplic plinthosol	Inceptisol	Tropept	Dystropept	Plinthic Udoxic Dystropept	9.8
Mayengbema	Leptosol	Lithic Leptosol	Ultisol	Udult	Paleudult	Plinthic Paleaquult	10.1
Pendembu	Nitosol	Humic Nitosol	Ultisol	Udult	Paleudult	Plinthaquic Paleudult	43.1
Moa	Ferrasol	Ferralic Cambisol	Inceptisol	Tropept	Dystropept	Fluventic Udoxic Dystropept	27

5.3 Soil map of Kailahun District

The soils of Kailahun District as indicated in Table 20, were mapped at association level on the basis of their representative characteristics, as presented in Figure 14.

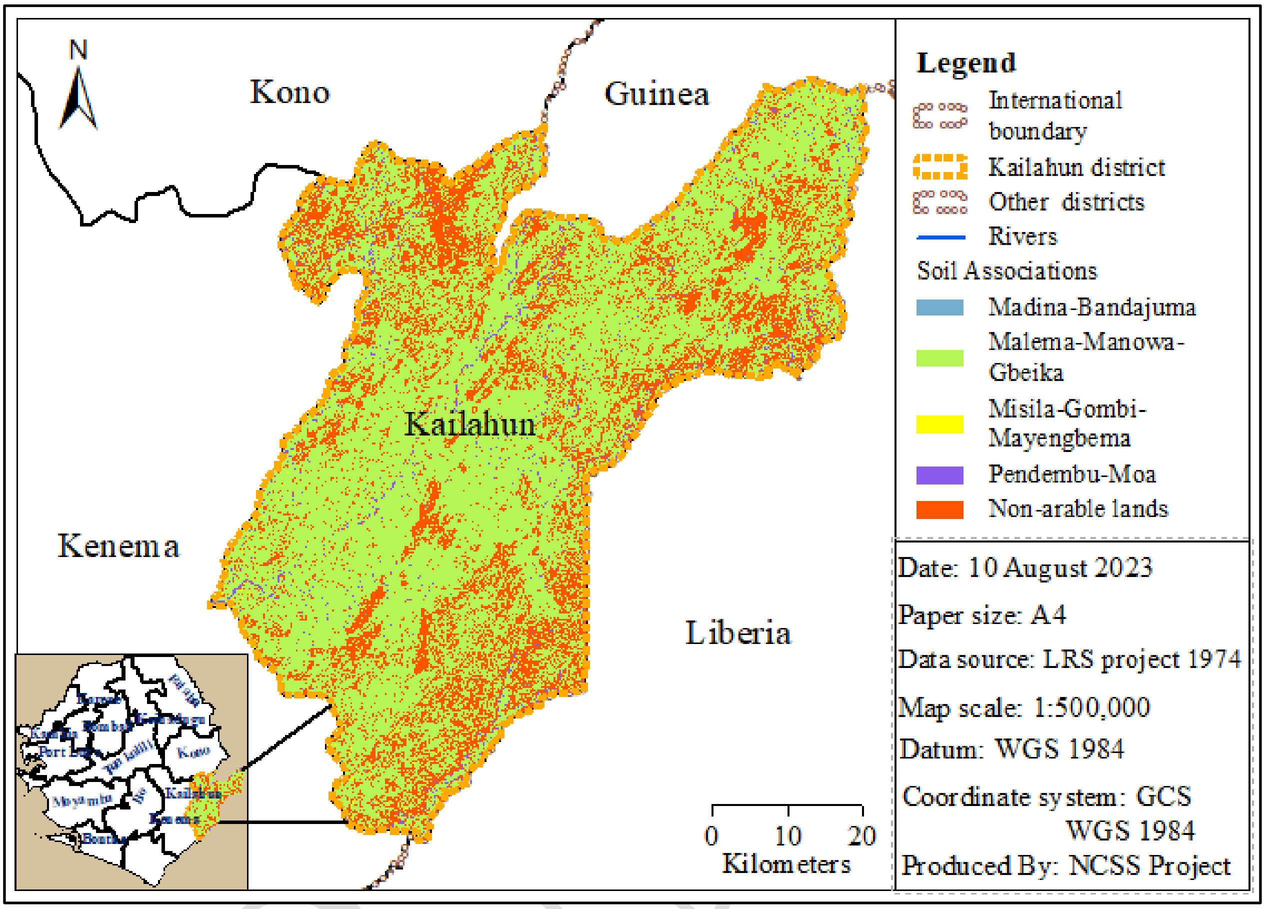

Figure 14. *Soil association map of Kailahun district*

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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 Kailahun District. The soils in Kailahun 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 Kailahun 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 Kailahun 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 distribution of the various land units is presented in Figure 15.

6.1.1 Arable and non-arable lands of Kailahun District

In order to evaluate the capability of land in Kailahun district, soil-site characteristics of the nine-soil series (Section 3.7.1 – 3.7.5) were matched with the criteria for land capability classification. The results, as presented in Table 21, indicates 2984.5 km^2 (71.9 %) of the land area is arable and 1166.7 km^2 (28.1 %) is non-arable. Pendembu and Moa soils are the most arable soils in the district. This is followed by Misila, Gombi and Mayengbema 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 intensive cultivation. They include soils of the Pendembu and Moa, which account for about 70.1 km^2 (1.7 %) of the total area. These soils are nearly level with slopes generally within 0-1 %. The soils are deep, relatively fertile, easily workable and are not subjected to damaging overflows. There are hardly any restrictions or limitations for their use, except for minor limitations, such as fertility. Apart from this single limitation, these lands are very good lands which can be safely cultivated by using appropriate farming methods. 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 Misila, Gombi and Mayengbema series. Use of these soils is constrained by one or more factors such as: (a) moderate limitations which reduce choice of crop, (b) gentle slope (2 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 results show that 31.1 km^2 (0.7 %) 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 options 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. Use of these soils is constrained 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 Malema, Manowa and Gbeika 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, 2879.7 km^2 (69.4 %) of the district is occupied by land capability class III lands as shown in Table 24. A sustainable alternate land use options for these lands could be agri-horticulture, growing of selected legumes (such as groundnut, cowpeas) and grasses.

d. ***Class IV lands:*** These lands are marginally suitable for cultivation of normal crops as they have very severe limitations on the choice of crops. These are sloping lands (10-15 % slopes) that are subject to severe erosion hazard if soil cover is removed. The soils within this landscape are gravelly, stony and sometimes rocky, and have extreme limitations of slopes, shallow depth and low water holding capacity. They include soils of the Madina and Bandajuma series, which cover 3.3 km^2 (0.1 %) of the district. These soils have limited use for agriculture but alternatively, can be used for agri-horticulture and silvipasture systems. However, careful management is needed to raise crops.

e. ***Non-arable lands:*** These are demarcated as steep slopes and hills, rock outcrops, settlements, roads and water bodies. They account for 1166.7 km^2 (28.1 %) of the district.

Table 21. *Area covered by soil associations/types in Kailahun district.*

Land capability group	**Land capability class**	**Soil-physiography**	**Soil association**	**Soil series**	**Area**	
					km^2	**%**
Arable	IV	Soils located on sloping terrains	Madina-Bandajuma	Madina, Bandajuma	3.6	0.22
	III	Soils located on upland eroded surfaces	Malema-Manowa-Gbeika	Malema, Manowa, Gbeika	2879.7	95.11
	II	Soils located on colluvial footslopes and upper river tributary terraces	Misila-Gombi-Mayengbema	Misila, Gombi, Mayengbema	31.1	2.26
	I	Soils located on bottomland swamps and stream terraces	Pendembu-Moa	Pendembu, Moa	70.1	2.41
Non-arable	Steep slopes and hills, rock outcrops, settlements, roads and water bodies				1166.7	28.1

The potential risk of degradation when these arable soils are put under agricultural use are also outlined in *Table 22* 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 22. *Land capability indices of soils and their implications for agricultural use in the Kailahun District*

Soil association	Soil individuals	Capability group	Capability class	Capability subclass/ Risk of hazards
Madina-Bandajuma	Madina	Arable	IV	Marginally suitable for cultivation but have severe limitations which reduce the choice of crops such as steep slope (> 15 %), high gravel content with sometimes boulders and rocky surfaces, somewhat shallow depth, high erosion hazards, low water holding capacity, low fertility, and unstable structure.
	Bandajuma			Marginally suitable for cultivation but have severe limitations which reduce the choice of crops such as moderately steep slope (10 to 25 %), high gravel content, somewhat shallow depth, high erosion hazards, low water holding capacity, low fertility, and unstable structure.
Malema-Manowa-Gbeika	Malema	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.
	Gbeika			
	Baoma			
Misila-Gombi-Mayengbema	Misila	Arable	II	Moderately suitable for cultivation but have moderate limitations of high gravel content, low water holding capacity, iron toxicity and some fertility related challenges such as pH, EC and exchangeable cations.
	Gombi			
	Mayengbema			
Pendembu-Moa	Pendembu	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, waterlogging, iron toxicity, and deposition of eroded sand and silt material from upland areas.
	Moa			

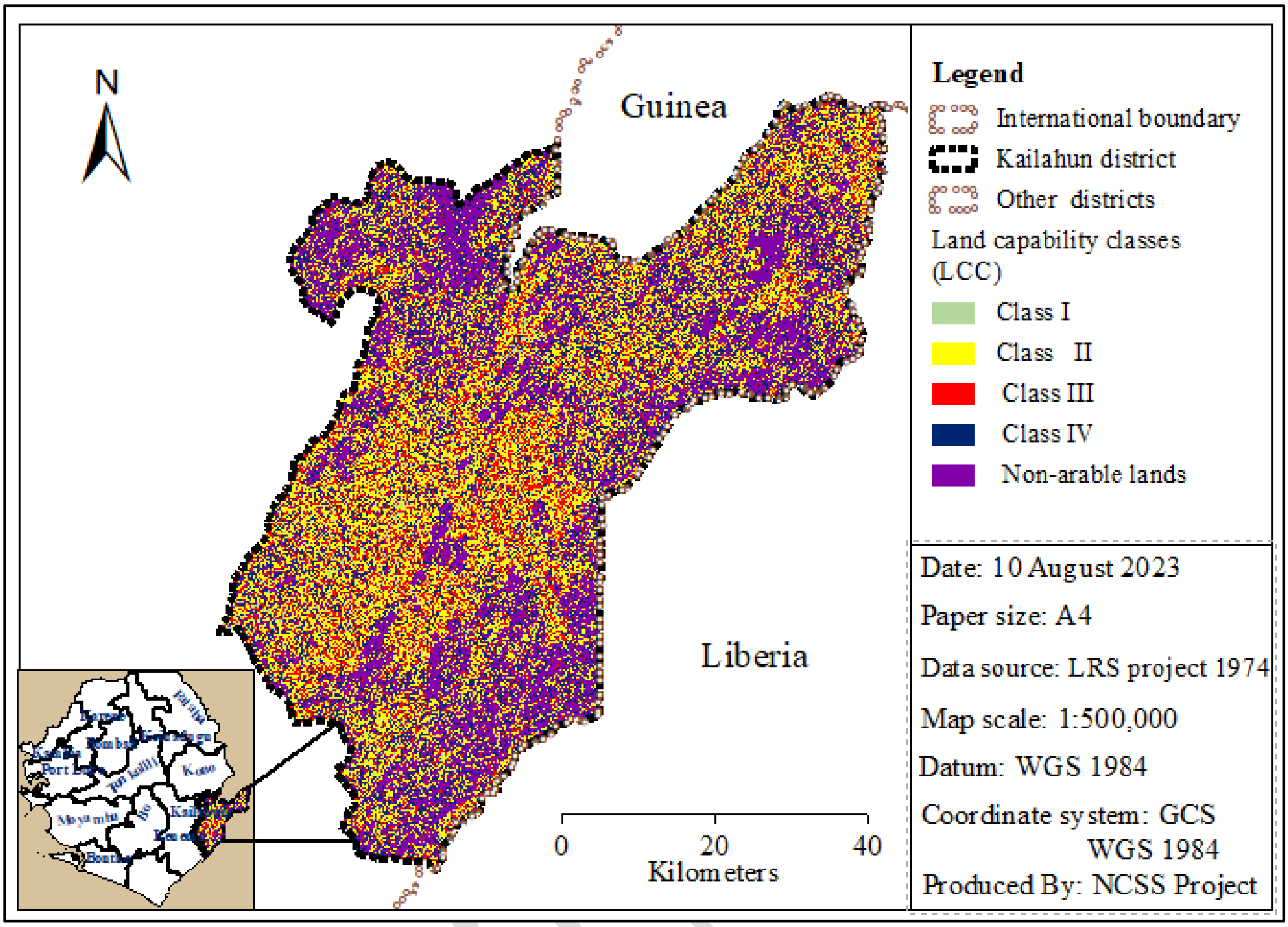

Figure 15. *Land capability map of Kailahun district*

6.2 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 to 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 in Kailahun district are 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 ten soil individuals (i.e., soil series) that are arable in the district, Moa series ranked the highest; being moderately suitable (S2) in their capacity to satisfy the optimal growth requirements and yield of rice in two (rainfed upland rice, natural flooded and irrigated rice cultivation systems) out of four cultivation schemes under low input level of management (Table 26). This is followed by Malema, Manowa, Gbeika, Misila, Gombi and Mayengbema soils, which are moderately suitable (S2) only for rainfed upland rice cultivation (Table 23 and 24). The other soil individuals ranked either marginally suitable (S3) or not suitable for rainfed upland rice and irrigated rice cultivation. Overall, the results shows that soils on steep slopes and hills are not suitable for rainfed bunded rice, natural flooded rice and irrigated rice cultivation but only marginally suitable (S3) for rainfed upland rice. 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 23, soils located on sloping terrains are generally not suitable for rice cultivation, especially rainfed bunded, natural flooded and irrigated rice production systems due to several limitations, mainly related to topography (i.e., slope) and soil physical conditions (i.e., texture, stoniness, etc.). These soils are only marginally suitable (S3) for rainfed upland rice cultivation, with limitations ranging from slope to soil texture.

Table 23. *Suitability of the Madina-Bandajuma soil association for rice cultivation under four farming systems*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Madina	Rainfed Upland rice			■			fs
	Rainfed bunded rice					■	ts
	Natural flooded rice					■	ts
	Irrigated rice					■	ts
Bandajuma	Rainfed Upland rice			■			fs
	Rainfed bunded rice					■	ts
	Natural flooded rice					■	ts
	Irrigated rice					■	ts

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

6.2.1.2 Soils located on upland erosion surfaces

According to the results presented in Table 24, soils located on upland eroded surfaces are moderately suitable (S2) for rainfed upland rice farming but generally not suitable for rainfed bunded, natural flooded and irrigated rice cultivation, due to limitations relating to slope, soil physical condition and fertility.

Table 24. *Suitability of the Malema-Manowa-Gbeika soil association for rice cultivation under four farming systems*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Malema	Rainfed Upland rice		■				sf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf
Manowa	Rainfed Upland rice		■				sf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf
Gbeika	Rainfed Upland rice		■				sf
	Rainfed bunded rice					■	tf
	Natural flooded rice					■	tf
	Irrigated rice					■	tf

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

6.2.1.3 Soils located on colluvial footslopes and upper terraces

According to the results presented in Table 25, the suitability of soils located on colluvial footslopes and upper river tributary terraces vary greatly, ranging from moderate (S2) for rainfed upland rice to currently not suitable (N1) for natural flooded rice and permanently not-suitable (N2) for rainfed bunded and irrigated rice systems due to limitations relating to slope, soil physical condition and fertility.

Table 25. *Suitability of the Misila-Gombi-Mayengbema soil association for rice cultivation under four farming systems*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Misila	Rainfed Upland rice		X				sf
	Rainfed bunded rice					X	stf
	Natural flooded rice				X		stf
	Irrigated rice					X	stf
Gombi	Rainfed Upland rice		X				sf
	Rainfed bunded rice					X	stf
	Natural flooded rice				X		stf
	Irrigated rice					X	stf
Mayengbema	Rainfed Upland rice		X				sf
	Rainfed bunded rice					X	stf
	Natural flooded rice			X			sf
	Irrigated rice					X	stf

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

6.2.1.4 Soils located on bottomland swamps and stream terraces

According to the results presented in Table 26, soils on bottomland swamps and stream terraces are generally suitable for rice cultivation under the four rice cultivation systems. Their suitability ranges from moderate (S2) for rainfed upland, natural flooded and irrigated rice to marginal (S3) for rainfed bunded rice production systems, with limitations of fertility, soil physical characteristics and wetness.

Table 26. *Suitability of the Pendembu-Moa soil association for rice cultivation under four farming systems*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Rainfed Upland rice		X				sf
	Rainfed bunded rice			X			sfw
	Natural flooded rice		X				sf
	Irrigated rice		X				sf
Moa	Rainfed Upland rice		X				sf
	Rainfed bunded rice			X			sfw
	Natural flooded rice		X				sf
	Irrigated rice		X				sf

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

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 ten soil individuals that have been classified as arable are also suitable for growing these crops (Tables 27, 28, 29, and 30). The suitability of these soil individuals ranges from highly suitable (S1) to marginally (S3), as discussed in *Section 6.2.2.1* to 6.2.2.*4* below.

6.2.2.1 Soils located on sloping terrains

A consideration of soil suitability evaluation for soils located on sloping terrains was done in order 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 the antecedent soil degradation when these areas are brought under intense cultivation, but at the time of field survey, vast portions of these erosion-prone areas were under agricultural land use; farmers reported that these areas are their only source of livelihood. From our investigation, we observed that the two major soil individuals of these landscape, i.e., the Madina and Bandajuma soils, are moderately suitable (S2) for cassava, groundnut and sweet potato, and marginally suitable (S3) for maize and cowpea (Table 27), with limitations ranging slope, fertility and soil physical characteristics such as pH, CEC and base saturation.

Table 27. *Suitability of the Madina-Bandajuma soil association for cultivation of other food crops*

Soil association/series	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Madina	Cassava		■				tf
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				tf
	Cowpea			■			stf
Bandajuma	Cassava		■				tf
	Maize			■			stf
	Sweet potato		■				sf
	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 upland erosion surfaces

Soils of Malema, Manowa, and Gbeika series are highly suitable (S1) for cassava, moderately suitable (S2) for sweet potato and groundnut, and marginally suitable (S3) for maize and cowpea (Table 28). Major limitations for use of these soil include moderate to strong slope, high gravel content in root zone layer and fertility problems.

Table 28. *Suitability of the Malema-Manowa-Gbeika soil association for cultivation of other food crops*

Soil association/series	**MAFS target crops**	**Suitability class**					**Limitations for management**
		S1	**S2**	**S3**	**N1**	**N2**	
Malema	Cassava	■					f
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				sf
	Cowpea			■			stf
Manowa	Cassava	■					f
	Maize			■			stf
	Sweet potato		■				sf
	Groundnut		■				sf
	Cowpea			■			stf
Gbeika	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 river tributary terraces

The suitability evaluation of soils on colluvial footslopes and upper river tributary terraces reveals that soils of Misila, Gombi and Mayengbema series are highly suitable (S1) for cassava, sweet potato and groundnut, and moderately suitable (S2) for maize and cowpea (Table 29). 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 29. *Suitability of the Misila-Gombi-Mayengbema soil association for cultivation of other food crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Misila	Cassava	■					f
	Maize		■				sf
	Sweet potato	■					f
	Groundnut	■					f
	Cowpea		■				sf
Gombi	Cassava	■					f
	Maize		■				sf
	Sweet potato	■					f
	Groundnut	■					f
	Cowpea		■				sf
Mayengbema	Cassava	■					f
	Maize		■				sf
	Sweet potato	■					f
	Groundnut	■					f
	Cowpea		■				sf

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

6.2.2.4 Soils located on bottomland swamps and stream terraces

Soils located on bottomland swamps and stream terraces 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 Kailahun district has revealed that soils located on bottomland swamps and stream terraces, been mapped as Pendembu and Moa series are moderately suitable (S2) for maize and sweet potato, and marginally suitable for cassava, groundnut and cowpea (Table 30).

Table 30. *Suitability of the Pendembu-Moa soil association for cultivation of other food crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Cassava			■			sfw
	Maize		■				fw
	Sweet potato		■				fw
	Groundnut			■			sfw
	Cowpea			■			sfw
Moa	Cassava			■			sfw
	Maize		■				fw
	Sweet potato		■				fw
	Groundnut			■			sfw
	Cowpea			■			sfw

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

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 Kailahun district, the same 2015 census report reveals that 3,174 households, which account for 0.3% of country's farming population are engaged in vegetable cultivation, accounting for 4,311 hectares (0.1%) of the land under cultivation and yield of 360,145 kg. Hence, soil suitability evaluation would be of immense relevance for improving the productivity of the vegetable subsector. Based on the results (Table 31, 32, 33 and 34), 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 located on sloping terrains in Kailahun district shows that the arable soils of Madina and Bandajuma series are moderately suitable (S2) for tomato, marginally suitable (S3) for cabbage and currently not-suitable (N1) for onion and carrot due to moderate to extreme limitations of shallow depth and slope, and moisture availability (Table 31). However, with suitable soil conservation management practices, the currently not-suitable soils can be upgraded to marginally suitable (S3) soils.

Table 31. *Suitability of the Madina-Bandajuma soil association for cultivation vegetable crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Madina	Onion				■		stf
	Tomato		■				st
	Cabbage			■			st
	Carrot				■		stf
Bandajuma	Onion				■		stf
	Tomato		■				st
	Cabbage			■			st
	Carrot				■		stf

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

6.2.3.2 Soils located on upland erosion surfaces

Soils on upland erosion surfaces show similar suitability status with soils on steep slopes and hills, i.e., moderately suitable (S2) for tomato, marginally suitable (S3) for cabbage and currently not-suitable (N1) for onion and carrot due to moderate to extreme limitations of shallow depth and slope, and moisture availability (Table 32). 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 32. *Suitability of the Malema-Manowa-Gbeika soil association for cultivation of vegetable crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Malema	Onion				■		stf
	Tomato		■				sf
	Cabbage			■			st
	Carrot				■		stf
Manowa	Onion				■		stf
	Tomato		■				sf
	Cabbage			■			st
	Carrot				■		stf
Gbeika	Onion				■		stf
	Tomato		■				sf
	Cabbage			■			st
	Carrot				■		stf

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

6.2.3.3 Soils located on colluvial footslopes and upper river tributary terraces

The suitability of soils on colluvial footslopes and upper river tributary terraces, i.e., soils of Misila, Gombi and Mayengbema series ranges from moderately suitable (S2) for onion, tomato and carrot, to marginally suitable (S3) for cabbage (Table 33). 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 33. *Suitability of the Misila-Gombi-Mayengbema soil association for cultivation of vegetable crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Misila	Onion						f
	Tomato						f
	Cabbage						sf
	Carrot						f
Gombi	Onion						f
	Tomato						f
	Cabbage						sf
	Carrot						f
Mayengbema	Onion						f
	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 bottomland swamps and stream terraces

Pendembu and Moa soils on bottomland swamps and stream terraces share similar features with Misila, Gombi and Mayengbema soils on colluvial footslopes and upper river tributary terraces. These soils are moderately suitable (S2) for onion, tomato and carrot, and marginally suitable (S3) for cabbage (Table 34). Major limitations are associated with waterlogging, flooding, and fertility, which can be overcome by suitable soil conservation management practices.

Table 34. *Suitability of the Pendembu-Moa soil association for cultivation of vegetable crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Onion						f
	Tomato						f
	Cabbage						fw
	Carrot						f
Moa	Onion						f
	Tomato						f
	Cabbage						fw
	Carrot						f

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

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 Kailahun district, 2015 census report reveals that out of a total of 69,569 agricultural households engaged in tree crop cultivation, 30,615 (i.e., 15.0 %) are engaged in cocoa cultivation, 21,186 (i.e., 10.4 %) are engaged in coffee cultivation, and 17,210 (i.e., 8.5 %) are engaged in oil palm cultivation. In terms of area under cultivation per tree crop, out of a total area of 499,264 ha under tree crop, cocoa accounts for 114,125 ha, coffee accounts for 66,814 ha, oil palm accounts for 62,658 ha, citrus accounts for 1,327 ha and cashew accounts for 44 ha. This is an indication of how important is the tree crop subsector in the national economy development. Based on the results (Table 35, 36, 37 and 38), 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 located on sloping terrains

The suitability of Madina and Bandajuma soils, located on sloping terrains, ranges from moderately suitable (S2) for cocoa, arabica coffee and robusta coffee, to marginally suitable (S3) for cashew and oil palm (Table 35). 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 35. *Suitability of the Madina-Bandajuma soil association for cultivation tree crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Madina	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew			■			tf
	Oil palm			■			tf
Bandajuma	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 upland erosion surfaces

The suitability of Malema, Manowa and Gbeika soils, located on upland erosion surfaces ranges from moderately suitable (S2) for cocoa and cashew, to marginally suitable (S3) for arabica coffee, robusta coffee and oil palm (Table 36). Major limitations are associated with coarse texture due to gravel and fertility, which can be overcome by suitable soil conservation management practices.

Table 36. *Suitability of the Malema-Baoma-Gbeika soil association for cultivation of tree crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Malema	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf
Manowa	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf
Gbeika	Cocoa		■				f
	Arabica coffee			■			tf
	Robusta coffee			■			tf
	Cashew		■				f
	Oil palm			■			tf

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

6.2.4.3 Soils located on colluvial footslopes and upper river tributary terraces

The suitability of arable soils of Misila, Gombi and Mayengbema series, located on colluvial footslopes and upper river tributary terraces indicates that soils are moderately suitable (S2) for cocoa, arabica coffee, robusta coffee and oil palm, and marginally suitable (S3) for cashew (Table 37). Despite this suitability, there might be few limitations of minor concern that are associated with fertility, which can be overcome by suitable soil conservation and management practices.

Table 37. *Suitability of the Misila-Gombi-Mayengbema soil association for cultivation of tree crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	**S2**	**S3**	**N1**	**N2**	
Misila	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew			■			fw
	Oil palm		■				f
Gombi	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew			■			fw
	Oil palm		■				f
Mayengbema	Cocoa		■				f
	Arabica coffee		■				f
	Robusta coffee		■				f
	Cashew			■			fw
	Oil palm		■				f

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

6.2.4.4 Soils located on bottomland swamps and stream terraces

The suitability of arable soils of Pendembu and Moa series located on bottomland swamps and stream terraces, ranges from marginally suitable (S3) for cocoa and oil palm to currently not-suitable (S3) for arabica coffee, robusta coffee and cashew (Table 38). 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 38. *Suitability of the Pendembu-Moa soil association for cultivation of tree crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	**S2**	**S3**	**N1**	**N2**	
Pendembu	Cocoa			■			fw
	Arabica coffee				■		tfw
	Robusta coffee				■		tfw
	Cashew				■		tfw
	Oil palm			■			fw
Moa	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)

6.2.5 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 are these crops in substituting for the staple food. Based on the results (Table 39, 40, 41, and 42), 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 Madina and Bandajuma series located on sloping terrains for fruit crops, ranges from marginally suitable (S3) for pineapple and banana, to currently not-suitable (S3) for mango and citrus (Table 39). 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 39. *Suitability of the Madina-Bandajuma soil association for cultivation fruit crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Madina	Mango				■		sf
	Citrus				■		sf
	Pineapple			■			f
	Banana			■			f
Bandajuma	Mango				■		sf
	Citrus				■		sf
	Pineapple			■			f
	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 upland erosion surfaces

The suitability of Malema, Manowa and Gbeika series located on upland erosion surfaces for fruit crops ranges from moderately suitable (S2) for pineapple and banana to marginally suitable (S3) for mango and citrus (Table 40). 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 40. *Suitability of the Malema-Manowa-Gbeika soil association for cultivation of fruit crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Malema	Mango			■			sf
	Citrus			■			sf
	Pineapple		■				f
	Banana		■				f
Manowa	Mango			■			sf
	Citrus			■			sf
	Pineapple		■				f
	Banana		■				f
Gbeika	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 river tributary terraces

The suitability Misila, Gombi and Mayengbema soils, located on colluvial footslopes and upper river tributary terraces for fruit crops shows that these soils are moderately suitable (S2) for mango, citrus, pineapple and banana (Table 41). 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 41. *Suitability of the Misila-Gombi-Mayengbema soil association for cultivation of fruit crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Misila	Mango		■				f
	Citrus		■				f
	Pineapple		■				f
	Banana		■				f
Gombi	Mango		■				f
	Citrus		■				f
	Pineapple		■				f
	Banana		■				f
Mayengbema	Mango		■				f
	Citrus		■				f
	Pineapple		■				f
	Banana		■				f

f= fertility (pH, CEC, Base saturation)

6.2.5.4 Soils located on bottomland swamps and stream terraces

The suitability of Pendembu and Moa soils located on bottomland swamps and stream terraces for fruit crops, shows that these soils are moderately suitable (S2) for banana, marginal suitable (S3) for mango and citrus, and somewhat permanently not-suitable for pineapple (Table 42). 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 42. *Suitability of the Pendembu-Moa soil association for cultivation of fruit crops*

Soil association/series	MAFS target crops	Suitability class					Limitations for management
		S1	S2	S3	N1	N2	
Pendembu	Mango						fw
	Citrus						fw
	Pineapple						tfw
	Banana						f
Moa	Mango						fw
	Citrus						fw
	Pineapple						tfw
	Banana						f

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

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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 Kailahun 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). 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 Kailahun district, we observed that some of the soils of Kailahun district share similar characteristics as those of Kenema and Kono districts since most of the soil associations and individuals are repeating. Hence, the soil fertility management options remain the same as for those discussed for soils of Kenema and Kono 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, upland eroded surfaces, and colluvial footslopes and upper river tributary terraces such as soils of the Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, and Mayengbema 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 Pujehun 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 Non-Acid Sulphate soils (i.e. soils located on bottomland swamps and stream terraces such as soils of the Pendembu and Moa 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 43 summarizes the highly suitable (S1) and moderately suitable (S2) classes of soils recommended for agricultural investment in Kailahun District.

7.8 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 43. *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	Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa	f (pH, CEC), s (texture)
	Rainfed bunded rice		NONE	t (slope)
	Natural flooded rice		Pendembu, Moa	f (pH, CEC), s (texture)
	Irrigated rice			
Other food crop production	Cassava	Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema	Madina, Bandajuma,	f (pH, CEC), s (texture)
	Maize	NONE	Misila, Gombi, Mayengbema, Pendembu, Moa	f (pH, CEC), s (texture)
	Sweet potato	Misila, Gombi, Mayengbema	Madina, Bandajuma, Malema, Manowa, Gbeika, Pendembu, Moa	f (pH, CEC), s (texture), w (drainage)
	Groundnut			f (pH, CEC), s (texture)
	Cowpea	NONE	Misila, Gombi, Mayengbema	f (pH, CEC)
Tree crop production	Cacao		Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema	f (pH, CEC)
	Arabica coffee		Madina, Bandajuma, Misila, Gombi, Mayengbema	f (pH, CEC), s (texture)
	Robusta coffee			
	Cashew		Malema, Manowa, Gbeika	f (pH, CEC), s (texture)
	Oil palm		Misila, Gombi, Mayengbema	f (pH, CEC)
Fruit crop production	Mango			
	Citrus			
	Pineapple		Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema	f (pH, CEC), s (texture)
	Banana		Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa	f (pH, CEC)
Vegetable production	Onion		Misila, Gombi, Mayengbema, Pendembu, Moa	f (pH, CEC)
	Tomato		Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa	f (pH, CEC)
	Cabbage		Misila, Gombi, Mayengbema	f (pH, CEC), s (texture)
	Carrot		Pendembu, Moa	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 for the district of Kailahun 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 (MAFS-AED) is now equipped with 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 take into consideration the evidence that soils with the highest potential for returns to investment in the Kailahun district are:

i. Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa soils of moderate suitability (S2) for rainfed upland rice;
ii. Pendembu and Moa soils of moderate suitability (S2) for natural flooded and irrigated rice;
iii. Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema soils of high suitability (S1) for cassava, and Misila, Gombi, Mayengbema of high suitability (S1) for sweet potato, and Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa soils of moderate suitability (S2) for cassava, maize, sweet potato, groundnut and cowpea;
iv. Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema soils of moderate suitability (S2) for cocoa, Arabica coffee, Robusta coffee, cashew and oil palm;
v. Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa soils of moderate suitability (S2) for mango, citrus, pineapple and banana; and
vi. Madina, Bandajuma, Malema, Manowa, Gbeika, Misila, Gombi, Mayengbema, Pendembu, Moa soils of moderate suitability (S2) for onion, tomato, cabbage and carrot.

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Appendices

1a. Soil profile description of profile pit No. KAI001; Madina series

District: Kailahun; **Chiefdom**: Yawei; **Village**: Madina; **GPS location**: 8.269791°/10.834464°; **Elevation**: 473m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain/ Interfluve side slope; Parent **Material**: Weathered Residium; Landscape **position**: Crest; **Slope**: 10.2%; **Vegetation**: Semi-deciduous dwarf shrubs; **Erosion class and intensity**: e2, moderate; **Drainage and permeability:** Well drained and rapid; **Landuse**: Tree crop plantation; **Major crops grown**: Cocoa and coffee.

Land System: Sandaru

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

Mapping Unit: KAI001
Gravel-free soil

Horizon (cm)	Morphological Description
Ap (0 – 40)	Pale brown (10YR6/3 dry) and brown (10YR5/3 moist); sandy clay loam; 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 smooth boundary to horizon below.
Bt1 (40 – 80)	Light yellowish brown (10YR6/4 dry) and yellowish brown (10YR5/4 moist); silty clay; moderate, fine, angular and sub-angular blocky; slightly hard (dry), friable (moist); sticky and plastic; plenty very fine, fine and very few medium pores; plenty very fine and fine roots; presence of few open boreholes, termites, ants and other insects; clear and gradual boundary to horizon below.
Bt2 (80 – 153)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); silty clay loam; moderate, fine, angular 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 open boreholes, termites, ants and other insects; clear and wavy boundary to horizon below.
C (153 – 202+)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); silty clay; moderate, fine, angular and sub-angular blocky; slightly hard (dry), friable (moist); sticky and plastic; plenty very fine and fine pores; few very fine and very few fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon above.

1b. Analytical laboratory data of profile pit No. KAI001; Madina series

Horizon (cm)	**Unit**	**0-40**	**40-80**	**80-153**	**153-202+**
Sand	%	72.80	72.80	72.80	68.80
Silt	%	7.28	5.28	1.28	3.28
Clay	%	19.92	21.92	25.92	27.92
Organic Carbon	%	1.89	0.89	0.65	0.81
Bray P1	mg/kg soil	5.30	1.80	1.08	0.00
pH 1:1 soil : water ratio		4.40	4.40	4.50	4.60
pH 1:1 M KCl ratio		3.40	3.50	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	3.90	4.40	3.68	4.15
Exchangeable calcium	mg/kg soil	2.01	2.23	1.68	2.16
Exchangeable magnesium	mg/kg soil	0.36	0.55	0.39	0.42
Exchangeable potassium	mg/kg soil	0.22	0.24	0.19	0.24
Exchangeable sodium	mg/kg soil	0.22	0.25	0.18	0.24
Exchangeable acidity	cmol/kg soil	1.09	1.13	1.24	1.09
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	6.00	7.00	6.00	4.00
DTPA extractable iron	mg/kg soil	2.66	128.43	16.68	0.87
DTPA extractable copper	mg/kg soil	3.58	2.71	2.24	1.79
DTPA extractable zinc	mg/kg soil	6.00	8.58	6.35	6.78

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__2a.__ Soil profile description of profile pit No. KAI002; Bandajuma series

District: Kailahun; **Chiefdom**: Yawei; **Village**: Bandajuma; **GPS location**: 8.315943°/10.849294°; **Elevation**: 237m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain; Parent **Material**: Weathered Residium; Landscape **position**: crest; **Slope**: 7.5%; **Vegetation**: Farm bush; **Erosion class and intensity**: e3, Severe; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow land; **Major crops grown**: Rice, beans, and cassava.

Land System: Sandaru
Classification : USDA Taxonomy: Plinthic dystropept **FAO-UNESCO:** Dystric Nitosol

Mapping Unit: KAI002
Gravelly soil

Horizon (cm)	Morphological Description
Ae (0 – 27)	Reddish brown (5YR5/3 dry) and (5YR4/3 moist); gravelly sandy loam; moderate, coarse, crumbly; slightly hard (dry), friable (moist); non sticky and non-plastic; common very fine, fine, medium, and coarse pores; common very fine, plenty fine, few medium, very few coarse roots; presence of earthworms, termites, millipedes, ants and other insects; clear and smooth boundary to horizon below.
Bv1 (27 – 66)	Yellowish red (5YR 4/6 dry) and (5Y/R4/6 moist); gravelly sandy clay; moderate, coarse, crumbly; slightly hard (dry), friable (moist); non sticky and non-plastic; few very fine, fine and common medium, and few coarse pores; common very fine, plenty fine, few medium, coarse and very coarse roots; presence of termites, ants and other insects; diffuse and irregular boundary to horizon below.
Bv2 (66 – 152+)	Yellowish red (5YR5/8 dry) and (5YR5/8 moist); gravelly sandy clay; strong, coarse, 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 earthworms, termites, ants and other insects; gradual and irregular boundary to horizon below.

2b. *Analytical laboratory data of profile pit No. KAI002; Bandajuma series*

Horizon (cm)	**Unit**	**0-27**	**27-66**	**66-152+**
Sand	%	74.08	66.08	58.08
Silt	%	5.08	5.08	5.08
Clay	%	20.84	28.84	36.84
Organic Carbon	%	2.00	1.04	0.80
Bray P1	mg/kg soil	9.99	7.25	0.15
pH 1:1 soil : water ratio		4.40	4.40	4.90
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	6.84	3.86	4.12
Exchangeable calcium	mg/kg soil	0.78	0.02	0.11
Exchangeable magnesium	mg/kg soil	1.75	0.25	1.48
Exchangeable potassium	mg/kg soil	0.16	0.1	0.11
Exchangeable sodium	mg/kg soil	0.17	0.08	0.09
Exchangeable acidity	cmol/kg soil	3.98	3.41	2.33
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	5.00	3.00	3.00
DTPA extractable iron	mg/kg soil	1.31	1.78	1.31
DTPA extractable copper	mg/kg soil	7.43	6.15	11.47
DTPA extractable zinc	mg/kg soil	53.8	46.48	30.70

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__3a.__ Soil profile description of profile pit No. KAI003; Malema series

District: Kenema; **Chiefdom**: Upper Bambara; **Village**: Malema; **GPS location**: 7.991973°/10.618492°; **Elevation**: 213m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain/ Interfluve crest; Parent **Material**: Weathered Residium; Landscape **position**: Crest; **Slope**: 7.8%; **Vegetation**: Semi-deciduous trees and shrubs; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Tree crop plantation; **Major crops grown**: Cocoa and coffee.

Land System: Blama

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

Mapping Unit: KAI003 Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ap (0 – 30)	Pale brown (10YR6/3 dry) and brown (10YR5/3 moist); sandy loam; 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 open boreholes, termites, millipedes, ants and other insects; clear and smooth boundary to horizon below.
Bt1 (30 – 61)	Light yellowish brown (10YR6/4 dry) and yellowish brown (10YR5/4 moist); sandy clay loam; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine and medium pores; common very fine and few fine roots; presence of open boreholes, termites, ants and other insects; clear and gradual boundary to horizon below.
Bt2 (61 – 90)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); sandy clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; plenty very fine, fine and medium pores; common very fine and few fine roots; presence of few open boreholes, termites, ants and other insects; clear and wavy boundary to horizon below.
Cr (90 – 153+)	Brownish yellow (10YR6/6 dry) and yellowish brown (10YR5/6 moist); gravelly sandy clay; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; plenty very fine, fine, few medium and coarse pores; few very fine and few fine roots; presence of termites, ants and other insects; clear and wavy boundary to horizon above.

3b. Analytical laboratory data of profile pit No. KAI003; Malema series

Horizon (cm)	Unit	0-30	30-61	61-90	90-153+
Sand	%	78.80	74.08	70.08	72.08
Silt	%	5.08	3.08	5.08	3.08
Clay	%	16.12	22.84	24.84	24.84
Organic Carbon	%	2.36	0.92	0.56	0.72
Bray P1	mg/kg soil	10.21	8.95	6.66	7.55
pH 1:1 soil : water ratio		4.30	4.20	4.50	4.60
pH 1:1 M KCl ratio		3.50	3.60	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	9.54	6.77	3.96	2.95
Exchangeable calcium	mg/kg soil	1.77	1.77	0.23	0.04
Exchangeable magnesium	mg/kg soil	5.58	1.61	1.30	0.67
Exchangeable potassium	mg/kg soil	0.24	0.24	0.12	0.10
Exchangeable sodium	mg/kg soil	0.22	0.22	0.1	0.08
Exchangeable acidity	cmol/kg soil	1.73	2.93	2.21	2.06
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	11.00	6.00	3.00	2.00
DTPA extractable iron	mg/kg soil	5.24	3.20	3.04	2.412
DTPA extractable copper	mg/kg soil	4.472	4.472	4.392	16.552
DTPA extractable zinc	mg/kg soil	40.7	26.62	23.24	18.16

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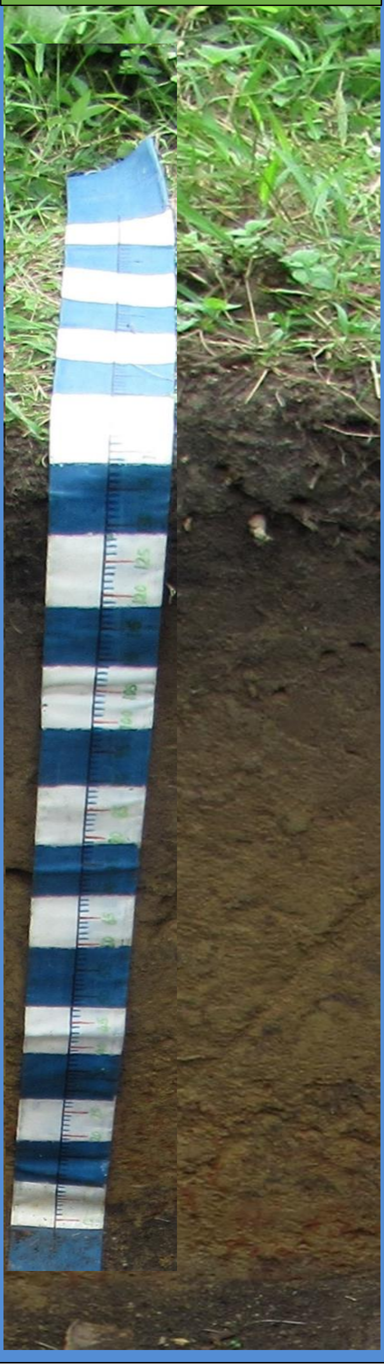
4a. Soil profile description of profile pit No. KAI004; Manowa series

District: Kailahun; **Chiefdom**: Peje Bongre; **Village**: Manowa; **GPS location**: 8.165244°/10.749939°; **Elevation**: 210m; **Physiography**: Undulating plain; La**ndform/facet**: Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Foot slope; **Slope**: 4.2%; **Vegetation**: Tree crops and wild palms; **Erosion class and intensity**: e0, Nil; **Drainage and permeability:** Well drained and rapid; **Landuse**: Plantation; **Major crops grown**: Oil palm, cocoa, coffee, mangoes and banana.

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

Mapping Unit: KAI004
Gravel-free soil underlain by hard bedrock



Horizon (cm)	Morphological Description
Ahe (0 – 26)	Dark gray (10YR4/1 dry) and very dark gray (10YR3/1 moist); loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); non-sticky and non-plastic; common very fine, fine and medium pores; common very fine, plenty fine, few medium, few coarse and very few vey coarse roots; presence of earthworms, termites, millipedes, ants and other insects; clear and smooth boundary to horizon below.
Bh (26 – 52)	Dark greyish brown (10YR 4/2 dry) and brown (10Y/R4/3 moist); clay loam; moderate, medium, crumbly and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; common very fine, fine and medium pores; common very fine, plenty fine and few medium roots; presence of termites, ants and other insects; clear and irregular boundary to horizon below.
Bt (52 – 102)	Yellowish brown (10YR5/4 dry) and dark yellowish (10YR4/4 moist); sandy clay; strong, fine, angular and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; common very fine, fine, medium and very few coarse pores; common very fine, plenty fine, and medium roots; presence of earthworms, termites, ants and other insects; gradual and smooth boundary to horizon below.
Cg (102 – 156+)	Light yellowish brown (10YR6/4 dry) and brownish yellow (10YR6/6 moist); sandy clay; strong, massive, angular and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and few coarse pores; common very fine, few fine and medium roots; presence of earthworms, termites, ants and other insects; presence of abundant soft mottles (2.5YR4/8 – red/moist); clear and smooth boundary to horizon below.

4b. *Analytical Laboratory Data of Profile Pit No. KAI004; Manowa series*

Horizon (cm)	**Unit**	**0-26**	**26-52**	**52-102**	**102-156+**
Sand	%	80.80	72.80	66.80	62.80
Silt	%	5.08	3.08	3.08	3.08
Clay	%	14.12	24.12	30.12	34.12
Organic Carbon	%	1.68	1.12	0.72	0.60
Bray P1	mg/kg soil	12.14	6.81	0.22	1.33
pH 1:1 soil : water ratio		4.60	4.50	4.60	4.90
pH 1:1 M KCl ratio		3.60	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	7.37	6.95	9.17	7.19
Exchangeable calcium	mg/kg soil	4.03	3.48	3.35	3.54
Exchangeable magnesium	mg/kg soil	0.71	0.4	2.82	1.35
Exchangeable potassium	mg/kg soil	0.43	0.38	0.37	0.39
Exchangeable sodium	mg/kg soil	0.51	0.44	0.42	0.45
Exchangeable acidity	cmol/kg soil	1.69	2.25	2.21	1.46
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	36.00	5.00	15.00	7.00
DTPA extractable iron	mg/kg soil	4.46	4.93	1.94	0.84
DTPA extractable copper	mg/kg soil	11.15	5.59	4.39	5.03
DTPA extractable zinc	mg/kg soil	61.69	48.73	36.34	8.10

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5a. Soil profile description of profile pit No. KAI005; Gbeika series

District: Kailahun; **Chiefdom**: Njaluahun; **Village**: Jonga; **GPS location**: 8.048812°/10.839471°; **Elevation**: 192m; **Physiography**: Alluvial plain; **Landform/facet**: Interfluve crest; **Parent Material**: Colluvium; **Landscape position**: Back slope; **Slope**: 3.6%; **Vegetation**: Outgrown oil palm plantation with semi-deciduous dwarf shrubs; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Well drained and rapid; **Landuse**: Tree cropping; **Major crops grown**: Oil palm.

Land System: Blama

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

Mapping Unit: KAI005
Gravel-free soil

Horizon (cm)	Morphological Description
Ah (0 – 32)	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist); sandy loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); not sticky and not plastic; plenty very fine, fine, medium, coarse pores; plenty very fine, fine, few medium roots; presence of open boreholes, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bt1 (32 – 66)	Dark yellowish brown (10YR 5/6 dry) and dark yellowish brown (10YR4/6 moist); sandy clay loam; moderate, fine, crumbly; slightly hard (dry), friable (moist); slightly sticky and slightly 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.
Bt2 (69 – 150+)	Yellowish brown (10YR 5/6 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; 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 above.

5b. Analytical laboratory data of profile pit No. KAI005; Gbeika series

Horizon (cm)	**Unit**	**0-32**	**32-56**	**56-150+**
Sand	%	82.08	84.08	86.08
Silt	%	5.08	3.08	1.08
Clay	%	12.84	12.84	12.84
Organic Carbon	%	1.44	0.8	0.16
Bray P1	mg/kg soil	18.06	1.04	15.98
pH 1:1 soil : water ratio		4.70	4.50	4.30
pH 1:1 M KCl ratio		3.50	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	5.93	4.84	3.76
Exchangeable calcium	mg/kg soil	0.31	1.15	1.99
Exchangeable magnesium	mg/kg soil	2.91	1.52	0.13
Exchangeable potassium	mg/kg soil	0.12	0.19	0.26
Exchangeable sodium	mg/kg soil	0.11	0.22	0.33
Exchangeable acidity	cmol/kg soil	2.48	1.76	1.05
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	11.00	6.00	1.00
DTPA extractable iron	mg/kg soil	1.47	1.11	0.75
DTPA extractable copper	mg/kg soil	8.35	4.99	1.63
DTPA extractable zinc	mg/kg soil	73.00	24.56	23.88

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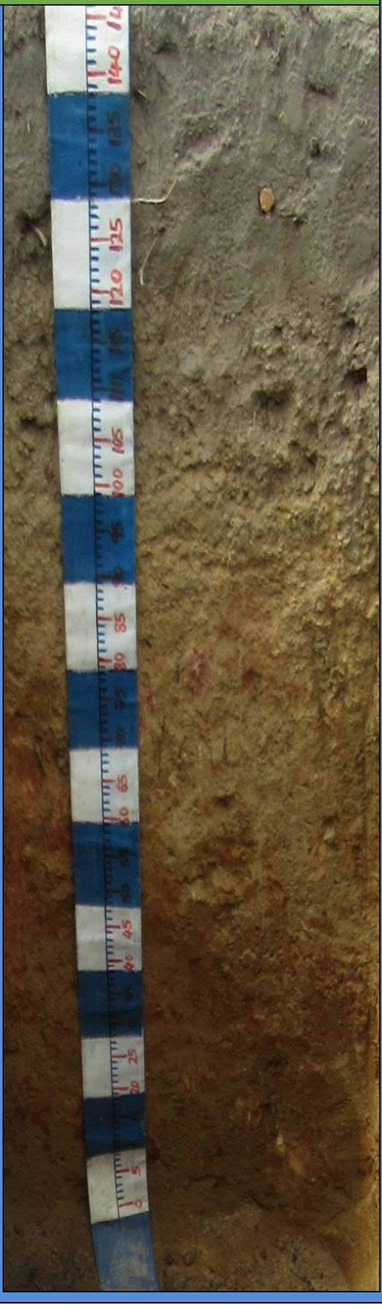
6a. Soil profile description of profile pit No. KAI006; Misila series

District: Kailahun; **Chiefdom**: Luawa; **Village**: Gbela; **GPS location**: 8.294071°/10.467233°; **Elevation**: 384m; **Physiography**: Interior plain; La**ndform/facet**: Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 3.6%; **Vegetation**: Semi-deciduous dwarf shrubs; **Erosion class and intensity**: e2, moderate; **Drainage and permeability:** Well drained and rapid; **Landuse**: Fallow shifting cultivation; **Major crops grown**: Rice, cassava, sesame, sour-sour.

Land System: Sandaru

Classification : USDA Taxonomy: Plinthic Paleudult **FAO-UNESCO:** Haplic plinthosol

Mapping Unit: KAI006 Gravel-free over gravel soil



Horizon (cm)	Morphological Description
Ap (0 – 33)	Gray (10YR5/1dry) and dark gray (10YR4/1 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 (33 – 68)	Pale brown (10YR6/3 dry) and brown (10YR5/3 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 (68 – 151+)	Brownish yellow (10YR6/6 dry) and dark yellowish brown (10YR4/6 moist); 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 soft plinthite 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. KAI006; Misila series*

Horizon (cm)	**Unit**	**0-33**	**33-68**	**68-151+**
Sand	%	72.80	62.80	68.80
Silt	%	13.28	11.28	7.28
Clay	%	13.92	25.92	23.92
Organic Carbon	%	1.73	0.58	0.42
Bray P1	mg/kg soil	4.49	3.41	0.72
pH 1:1 soil : water ratio		4.40	4.70	4.90
pH 1:1 M KCl ratio		3.50	3.50	4.10
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	4.15	4.07	6.00
Exchangeable calcium	mg/kg soil	2.60	2.63	3.99
Exchangeable magnesium	mg/kg soil	0.41	0.32	0.96
Exchangeable potassium	mg/kg soil	0.28	0.28	0.41
Exchangeable sodium	mg/kg soil	0.30	0.31	0.49
Exchangeable acidity	cmol/kg soil	0.56	0.53	0.15
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	10.00	2.00	6.00
DTPA extractable iron	mg/kg soil	514.51	56.29	505.14
DTPA extractable copper	mg/kg soil	5.38	5.86	2.87
DTPA extractable zinc	mg/kg soil	4.29	3.09	11.68

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7a. Soil profile description of Profile Pit No. KAI007; Gombi series

District: Kailahun; **Chiefdom**: Kissi Teng; **Village**: Fowa; **GPS location**: 8.313217°/10.445331°; **Elevation**: 380m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain/ Interfluve crest; **Parent Material**: Weathered Residium; **Landscape position**: Summit; **Slope**: 1.8%; **Vegetation**: Bush regrowth with 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, sesame, maize, and groundnut.

Land System: Kulufaga

Classification : USDA Taxonomy: Plinthic Udoxic Dystropept **FAO-UNESCO:** Haplic plinthosol

Mapping Unit: KAI007 Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ap (0 – 11)	Reddish gray (5YR5/2 dry) and dark reddish gray (5YR4/2 moist); loamy sand; moderate, fine, crumbly and sub-angular blocky; 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; clear and smooth boundary to horizon below.
Btv1 (11 – 31)	Reddish brown (5YR5/4 dry) and reddish brown (5YR4/4 moist); sandy clay; moderate, medium, crumbly; hard (dry), firm (moist); slightly sticky and slightly plastic; plenty very fine, fine, medium and coarse pores; plenty very fine, fine, few medium roots; presence of soft plinthite having red colour 7.5YR5/8 moist (covering about 20-25% of soil mass), earthworms, termites, ants and other insects; clear and wavy boundary.
Btv2 (31 – 67)	Reddish brown (5YR5/6 dry) and reddish brown (5YR4/6 moist); sandy clay; strong, medium, crumbly and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, medium, and few coarse pores; plenty very fine and fine, few medium roots; presence of soft plinthite having red colour 7.5YR5/8 moist (covering about 30-40% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon above.
Bt2 (67 – 117)	Yellowish red (5YR6/8 dry) and yellowish red (5YR5/8 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 weathered plinthite 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.
Cssg (117 – 156+)	Yellowish red (5YR5/8 dry) and yellowish red (5YR5/6 moist); sandy clay; strong, fine, angular and sub-angular blocky; very hard (dry), firm (moist); sticky and plastic; plenty very fine, fine, medium pores; few very fine and fine, very few medium roots; presence of weathered plinthite 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.

7b. Analytical laboratory data of profile pit No. KAI007; Gombi series

Horizon (cm)	Unit	0-11	11-31	31-67	67-117	117-156+
Sand	%	76.80	70.80	64.80	58.80	52.80
Silt	%	9.28	3.28	2.72	8.72	14.72
Clay	%	13.92	25.92	32.48	32.48	32.48
Organic Carbon	%	1.77	0.62	0.53	0. 68	0..83
Bray P1	mg/kg soil	4.04	3.86	3.68	3.5	3.32
pH 1:1 soil : water ratio		4.50	4.50	4.50	4.50	4.50
pH 1:1 M KCl ratio		4.50	3.50	3.50	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	6.47	4.77	3.44	3.86	5.57
Exchangeable calcium	mg/kg soil	4.32	2.85	1.38	1.09	1.56
Exchangeable magnesium	mg/kg soil	0.64	0.23	0.18	0.59	1.00
Exchangeable potassium	mg/kg soil	0.44	0.3	0.16	0.02	0.12
Exchangeable sodium	mg/kg soil	0.54	0.34	0.14	0.06	0.26
Exchangeable acidity	cmol/kg soil	0.53	1.05	1.58	2.10	2.63
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	12.00	4.00	4.00	12.00	20.00
DTPA extractable iron	mg/kg soil	545.31	48.30	448.72	945.74	1442.75
DTPA extractable copper	mg/kg soil	1.768	6.168	10.57	14.97	19.37
DTPA extractable zinc	mg/kg soil	7.38	1.8	3.78	9.36	14.94

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__8a.__ Soil profile description of profile pit No. KAI008; Mayengbema series

District: Kenema; **Chiefdom**: Luawa; **Village**: Soru; **GPS location**: 8.292535°/10.435276°; **Elevation**: 371m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain/ Interfluve side slope; **Parent Material**: Weathered Residium; **Landscape position**: Back slope; **Slope**: 9.8%; **Vegetation**: Plantation forestry with deciduous and semi-deciduous trees and shrubs; **Erosion class and intensity**: e1, slight; **Drainage and permeability:** Moderately well drained and moderately rapid; **Landuse**: Tree crop plantation; **Major crops grown**: Cocoa, Coffee, Avogadro.

Land System: Kulufaga

Classification : USDA Taxonomy: Plinthic Paleaquult **FAO-UNESCO:** Lithic Leptosol

Mapping Unit: KAI008
Gravel-free over gravel soil

Horizon (cm)	Morphological Description
Ah (0 – 33)	Very dark gray (10YR 3/1 dry) to dark grayish brown (10YR 4/2 moist); Loamy sand; 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 earthworms and worm casts, few burrows, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Bt1 (33 – 60)	Yellowish brown (10YR 5/4 dry) to gray (10YR 5/1 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, medium, very few coarse roots; presence of earthworms and few burrows, termites, ants and other insects; clear and wavy boundary to horizon below.
Bt2 (60 – 92)	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, fine, medium roots; presence of termites, ants and other insects; clear and smooth boundary to horizon below.
Cr (92 – 174+)	Pale brown (2.5Y7/4 dry) and light yellowish brown (2.5Y6/4 moist); gravelly sandy clay; strong, coarse, crumbly and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; plenty fine, medium, few coarse pores; very few very fine and few fine, medium roots; horizon dominated by iron-rich reddish materials; presence of termites, ants and other insects; clear and smooth boundary to horizon above.

8b. Analytical laboratory data of profile pit No. KAI008; Mayengbema series

Horizon (cm)	**Unit**	**0-33**	**33-60**	**60-92**	**92-174+**
Sand	%	76.80	70.80	64.80	58.80
Silt	%	9.28	3.28	7.28	4.61
Clay	%	13.92	25.92	27.92	36.59
Organic Carbon	%	1.50	0.65	0.35	0.32
Bray P1	mg/kg soil	12.03	4.49	0.09	6.40
pH 1:1 soil : water ratio		4.30	4.40	4.20	4.20
pH 1:1 M KCl ratio		3.50	3.40	3.50	3.47
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	5.62	5.48	5.05	4.81
Exchangeable calcium	mg/kg soil	3.77	3.40	3.07	2.71
Exchangeable magnesium	mg/kg soil	0.40	0.37	0.50	0.52
Exchangeable potassium	mg/kg soil	0.39	0.36	0.32	0.29
Exchangeable sodium	mg/kg soil	0.46	0.41	0.37	0.32
Exchangeable acidity	cmol/kg soil	0.60	0.94	0.79	0.96
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	18.00	9.00	12.00	7.00
DTPA extractable iron	mg/kg soil	4.39	232.76	64.50	160.65
DTPA extractable copper	mg/kg soil	5.31	4.13	3.97	3.13
DTPA extractable zinc	mg/kg soil	6.52	6.09	7.81	8.10

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9a. *Soil profile description of profile pit No. KAI009; Pendembu series*

District: Kailahun; **Chiefdom**: Upper Bambara; **Village**: Pendembu; **GPS location**: 8.117371°/10.685105°; **Elevation**: 214m; **Physiography**: Undulating plain; La**ndform/facet**: Dissected plain; Parent **Material**: Weathered Residium; Landscape **position**: Back slope; **Slope**: 4.1%; **Vegetation**: Farm bush with newly planted oil palm; **Erosion class and intensity**: e3, severe; **Drainage and permeability:** Well drained and rapid; **Landuse**: Plantation; **Crops grown**: Oil palm.

Land System: Blama

Classification : USDA Taxonomy: Plinthaquic paleudult **FAO-UNESCO:** Humic Nitosol

Mapping Unit: KAI009 Gravel-free soil underlain by hard bedrock

Horizon (cm)	Morphological Description
Ah (0 – 20)	Dark brown (10YR 3/3 dry) and dark yellowish brown (10Y/R4/3 moist); sandy loam; moderate, fine crumbly to angular blocky; slightly hard (dry), firm (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.
Bt1 (20 – 35)	Dark yellowish brown (10YR 4/4 dry) and (10Y/R4/6 moist); sandy clay; moderate, fine, angular and sub-angular blocky; hard (dry), firm (moist); slightly sticky and slightly 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, ants and other insects; clear and wavy boundary to horizon below.
Bt2 (35 – 85)	Yellowish brown (10YR 5/6 dry) and brownish yellow (10Y/R6/8 moist); sandy clay; strong, fine, angular and sub-angular blocky; very hard (dry), firm (moist); slightly sticky and slightly plastic; common very fine, fine and medium, and few coarse pores; common very fine, plenty fine, few medium roots; presence of earthworms, termites, ants and other insects; clear and wavy boundary to horizon below.
Cr (85 – 148+)	Yellowish brown (10YR 5/6 dry) and dark yellowish brown (10Y/R4/6 moist); sandy clay; strong, coarse, angular and sub-angular blocky; very hard (dry), very firm (moist); sticky and plastic; common very fine, fine and medium, and few coarse pores; common very fine, plenty fine, few medium roots; presence of earthworms, termites, ants and other insects; presence of abundant, fine and coarse mottles in from 109+ cm; clear and smooth boundary to horizon below.

9b. Analytical laboratory data of profile pit No. KAI009; Pendembu series

Horizon (cm)	**Unit**	**0-20**	**20-35**	**35-85**	**85-148+**
Sand	%	70.80	54.80	38.80	22.80
Silt	%	9.28	7.28	5.28	3.28
Clay	%	19.92	37.92	55.92	73.92
Organic Carbon	%	3.08	0.73	0.62	0.97
Bray P1	mg/kg soil	1.80	0.54	0.72	1.98
pH 1:1 soil : water ratio		4.30	4.80	5.30	5.80
pH 1:1 M KCl ratio		3.40	3.80	4.20	4.60
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	6.57	2.88	1.03	4.35
Exchangeable calcium	mg/kg soil	4.17	1.75	0.67	3.09
Exchangeable magnesium	mg/kg soil	0.96	0.44	0.08	0.60
Exchangeable potassium	mg/kg soil	0.43	0.2	0.03	0.26
Exchangeable sodium	mg/kg soil	0.52	0.19	0.14	0.47
Exchangeable acidity	cmol/kg soil	0.49	0.30	0.11	0.08
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	19.00	5.00	9.00	23.00
DTPA extractable iron	mg/kg soil	43.63	200.58	357.52	514.46
DTPA extractable copper	mg/kg soil	3.34	2.24	1.14	0.04
DTPA extractable zinc	mg/kg soil	14.08	7.12	0.16	6.80

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__10a.__ Soil profile description of profile pit No. KAI010; Moa series

District: Kailahun; **Chiefdom**: Upper Bambara; **Village**: Kamalu; **GPS location**: 7.98135°/11.33831°; **Elevation**: 191m; **Physiography**: Alluvial plain; La**ndform/facet**: Dissected plain; **Parent Material**: Alluvium; **Landscape position**: Foot slope; **Slope**: 1.1%; **Vegetation**: Farm bush; **Erosion class and intensity**: e3, severe; **Drainage and permeability:** Moderately well drained and moderately rapid; **Landuse**: Agriculture; **Major crops grown**: Rice, sesame, sorghum.

Land System: Blama

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

Mapping Unit: KAI010
Gravel-free soil

Horizon (cm)	Morphological Description
Ah (0 – 27)	Dark grayish brown (10YR4/2 dry) and very dark grayish brown (10YR3/2 moist); sandy loam; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; common very fine, fine and medium pores; common very fine, plenty fine, few medium, and very few coarse roots; presence of earthworms, termites, millipedes, ants and other insects; clear and wavy boundary to horizon below.
Btg1 (34 – 55)	Brown (10YR 4/3dry) and grayish brown (10YR4/2 moist); sandy clay loam; moderate, fine, crumbly and sub-angular blocky; slightly hard (dry), friable (moist); slightly sticky and slightly plastic; common very fine, fine and medium pores; common very fine, plenty fine, and few medium roots; presence of termites, ants and other insects; clear and wavy boundary to horizon below.
Btg2 (55 – 99)	Dark yellowish brown (10YR 4/6 dry) and dark yellowish brown (10YR4/4moist); sandy clay; moderate, fine, angular and sub-angular blocky; slightly hard (dry), firm (moist); sticky and plastic; common very fine, fine and medium, and few coarse pores; common very fine, plenty fine, and few medium roots; presence of slickensides/ pressure faces, faintly developed soft mottles having red colour 2.5YR5/8 moist (occurring at spots covering about 10-15% of soil mass), termites, ants and other insects; clear and wavy boundary to horizon below.
Crg (99 – 157+)	Yellowish brown (10YR5/6 dry) and dark yellowish brown (10YR4/6 moist); sandy clay; strong, massive, angular and sub-angular blocky; hard (dry), firm (moist); sticky and plastic; common very fine, fine and medium, and few coarse pores; few very fine, fine and medium roots; presence of presence of slickensides/ pressure faces, prominent mottles having red colour 2.5YR4/8 moist (covering about 50% of soil mass), earthworms, termites, ants and other insects; clear and smooth boundary to horizon below.

10b. Analytical laboratory data of profile pit No. KAI010; Moa series

Horizon (cm)	Unit	0-27	27-55	55-99	99-157+
Sand	%	76.96	84.96	84.96	90.29
Silt	%	12.56	0.56	7.28	1.52
Clay	%	10.48	14.48	7.76	8.19
Organic Carbon	%	1.70	0.94	1.32	0.94
Bray P1	mg/kg soil	17.90	17.90	6.49	2.69
pH 1:1 soil : water ratio		4.10	4.60	4.80	5.20
pH 1:1 M KCl ratio		3.70	3.80	4.30	4.53
Effective cation exchange capacity (ECEC), which is the sum of exch Ca, Mg, K, Na, Al and H	cmol+/kg soil	8.13	6.07	1.84	1.99
Exchangeable calcium	mg/kg soil	5.01	4.46	0.31	1.44
Exchangeable magnesium	mg/kg soil	1.16	0.70	0.74	0.45
Exchangeable potassium	mg/kg soil	0.18	0.09	0.09	0.03
Exchangeable sodium	mg/kg soil	0.09	0.07	0.06	0.04
Exchangeable acidity	cmol/kg soil	1.69	0.75	0.64	0.02
Electrical conductivity(salinity) in 1:5 soil water ratio	µS/cm	30.00	75.00	30.00	45.00
DTPA extractable iron	mg/kg soil	64.18	129.76	69.88	93.64
DTPA extractable copper	mg/kg soil	32.39	37.59	27.05	27.00
DTPA extractable zinc	mg/kg soil	2.34	74.15	45.66	84.04

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