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RESEARCH

Using Digital Tools to Assess Soil Variables in Selected Counties in North Rift, Kenya

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Abstract

The need for techniques and instruments that enable rapid soil testing has gained attention in the face of climate change and environmental degradation. This could improve efficiency and productivity by providing real-time, high-quality, and accessible data for decision-making. This study used GPS tools to visualize, analyze, and gather essential field information and applied Near Infra-Red Spectrometry to assess soil parameters and recommend corrective action for sustainable livelihood in five Counties in North Rift Kenya. Soil reaction varied from 5.5 in Kaptega, Transnzoia, to 7.8 in Kospir, Turkana counties. Low soil pH and CEC were recorded in parts of Nandi and Transnzoia counties. Soils from the dryland ecologies in Turkana, W. Pokot, and Samburu were predominantly alkaline. Total organic Carbon was generally low in the dryland ecologies of Samburu and Turkana. Low soil fertility was generally indicated in Samburu, Turkana, and W. Pokot. This was attributable to the low organic carbon levels and low precipitation, which may have negatively influenced soil microbial activity. Sustainable farming practices such as crop rotation, mulching, mixed farming, cover cropping, and minimum/conservation tillage are recommended in areas where crop cultivation is feasible. Amelioration of soils with agricultural lime and organic matter is highly recommended in the affected areas within the agropastoral counties for improved production to guarantee food security and sustainable livelihoods.

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Statement of Sustainability: The study acknowledges that providing real-time, high-quality, and accessible data for decision-making will lead to effective soil management and improved agricultural production. This is crucial in attaining sustainable development goals, specifically food security.

1. Introduction

The repercussions of climate change, environmental degradation, and inadequate conservation practices could adversely affect the future of agri-food systems in the face of expanding human and livestock populations. Counties in the North Rift region of Kenya that contribute to food security and pastoral livelihoods have been impacted. According to Jaetzold (2012), the North Rift counties of Nandi, Samburu, Transnzoia, Turkana, and West Pokot are agropastoral and can be roughly classified into four agro-ecological zones: Upper Highland (UH), Lower Highland (LH), Upper Midland (UM), and Lower Midland (LM). Nandi County is distinguished by its fertile volcanic soils and a temperate, humid environment that offers considerable potential for agricultural development. The Nandi Hills, which extend northwards, constitute a significant geographical feature of the county, their jug-shaped topography extending to the south of the

Equator. Prominent plant species in the region include *Podocarpus latifolius* and *Nuxia congesta*, found in the forest ecosystems.

The grasslands are characterized by the presence of *Andropogon gayanus* and *Pennisetum mezianum*, while the cultivated areas are prominent for their Arabica coffee and Tea (FAO, 2021). Samburu is distinguished by its arid and warm temperature, encompassing desert and semi-desert regions. The region's topography is characterized by an average elevation of 977 meters above sea level, with elevations ranging from 275 to 2,812 meters. The Ewaso Nyiro River serves as the reserve's sole permanent water source and delineates its southern boundary. The topography is characterized by semi-arid regions, interspersed with patches of forest and grassland. The vegetation is notable for the presence of *Acacia drepanolobium*, *Commiphora africana* in the semi-arid regions; *Ficus sycomorus*, *Brachystegia spiciformis* in the forest areas; and *Sporobolus pyramidalis*, *Themeda triandra* in the grasslands. The primary economic activities in Samburu are tourism, nomadic pastoralism, and commercial businesses (KNBS, 2020). The county of Transzoia is situated 380 km northwest of Nairobi, between the Nzoia River and Mt. Elgon. The county's geographical proximity to the Republic of Uganda (northeast), Bungoma (west), Elgeyo Marakwet (east), Uasin Gishu and Kakamega (south), and West Pokot (north) emphasizes its strategic geographical location. The county's economic foundation is predominantly supported by large- and small-scale dairy and maize farming. This agricultural prowess has led to the region being recognized as Kenya's bread basket. The topography of the region is diverse, encompassing montane forests, grasslands, and agricultural lands. Prominent plant species include *Podocarpus latifolius*, *Kuloa usambarensis*, *Allophylus africanus* in forest areas, *Themeda triandra*, and *Hyparrhenia filipendula* in the grasslands, and *Zea mays* (maize), *Phaseolus vulgaris* (beans), and *Solanum tuberosum* (potato) in the cultivated lands (World Bank, 2021).

Turkana County is characterized by arid to semi-arid features, marked by sparse vegetation and a mean annual precipitation of 50 mm. The region's soils are predominantly rocky, shallow, and stony, and the prevailing winds are firm and dry. Under these climatic conditions, wind erosion and deposition are increasingly significant, extending eastward toward Lake Turkana (World Bank, 2021). Prominent plant species in the arid zones include *Vachellia tortilis* and *Commiphora africana*. Seasonal plants include *Cleome gynandra* and *Hibiscus sabdariffa*, while endemic species include *Maerua angolensis* and *Boscia angustifolia*. The high temperatures, sandy soils, and minimal annual rainfall (an average of 300–400 mm) of Turkana render it an arid or semi-arid land. In Kakuma, Turkana West, 80% of the area is classified as desert, 32% is designated as arable, and 3% is utilized for rain-fed agriculture (Akuja and Kandagor, 2019). West Pokot County is characterized by a diverse topography, with the dry plains in the northern and northeastern regions situated less than 900 meters above sea level. The Cherangani Hills, which reach an altitude of 3,370 meters, are located in the southern region, and their impressive escarpments, which exceed 700 meters in some areas, are a distinguished feature of the landscape. The high-altitude regions offer considerable potential for agricultural development, while medium-altitude areas, ranging from 1,500 to 2,100 meters, are primarily dedicated to pastoral activities and experience minimal rainfall. The low-altitude regions, such as Kongelai, Kacheliba, and Alale, are characterized by predominantly semi-arid vegetation, interspersed with montane forest patches. Significant plant species include *Juniperus procera*, *Olea europaea* subsp. *africana* in forest areas, *Vachellia nilotica*, and *Commiphora africana* in the Semi-Arid Zones, and *Cenchrus ciliaris* and *Digitaria decumbens* in the Grasslands. In West Pokot, the predominant economic activity is agriculture, with over 80% of the population engaged in farming and related occupations, as reported by the World Bank (2021).

This study used digital tools to expedite the testing of soils in the five selected counties in North Rift Kenya. The objective of the study was to assess the soil fertility status of forest and grassland ecosystems and to recommend appropriate measures to mitigate the impact of climate change, soil, and environmental degradation due to land use practices on rural livelihoods. The study hypothesized that forest ecosystems would have richer soils than grassland and cultivated areas. The grassland areas in pastoralist zones are subject to heavy continuous grazing by wild and domestic livestock, leading to green degradation.

2. Materials and Methods

2.1. Study Location

Investigation was conducted in Nandi, Samburu, Transnzoia, Turkana, as well as West Pokot, Counties in North Rift, Kenya. Counties lie between latitude (0.1836° and 3.3122° North and longitude (34.9507° and 36.9541° East) (Table 1). The North Rift region of Kenya was selected for its immense contribution to food security and pastoral livelihoods. The region is considered the bread basket of the country yet it is exposed to extreme climate events that could compromise its biodiversity and agricultural productivity.

Table 1. Grid location and long-term climate data in the selected counties.

Parameter	Nandi	Samburu	Transnzoia	Turkana	West Pokot
Latitude (°N)	0.1836	1.2155	1.0567	3.3122	1.6210
Longitude (°E)	35.1269	36.9541	34.9507	35.5658	35.3905
Altitude (m)	1994.15	800-1230	1864.59	1138	2165.01
Temp. (°C) Max	26.52	32.00	25.38	33.93	25.38
Min	14.86	17.00	12.33	26.04	12.33
Mean annual rainfall (mm)	199.89	306.1	127.7	50.35	127.7

Source: Kenya Meteorological Department (https://meteo.go.ke/forecast/Seasonal-Forecast).

2.2. Sampling Points

An exploratory desktop survey was conducted using geospatial tools to visualize, analyze, and share essential information on the study area. The information collected included coordinates of plant and soil characteristics. Areas under different vegetation cover were also demarcated. A field visit was subsequently conducted using the Garmin Etrex30x Global Positioning Systems (GPS) tool to locate the specific points sampled (Table 2 and Figure 1).

Table 2. Sampling points in this study.

County	Landmark	Latitude (°N)	Longitude (°E)	Dominant Soil Type	Dominant Plant Species
Nandi	Cheplong'ony (forest)	0.0445	35.0083	Clay	*Polycias fulva, Acanthus pubesens, Croton megalocarpus*
	Kimwan (grassland)	0.0107	34.8239	Clay	*Cynodon dactylon, Stachytaphata stephania*
Samburu	Loturo (grassland)	0.5000	36.4300	Sandy clay loam	*Senna didimobotria, Croton punctatus, Indigofera arecta*
	Kirisia (forest)	1.0720	36.4110	Clay loam	*Croton megalocarpus, Marakwet shiny*
Transzoia	Kaptega (riverine)	1.0509	34.5117	Clay	*Cissampelos mucronata, Vernonia amegdalena*
	Cholim (grassland)	1.0282	34.5200	Clay	*Rubus codifolia, Rhus natalensis*
Turkana	Turkwel river (riverine)	3.1920	34.9600	Clay loam	*Prosopis juliflora, Vachelia recifiens*
	Kospir (grassland)	2.5300	35.1600	Sandy loam	*Salvadora posica*
West Pokot	Kamatira (forest)	1.1541	35.1065	Clay	*Acharanthes aspera, Maesa lanciolata, vachelia asiatica*
	Mtemburi (grassland)	1.1180	35.0400	Clay	*Rhus natalensis, Rhus vulgaris*

2.3. Sampling Technique

A field survey was conducted using the Global Positioning System to demarcate areas under different vegetation cover. The grid locations were identified and recorded. The zone soil sampling method was adopted with composite soil samples collected from each vegetation zone (Farmaha et al., 2020). The fields were divided into zones based on crop maps or the soil type. The larger the zone, the more soil test probes were taken (at least five subsamples for each zone). Transect belts were laid in the selected areas under the different vegetation types. Transect belts of 1 km were laid at each sampling point. A soil auger was used to collect the soil samples at 0-30 cm depth from 11 stations in the five counties from 6th-14th September 2023. The samples were kept in plastic bags and labeled. A record of the field number, grid location, and date on which the samples were taken was also kept.

2.4. Sample Scanning

A composite soil sample from each sampling location was mixed well in a bucket. A full scoop of material (about 250 g of soil) was taken and introduced into a special cup for each scan. Up to five scans per sample were done. Data on the soil's physical and chemical characteristics was determined by Near Infra-Red Spectrometry-MEMS technology using a digital soil testing handheld unit (AgroCares Scanner E-series). The Scanner was combined with a mobile phone application (AgroCares Scanner Solution app, https://agrocares.com/scanners/). A stable internet connection was required to log in, scan, and synchronize the data. Scanning a sample without the internet and synchronizing it later was also possible. In this case, the user did not log out or close the app before synchronization was completed. This prevented the loss of the data.

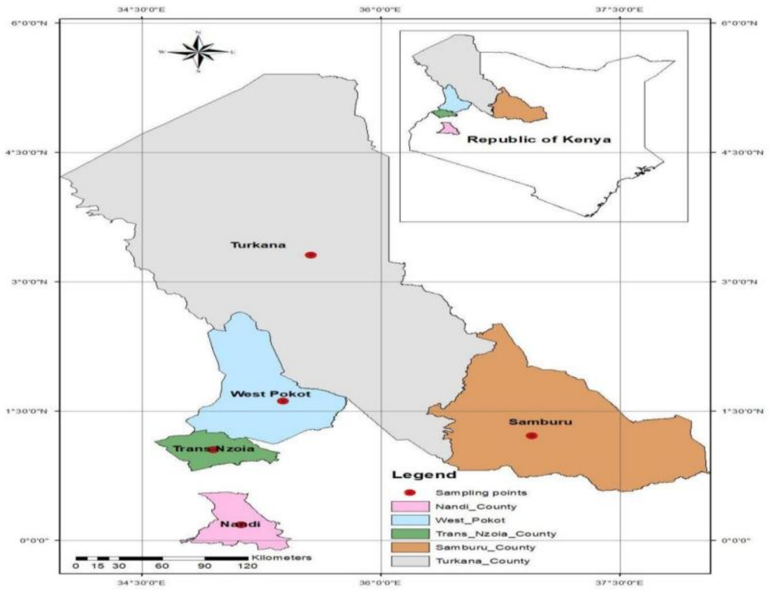

Figure 1. Map of the study area.

3. Results and Discussion

Results obtained have been summarized in Table 3 and illustrated in Figures 2-11.

3.1. Soil pH

Soil reaction varied from 5.5 in Kaptega, Transnzoia, to 7.8 in Kospir, Turkana. Soils from the dryland ecologies in Samburu, Turkana, and W. Pokot were predominantly alkaline with pH values greater than 7.

Table 3. Soil characteristics at the sampling points.

County	Landmark	pH (H_2O)	N (g/kg)	P (M3) (mg/kg)	K exch. (mmol+/kg)	Organic Carbon (g/kg)	CEC mmol+/kg)	Soil correction plan
Nandi	Cheplong'ony (forest)	6.3	1.8	18	2.5	59.3	217	AL+OM
	Kimwan (grassland)	6.6	1.6	15	2.6	42.5	378	AL+OM
Samburu	Loturo (grassland)	7.7	0.7	24	2.7	8.7	226	OM
	Kirisia (forest)	7.0	1.4	26	2.7	21.3	237	OM
Transzoia	Kaptega (riverine)	5.5	2.2	16	*2.5*	60.4	154	AL
	Cholim (grassland)	6.5	1.9	15	2.8	61.5	407	AL
Turkana	Turkwel river (riverine)	7.5	2.1	34	3.1	38.9	307	C/FYM
	Kospir (grassland)	7.8	0.5	30	2.8	5.5	108	C/FYM
West Pokot	Kamatira (forest)	6.4	1.7	20	27	24.0	280	OM
	Mtemburi (grassland)	6.0	1.5	18	2.6	21.6	110	OM
Parameter range	Low	6.0	1	20	1.5	17	75	
	High	7.2	2	40	3.0	50	200	

Key: AL - agricultural lime; C - compost manure; FYM - farmyard manure; OM - organic matter

The soil chemical property that constrains field productivity is acidification plus the presence or absence of minerals. Soil acidification is a slow natural process that occurs during pedogenesis and is either accelerated or slowed down by farming practices (Wang et al., 2024). Adverse acidification decreases water and nutrient retention capacity in soils thus reducing biotic activity. Major causes of soil acidity in agricultural systems are the imbalances of Carbon (C) and Nitrogen (N) cycles (Uwiragiye et al., 2023) the principal adverse effects of acidity occur at soil pH 5.5 due to the dissolution of Aluminium (Al) ions and the onset of Aluminium toxicity. Aluminum phytotoxicity results in rapid inhibition of root growth due to impediment of both cell division and elongation, resulting in a reduced volume of soil explored by the plant root system and direct influence of Calcium (Ca) and Phosphate (P) uptake across the cell membrane of damaged roots (Chianu and Mairura, 2011). This will often lead to reduced crop yield and field productivity. In S. Africa, high pH and P values, low Al and Na were reported to be associated with high sugarcane-yielding points (Van Antwerpen et al., 2007). The low pH (acidic soils) in Transnzoia were associated with land use practices (use of acidifying fertilizers for crop production. The soil acidification trend is accelerated when Diammonium phosphate (DAP), Urea, and Sulfate of ammonia become the dominant basal and N-fertilizers every cropping season respectively (Chianu and Mairura, 2010).

3.2. Organic Carbon

Total organic Carbon was generally low in the grasslands of the dryland ecologies of Samburu, Turkana, and West Pokot. The lowest value of 5.5 g/kg was recorded at Kospir grassland in Turkana, followed by 8.7 g/kg at Loturo grassland in Samburu, and 21.6 g/kg at Mtemburi grassland in W Pokot. Soil organic matter is an indicator of biological activity in the soil as it provides a substrate for soil microorganisms (Nocita et al., 2013). The microorganisms are responsible for converting unavailable plant and animal nutrients into forms that can be assimilated by plants. One of the products of soil organic matter decomposition is humus which influences the chemical properties in cation exchange capacity. Organic matter also improves soil structure and water-holding capacity (Nocita et al., 2013). Soil quality requires the integration of three major components: Sustainable biological productivity, Environmental Quality, and Plant health. Soil quality indicators or parameters can be used to investigate soil degradation and sustainability under continuous production. The indicators for biological productivity include organic matter, organic carbon, total Nitrogen, and C: N ratio (Xu et al., 2018). Chemical parameters include pH, CEC, exchangeable bases Ca, K, and Mg-base saturation while physical parameters encompass particle size distribution, aggregate size distribution, water stability of aggregates, bulk density, water holding capacity, and stabilized infiltration rate (Yves et al., 2023). Regular monitoring of these parameters can be used to check the health status of the soil, detect problems early, and recommend best management practices (BMPs) which ensures continuous good soil health. The use of organic manures such as farm yard manure and agricultural lime for soil amendment is highly recommended.

3.3. Total Nitrogen (N), Phosphorus (P), and Potassium (K)

N, P, and K levels were generally adequate to high except in Nandi and Transnzoia where less than the desired level of 20 g/kg P (M3) was consistently recorded. Nitrogen is essential in crop production affecting essential physiological processes such as photosynthesis. It is one of the building blocks of proteins and helps provide strong productive growth and high yield (Jin et al., 2020). When inadequately applied, N limits crop productivity while when excessively applied may contaminate underground water. It is liable to losses through leaching, volatilization, and de-nitrification. Nitrogen cycle terms are major contributors to acidification under cropping systems and N-fertilizer management is likely to be the most critical acidification factor (Chianu and Mairura, 2011). In Transnzoia and Nandi counties, continuous use of ammonium-based fertilizers, crop removal through harvests, lack of crop rotation, and high precipitation are factors thought to have lowered the soil pH. The likelihood of P-fixation was noticeable from the low pH recorded. The application of agricultural lime is recommended for the mitigation of the low pH. Potassium plays a key role in plant metabolism. It is the most abundant cation accumulating in the cell sa of the plant. By acting as an enzyme activator, K is fundamental to the synthesis and translocation of sugars from the leaves to the storage tissues of plants. It also plays a significant role in the hydration and osmotic concentration within the stomata and guard cells (Abassi et al., 2016). The importance of balanced nutrition particularly between N and K in the attainment of maximum yield should not be overlooked in K-deficient soils.

3.4. Cation Exchange Capacity (CEC)

Cation exchange capacity was generally within the desired parameters in all the sampled zones. However, lower values of 108, 110, and 154 mmol+/kg were recorded at Kospir grassland in Turkana, Mtemburi grassland in W. Pokot, and Kaptega in Transnzoia respectively (Figures 6, 9, and 11). Cation exchange capacity (CEC) is a critical property of soil that determines its ability to hold and exchange cations (positively charged ions). The three main factors that influence this capacity are the soil's clay content, organic matter content, and pH level. CEC influences the soil organic matter decomposition into the humus fraction. According to Dengke et al. (2024), soil basic physicochemical properties explain >80 % of CEC variation. Cation exchange capacity is a crucial metric for managing soil fertility and promoting agricultural sustainability (Ulusoy et al., 2016). The low CEC in the highlighted zones was attributable to the low organic carbon levels and low precipitation in the dryland ecologies, which may have negatively influenced soil microbial activity. Although Transnzoia recorded low CEC, the fertility levels of soils in the region are known to be high; this may have been due to the observed acidic soil condition (Zingore et al., 2015).

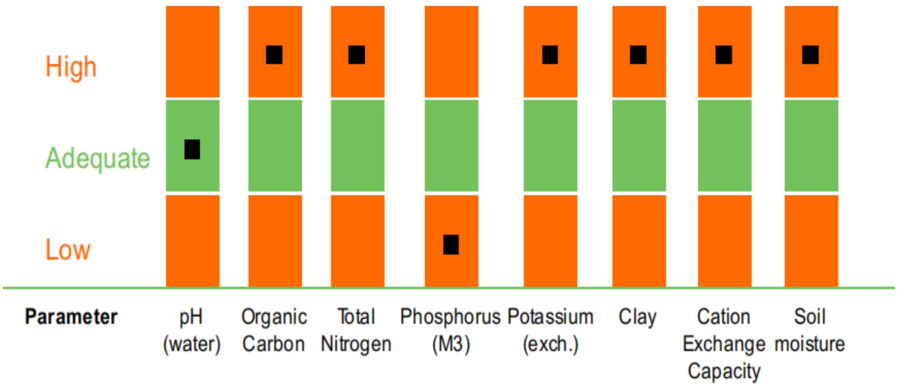

Figure 2. Soil parameters at Cheplongony Forest, Nandi.

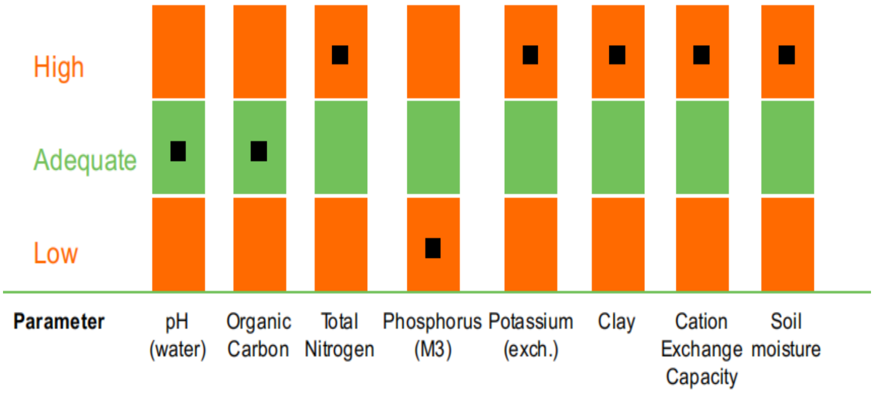

Figure 3. Soil parameters at Kimwan Grassland, Nandi.

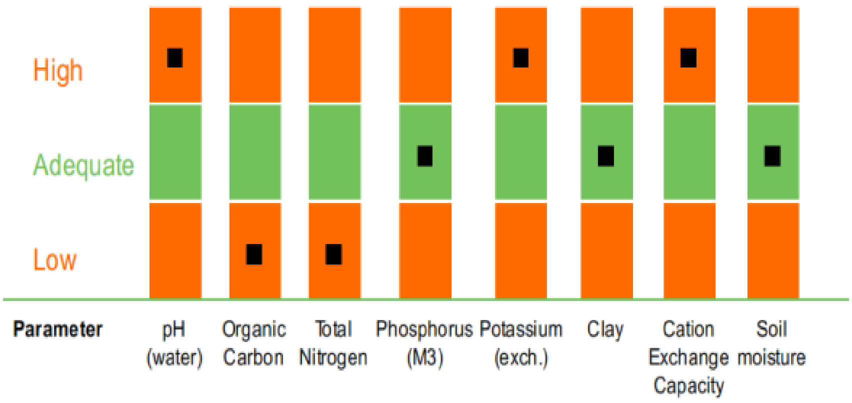

Figure 4. Soil parameters at Loturo Grassland, Samburu.

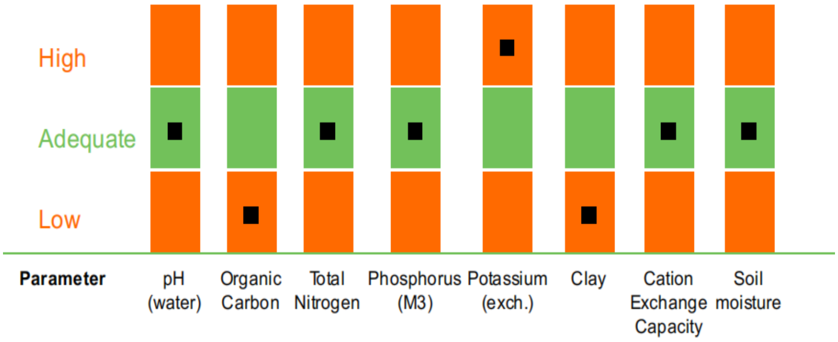

Figure 5. Soil parameters at Kisiria Forest, Samburu.

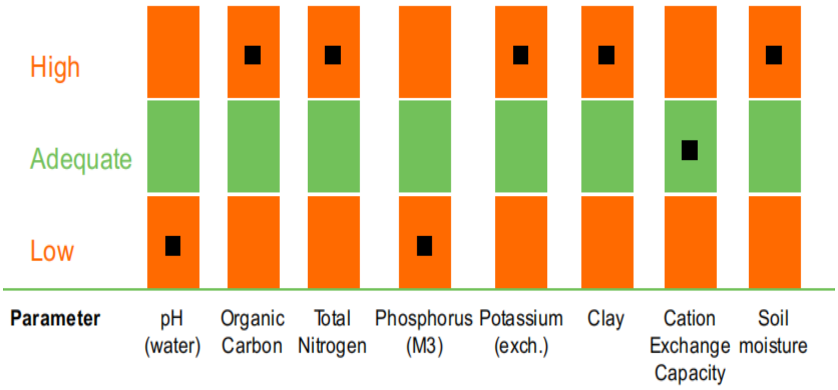

Figure 6. Soil parameters at Kaptega riverine, Transnzoia.

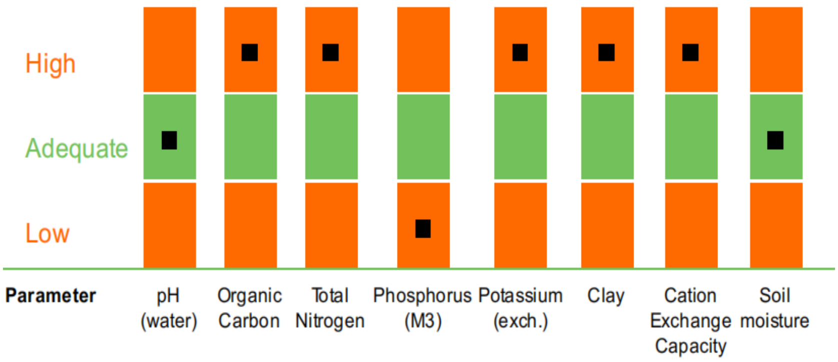

Figure 7. Soil parameters at Cholim Grassland, Tranzoia.

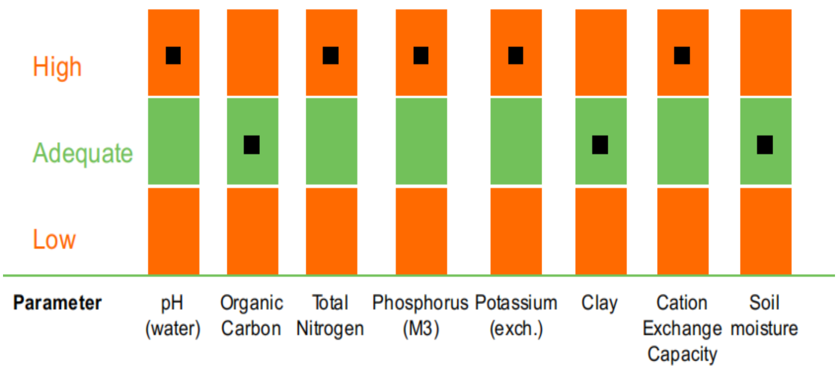

Figure 8. Soil parameters at Turkwel River Riverine, Turkana.

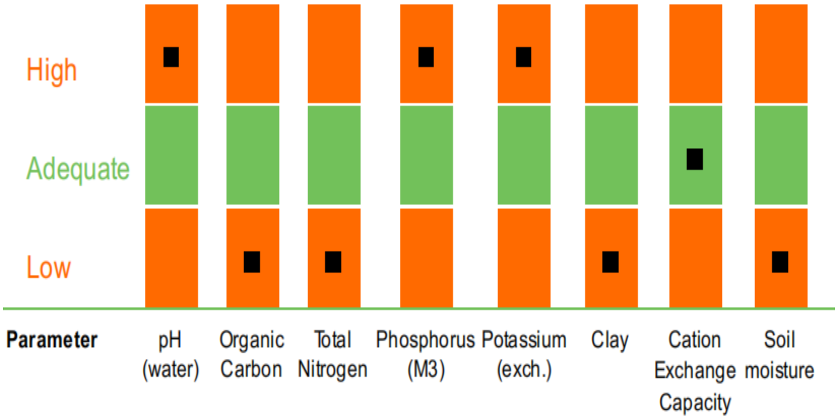

Figure 9. Soil parameters at Kospir Grassland, Turkana.

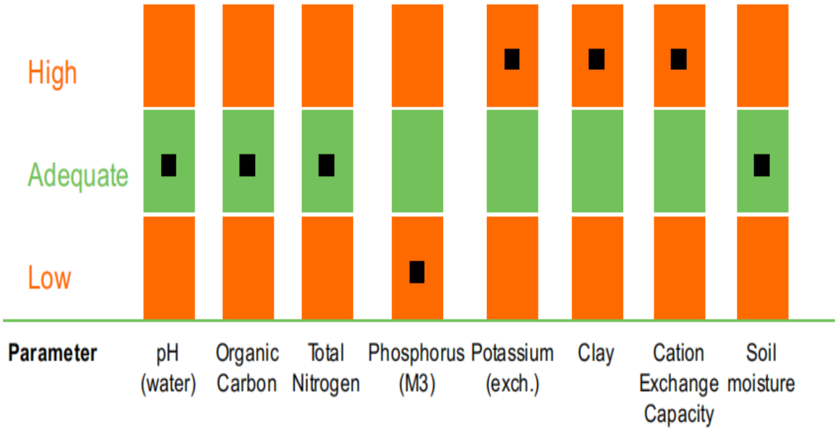

Figure 10. Soil parameters at Kamatira Forest, West Pokot.

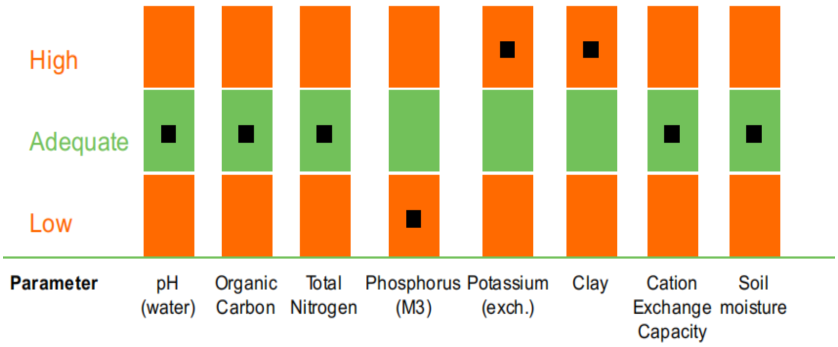

Figure 11. Soil parameters at Mtemburi Grassland, West Pokot.

4. Conclusion

Agricultural productivity depends on the farmland quality, and a soil test can timely report a problem in crop growth conditions. Field suitability analysis helps choose the appropriate crops or decide on land use for farming. Regular soil testing is ultimately important not only for growers but can also provide valuable field insights to all agribusiness players, including agri-coops, crop insurers, banks, input suppliers, or commodity traders. Nonetheless, designated laboratories describe only the current field properties. So, while analyzing soil test results for decisions on field amelioration, it's better to combine lab reports with historical data from satellite imagery analytics. Regular monitoring of the chemical, physical, and biological parameters can be used to check the health status of the soil, detect problems early, and recommend best management practices (BMPs) which ensures continuous good soil health. Techniques that improve efficiency and productivity by providing real-time, high-quality, and accessible data for decision-making are critical in this process. From this study, it was evident that soil acidity was noticeable in Nandi and Transnzoia counties, where crop cultivation is primarily practiced. Amelioration of soils with agricultural lime and organic matter is highly recommended in the affected areas for improved production to guarantee food security and sustainable livelihoods. Sustainable farming practices such as crop rotation, mulching, mixed farming, cover cropping, minimum/conservation tillage, and fast-maturing crop varieties are recommended where crop cultivation is feasible, but the areas experience moisture deficits. These measures increase soil quality and structure while increasing production, a key aim of climate-smart agriculture (CSA) The use of organic manures such as farm yard manure and agricultural lime for soil amendment is highly recommended. A participatory framework involving sensitization meetings and practical demonstrations on soil sampling, analysis, and identification of potential indicator plant species should be drawn with the community opinion leaders, students, and government officials as change agents.

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Supplementary Information Availability: Not applicable.

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