Agro-Pedological Characterization and Maize Land Suitability Assessment in a Community Agricultural Estate of Southern Senegal

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Abstract

Soil fertility decline remains a major constraint to agricultural productivity in tropical regions, particularly in large-scale community farming schemes. In Senegal, the Community Agricultural Estates (DAC) established under the PRODAC program aim to promote youth employment and intensify agricultural production, yet their sustainability strongly depends on soil quality. This study aimed to characterize the agro-pedological properties and assess the crop suitability of soils in the SEFA Community Agricultural Estate, located in the Sédhiou region (southern Senegal), with a focus on maize cultivation. A total of 26 soil samples were collected at a depth of 0–30 cm from five representative land-use units (Open Field, Greenhouse, Pivot, Xelcom Tarpaulin, and CAC). Physical and chemical analyses included particle size distribution, pH, electrical conductivity (EC), organic matter (OM), available phosphorus, exchangeable bases, cation exchange capacity (CEC), and base saturation. Results revealed a strong dominance of clay-textured soils, moderately acidic to acidic pH values (5.2–6.4), and low salinity levels (EC < 500 µS/cm). Organic matter contents were generally low to moderate, except in pivot-irrigated plots, while available phosphorus levels were largely deficient in most parcels. CEC values were high, indicating good nutrient retention potential, although acidity limited nutrient availability. The overall land suitability assessment showed moderate to low suitability for maize, mainly constrained by soil acidity, low organic matter, and phosphorus deficiency. Soil amendment through liming, organic matter inputs, and adapted phosphorus fertilization is therefore recommended to enhance soil productivity and ensure sustainable management of the SEFA DAC.

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1. Introduction

Soil is a fundamental natural resource for agricultural production and food security, particularly in tropical regions where crop productivity largely depends on inherent soil properties and climatic conditions. Classical pedological studies have long established that soil texture, organic matter content, soil reaction, and nutrient availability are key determinants of soil fertility and crop performance (Aubert, 1954) [1]; (Duchaufour, 1983) [10]; (Brady & Weil, 2008) [5]. In tropical environments, prolonged weathering, intense rainfall, and continuous cultivation often lead to nutrient depletion and soil degradation, thereby constraining agricultural productivity (Dabin, 1970) [8]; (FAO, 2006) [12].

In sub-Saharan Africa, soil fertility decline remains one of the major biophysical constraints to sustainable agriculture. Early research highlighted the prevalence of acidic soils, low organic matter contents, and phosphorus deficiency as dominant limitations affecting crop yields (Charreau & Fauck, 1965) [7]; (Sanchez *et al*., 2003) [19]. More recent regional assessments confirm that these constraints persist and are even exacerbated by population pressure, land-use intensification, and climate variability (Kihara *et al*., 2020) [16]; (Sommer *et al*., 2022) [20]. Current estimates indicate that more

than 30% of cultivated soils in humid and sub-humid zones of Africa are affected by soil acidity, significantly reducing nutrient use efficiency and crop response to fertilization (IFDC, 2023) [15].

In Senegal, agriculture plays a central socio-economic role, yet crop yields remain well below their potential. Classical soil surveys conducted in southern Senegal reported the dominance of ferruginous and hydromorphic soils characterized by acidity, low base saturation, and rapid organic matter mineralization (Duchaufour, 1983) [10]; (Diatta *et al*., 2014) [9]. Recent soil health assessments corroborate these findings, emphasizing that soil organic carbon depletion and nutrient imbalances continue to limit crop productivity despite favorable climatic conditions in regions such as Sédhiou (Batjes *et al*., 2021) [4]; (Vågen *et al*., 2021) [23].

Maize (Zea mays L.) is a major staple crop in Senegal and across West Africa, playing a critical role in food security, livestock feeding, and income generation. Although maize has a high yield potential, its productivity is particularly sensitive to soil fertility constraints, especially soil acidity, low organic matter content, and limited phosphorus availability (Gbegbelegbe *et al*., 2006) [13]; (Kihara *et al*., 2020) [16]. Recent studies have shown that phosphorus deficiency remains one of the most important yield-limiting factors for maize in tropical soils due to strong fixation by iron and aluminum oxides under acidic conditions (Bai *et al*., 2022) [2]; (Omuto *et al*., 2023) [18].

Agro-pedological characterization combined with land suitability assessment provides a robust framework for identifying soil constraints and guiding sustainable land management. Classical land evaluation approaches developed by the FAO emphasize the importance of matching soil properties with crop requirements to optimize land use (FAO, 1976) [11]; (Sys *et al*., 1993) [21]. These approaches have recently been strengthened by advances in digital soil mapping and multi-criteria evaluation methods, which allow improved spatial assessment of soil fertility and crop suitability at local and regional scales (Hengl *et al*., 2021) [14]; (Omuto *et al*., 2023) [18].

In the Sédhiou region of southern Senegal, community-based agricultural estates have been established to enhance land productivity and promote agricultural intensification. However, detailed, site-specific soil information remains limited, constraining effective land-use planning and soil fertility management. In this context, the present study aims to (i) characterize the main physical and chemical properties of soils in the SEFA Community Agricultural Estate, (ii) assess their fertility status, and (iii) evaluate their suitability for maize cultivation. The findings are expected to contribute to improved soil management strategies and support sustainable agricultural development in tropical environments.

2. Methodology

2.1. Area of the Study

The study was conducted in the SEFA Community Agricultural Estate, located in the Sédhiou region in southern Senegal (Figure 1). The area belongs to the Sudanian–Guinean agro-ecological zone and is characterized by a humid tropical climate with a unimodal rainy season extending from June to October. Mean annual rainfall is approximately 1,000 mm, while average annual temperatures range between 25 and 35 °C.

The topography is predominantly flat to gently undulating, favoring agricultural mechanization and irrigation development. The soils are mainly ferruginous tropical soils and hydromorphic soils developed on alluvial and sedimentary materials. These soils are intensively used for cereal and vegetable production, with maize being one of the dominant crops.

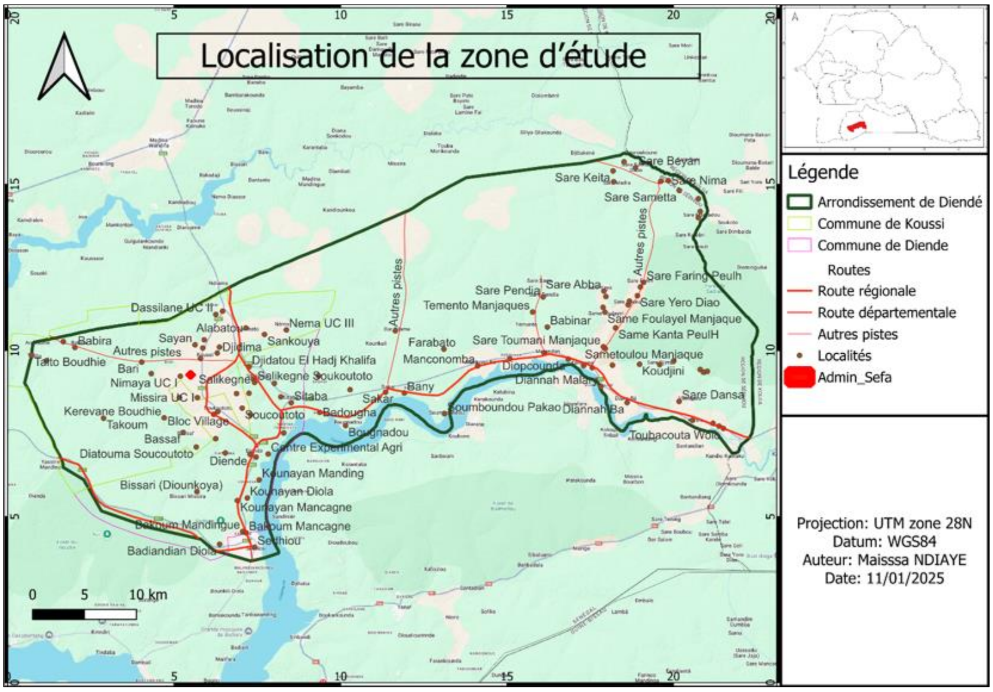

Fig 1: Location of the SEFA Community Agricultural Estate in the Sédhiou region, southern Senegal.

2.2. Soil Types and Land Use

The spatial distribution of soil types and land-use patterns within the SEFA estate is presented in Figure 2. Ferruginous tropical soils dominate the upland areas, while hydromorphic soils are mainly found in low-lying zones. Land use is diversified and includes open-field cropping systems, greenhouse vegetable production, pivot-irrigated fields, and community-managed agricultural areas.

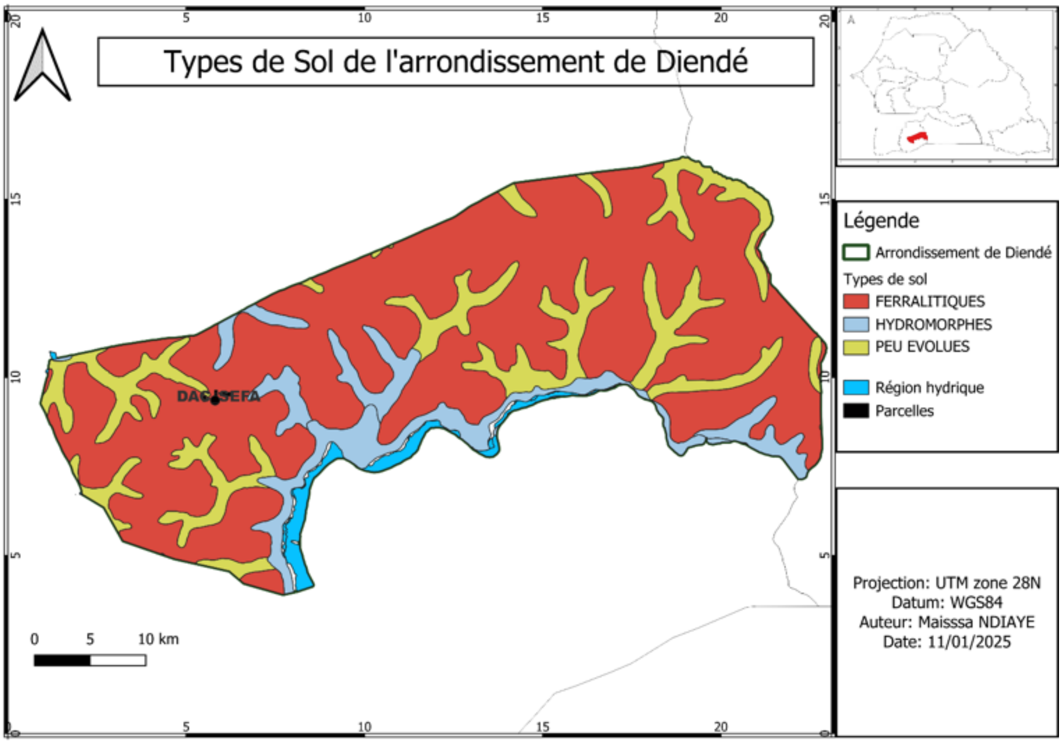

Fig 2: Soil types and land-use map of the SEFA Community Agricultural Estate.

2.3. Soil Sampling Design

Soil sampling was carried out using a stratified sampling approach based on land-use units and management practices. Five representative land-use units were selected: Open Field, Greenhouse, Pivot-irrigated field, Xelcom Tarpaulin unit, and Community Agricultural Cooperative (CAC) area.

Within each unit, soil samples were collected from the 0–30 cm depth, corresponding to the main rooting zone for maize. A total of 26 composite soil samples were collected across the study area. Each composite sample consisted of several subsamples taken from homogeneous zones and thoroughly mixed to ensure representativeness. The spatial distribution of sampling points is shown in Figure 3.

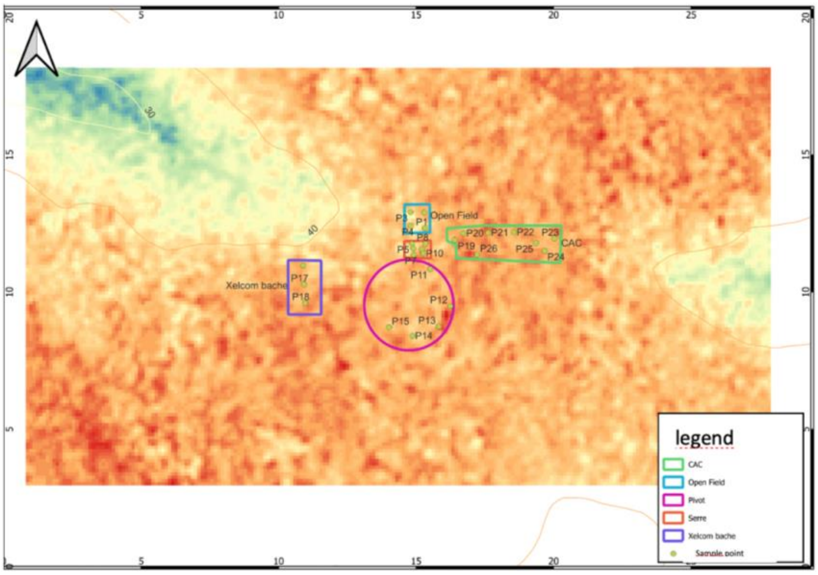

Fig 3: Soil sampling design and spatial distribution of sampling points across the SEFA estate.

2.4. Laboratory Analyses

Soil samples were air-dried, gently crushed, and sieved to 2 mm prior to analysis. All analyses were conducted at the Soil Science Laboratory of the École Nationale Supérieure d'Agriculture (ENSA), Thiès.

Particle size distribution was determined using the Robinson pipette method, and soil texture was classified according to the USDA textural triangle. Soil pH was measured potentiometrically in a soil–water suspension at a ratio of 1:2.5. Electrical conductivity (EC) was measured in a 1:5 soil–water extract and expressed in µS cm⁻¹.

Soil organic carbon was determined using the modified Anne method, and soil organic matter content was calculated using an appropriate conversion factor. Available phosphorus was extracted using the modified Olsen method and quantified spectrophotometrically. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) were determined by atomic absorption spectrophotometry. Cation exchange capacity (CEC) was calculated as the sum of exchangeable bases, and base saturation was expressed as the percentage of CEC occupied by exchangeable bases.

2.5. Soil Fertility and Land Suitability Assessment

Soil fertility status was assessed by interpreting analytical results using internationally recognized reference thresholds for pH, salinity, organic matter content, available phosphorus, exchangeable bases, and CEC.

Land suitability for maize (*Zea mays* L.) was evaluated using a multi-criteria approach based on the FAO land evaluation framework. Key soil parameters influencing maize growth were scored according to their degree of limitation and combined to classify soils into suitability classes. Spatial analysis and map production were performed using QGIS software.

3. Results

3.1. Soil Texture

Particle size analysis indicated a clear predominance of clay-textured soils across the SEFA Community Agricultural Estate. More than 90% of the analyzed samples were classified as clay according to the USDA textural triangle. This texture was consistently observed across all land-use units, including Open Field, Greenhouse, Pivot, Xelcom Tarpaulin, and CAC areas.

Minor textural variations were recorded at a few sampling points located in low-lying areas, where slightly higher proportions of silt and sand were observed. Overall, the dominance of clayey soils suggests a high capacity for water and nutrient retention.

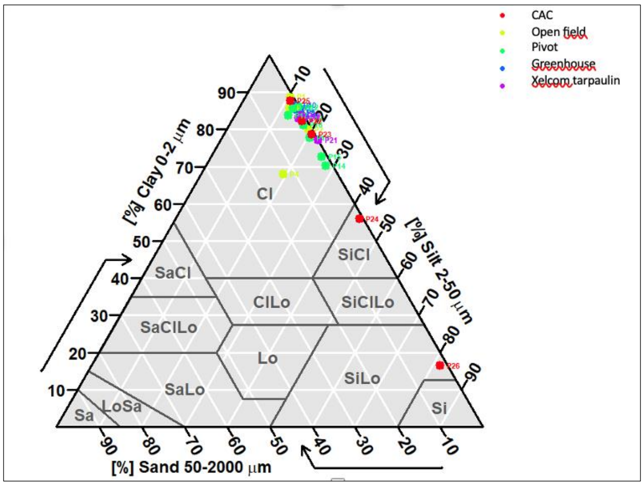

Fig 4: USDA soil textural classification of soils from the SEFA Community Agricultural Estate.

3.2. Soil Reaction and Electrical Conductivity

Soil pH values ranged from 5.2 to 6.4, indicating acidic to slightly acidic conditions throughout the study area. The Open Field and Greenhouse units exhibited relatively higher mean pH values, whereas soils from the CAC, Pivot, and Xelcom Tarpaulin units were characterized by stronger acidity.

Electrical conductivity values were consistently below 500 µS cm⁻¹ for all samples, classifying the soils as non-saline. However, relatively higher EC values were observed in the Greenhouse unit compared to other land-use units, although they remained well below salinity thresholds.

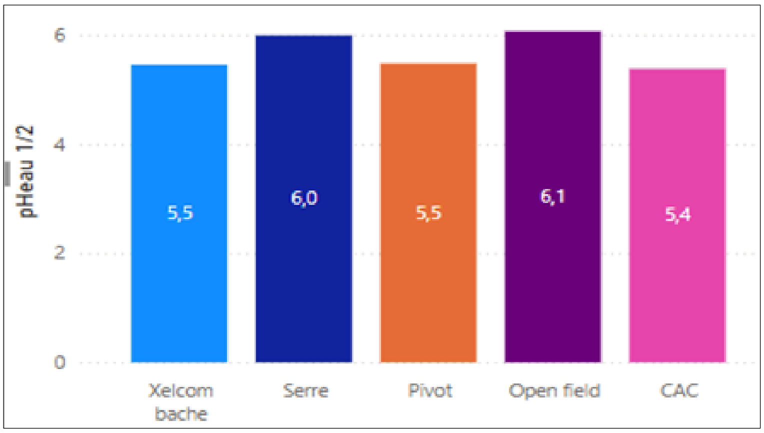

Fig 5: Variation of soil pH across land-use units.

3.3. Soil Organic Matter Content

Soil organic matter content showed marked spatial variability among land-use units. The highest values were recorded in the Pivot-irrigated fields, where soils exhibited moderate organic matter levels. In contrast, soils from the Greenhouse unit showed low but relatively homogeneous organic matter contents.

The Open Field, CAC, and Xelcom Tarpaulin units were characterized by very low organic matter levels, indicating poor organic status and limited organic inputs.

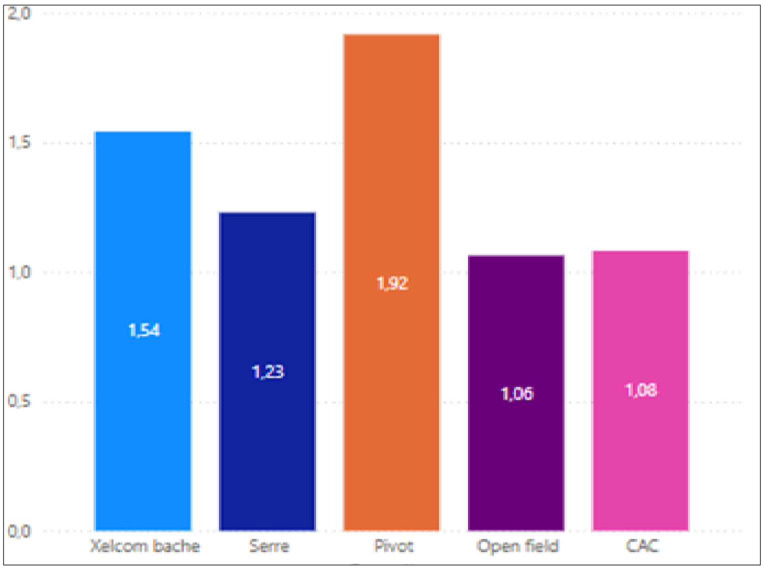

Fig 6: Distribution of soil organic matter content (%) across land-use units.

3.4. Available Phosphorus

Available phosphorus concentrations were generally low across the study area. Most soil samples were classified as deficient according to standard interpretation thresholds. Moderate to high phosphorus levels were observed only in a limited number of samples from the Greenhouse and Open Field units.

A clear relationship between soil pH and phosphorus availability was observed, with higher phosphorus levels occurring in soils with relatively higher pH values.

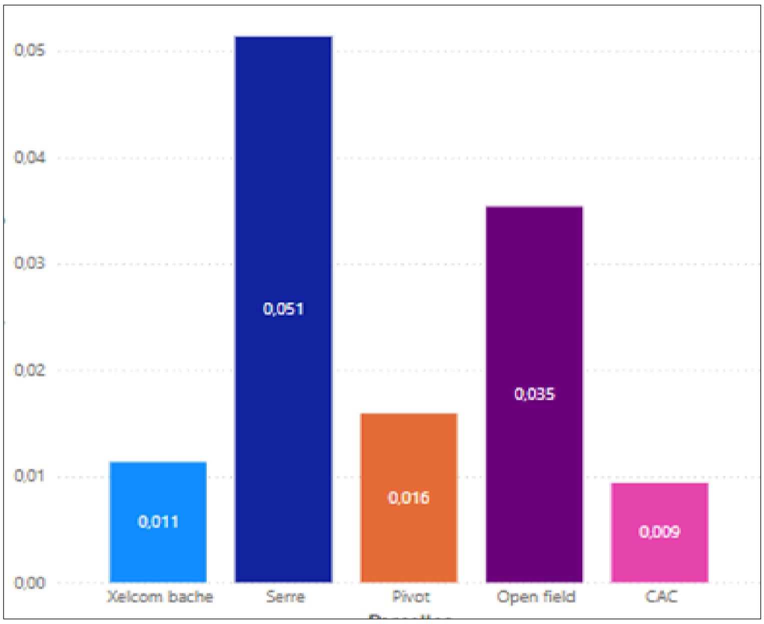

Fig 7: Available phosphorus levels and relationship with soil pH.

3.5. Exchangeable Bases and Cation Exchange Capacity

Exchangeable base contents varied among land-use units. The Greenhouse soils exhibited the highest values, followed by the Pivot unit, while lower contents were observed in the CAC, Open Field, and Xelcom Tarpaulin units.

Cation exchange capacity values were generally high across all soils, reflecting their clay-rich nature. Despite this high CEC, base saturation levels ranged from low to moderate, particularly in the more acidic units, indicating that a significant proportion of exchange sites were occupied by acidic cations.

3.6. Land Suitability for Maize Cultivation

The land suitability assessment revealed clear spatial differences in soil aptitude for maize cultivation. Soils from the Open Field and Greenhouse units were classified as moderately suitable, whereas soils from the CAC, Pivot, and Xelcom Tarpaulin units were classified as marginally suitable.

The main limiting factors identified were soil acidity, low organic matter content, and deficient available phosphorus. No land-use unit was classified as highly suitable without soil fertility improvement measures.

4. Discussion

4.1. Soil Texture and Agronomic Implications

The predominance of clay-textured soils across the SEFA Community Agricultural Estate (Figure 4) reflects soil formation processes typical of humid and sub-humid tropical environments. Similar textural dominance has long been reported in ferruginous and hydromorphic soils of southern Senegal and West Africa (Charreau & Fauck, 1965) [7]; (Duchaufour, 1983) [10]. More recent digital soil mapping and land suitability studies confirm that fine-textured soils dominate large agricultural landscapes in the region and strongly influence land suitability for maize production (Hengl *et al*., 2021) [14]; (Omuto *et al*., 2023) [18].

Clay-rich soils generally exhibit high water and nutrient retention capacity, which can be advantageous for crop growth (Brady & Weil, 2008) [5]. However, their low permeability and structural sensitivity may restrict root development and induce temporary waterlogging, particularly under intense rainfall and low organic matter conditions (FAO, 2006) [12]; (Kihara *et al*., 2020) [16]. This dual behavior highlights the importance of soil structure management to optimize crop performance.

4.2. Soil Acidity as a Major Chemical Constraint

The acidic soil conditions observed in the study area (Figure 5) are consistent with earlier findings in tropical soils, where prolonged weathering and leaching of base cations lead to soil acidification (Dabin, 1970) [8]; (Duchaufour, 1983) [10]. Soil acidity has long been recognized as a major factor limiting nutrient availability and crop productivity (Brady & Weil, 2008) [5].

Recent regional assessments confirm that soil acidity remains one of the most widespread chemical constraints in sub-Saharan Africa, affecting a significant proportion of cultivated soils and reducing fertilizer use efficiency (Kihara *et al*., 2020) [16]; (IFDC, 2023) [15]. Acidic conditions enhance phosphorus fixation by iron and aluminum oxides and may increase aluminum toxicity, which negatively affects maize root growth and nutrient uptake (FAO, 2006) [12]; (Bai *et al*., 2022) [2].

4.3. Organic Matter Deficiency and Soil Fertility Decline

The generally low soil organic matter contents recorded across most land-use units (Figure 6) reflect a well-documented trend in tropical agricultural systems. Classical studies have shown that organic matter declines rapidly following land cultivation due to high mineralization rates under warm and humid conditions (Aubert, 1954) [1]; (Fauck *et al*., 1969). Soil organic matter is a key driver of soil structure, nutrient cycling, and biological activity (Duchaufour, 1983) [10]; (Brady & Weil, 2008) [5].

Recent studies further emphasize that soil organic carbon depletion reduces soil resilience to climate variability and limits sustainable intensification in African farming systems (Lal, 2020) [17]; (Batjes *et al*., 2021) [4]. Increasing organic matter through residue management, compost application, and integrated soil fertility management has been shown to improve maize productivity and nutrient use efficiency in West Africa (Vanlauwe *et al*., 2021) [22]; (Stewart *et al*., 2023).

4.4. Phosphorus Deficiency and Its Interaction with Soil Acidity

The low levels of available phosphorus observed across the SEFA estate (Figure 7) confirm phosphorus deficiency as a major constraint to maize production. This limitation has been extensively described in tropical soils, where phosphorus is strongly fixed by iron and aluminum oxides under acidic conditions (Dabin, 1970) [8]; (Pousset, 2002).

More recent research corroborates that phosphorus deficiency remains one of the primary yield-limiting factors for maize in sub-Saharan Africa, particularly in acidic soils (Kihara *et al*., 2020) [16]; (Bai *et al*., 2022) [2]. Integrated management strategies combining pH correction, organic matter inputs, and site-specific phosphorus fertilization are now widely recommended to improve phosphorus availability and crop response (Vanlauwe *et al*., 2021) [22]; (Omuto *et al*., 2023) [18].

4.5. Exchangeable Bases, CEC, and Nutrient Retention Capacity

High cation exchange capacity values observed across the study area (Table 3) reflect the clay-rich mineralogy of the soils, a property long recognized as a key indicator of nutrient retention potential (Duchaufour, 1983) [10]; (Brady & Weil, 2008) [5]. However, the low base saturation levels indicate a dominance of acidic cations on exchange sites, limiting nutrient availability for crops.

Recent soil fertility studies across Africa show that soils with high CEC may still exhibit low productivity when base cations are depleted, highlighting the importance of chemical balance rather than CEC alone (Sommer *et al*., 2022) [20]; (IFDC, 2023) [15]. Liming and organic amendments have been shown to increase base saturation and improve maize yield response under similar conditions (Bai *et al*., 2022) [2].

4.6. Land Suitability for Maize and Management Implications

The land suitability assessment (Figure 8) indicates that soils within the SEFA Community Agricultural Estate are predominantly moderately to marginally suitable for maize cultivation. This finding is consistent with both classical land evaluation frameworks (FAO, 1976) [11]; (Sys *et al*., 1993) [21] and recent spatial analyses of maize suitability in West Africa, which highlight soil fertility constraints as key limiting factors (Hengl *et al*., 2021) [14]; (Omuto *et al*., 2023) [18].

While current soil conditions limit maize productivity, recent soil health frameworks emphasize that targeted soil management interventions can significantly improve land suitability and crop performance (Lal, 2020) [17]; (Vanlauwe *et al*., 2021) [22]. Corrective measures such as liming, organic matter restoration, and balanced fertilization could therefore enhance maize production potential and support sustainable intensification within the SEFA estate.

5. Conclusion

This study provided a comprehensive agro-pedological characterization and land suitability assessment of soils in the SEFA Community Agricultural Estate located in the Sédhiou region of southern Senegal. The results highlighted a predominance of clay-textured soils with high cation exchange capacity, indicating a strong potential for water and nutrient retention. However, this potential is currently constrained by major chemical limitations, including soil acidity, low organic matter content, and widespread phosphorus deficiency.

The land suitability evaluation showed that most soils within the estate are moderately to marginally suitable for maize cultivation under current management conditions. Soil acidity and low nutrient availability were identified as the principal limiting factors affecting crop productivity, despite favorable climatic conditions. These findings underscore the importance of considering both inherent soil properties and management-induced constraints when planning agricultural intensification in tropical environments.

The study further demonstrates that targeted soil management interventions such as liming to correct acidity, organic matter restoration to improve soil structure and biological activity, and site-specific phosphorus fertilization have the potential to significantly enhance soil fertility and maize productivity. By providing site-specific soil information, this work contributes valuable scientific evidence to support sustainable land management and informed decision-making in community-based agricultural systems in southern Senegal.

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