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Pedological Characteristics of the Four (4) Land-Use Units in the Kadzel Sub-Watershed (Lake Chad Basin, Diffa, Niger)

KAREMA ARY MADOU Kaoulé [a*], AMADOU ISSOUFOU Abdourhimou [a], OUSMANE ELH FADA Bagalé [b], ALI MAHAMANE Maimounatou [a] and MOUSSA MAMOUDOU Boubacar [a]

[a] Department of Soil and Environment, Faculty of Agronomic and Ecological Sciences, Hummay Salamna University (UHS), PO Box 78, Diffa, Niger.
[b] Faculty of Science and Technology, Abdou Moumouni University, Niamey, Niger.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Soil degradation in the Sahel poses challenges for agricultural production and the maintenance of soil functions. This study characterised the morphological and physicochemical properties of soils across four land-use units in the Kadzel sub-watershed, Diffa, Niger: gallery forest, irrigated cultivation, shrub–tree steppe and fallow fields. A stratified sampling approach was used to collect 195 individual soil samples, which were combined into 13 composite samples from the 0–20 cm layer. Four soil pits, one in each land-use unit, were examined to describe soil morphology to a depth of 100 cm. Laboratory analyses covered soil pH, organic carbon, organic matter, phosphorus, electrical conductivity, exchangeable bases and cation exchange capacity. Analysis of variance

**Corresponding author: E-mail: madoukaoulekaremaary@gmail.com;*

Contact Email(s): madoukaoulekaremaary@gmail.com;

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indicated significant differences in soil chemical characteristics among the land-use units ($p < 0.05$). The gallery forest exhibited comparatively high exchangeable calcium, organic matter and cation exchange capacity, while the irrigated cultivation zone had elevated available phosphorus. Fallow-field soils were predominantly sandy and exhibited comparatively low nutrient availability and cation exchange capacity. Morphological observations revealed contrasting textures and structural characteristics across the profiles. The first two principal component axes explained 73.4% of the variation in the analysed morphological properties. Estimated soil water reserves were highest in irrigated cultivation and lowest in fallow fields. These findings indicate distinct soil conditions across the four land-use units and support the need for land-use-specific soil management and rehabilitation approaches.

Keywords: Kadzel sub-watershed; land use; soil morphology; soil fertility; cation exchange capacity; soil water reserves; soil degradation.

1. Introduction

Soils in arid and semi-arid regions, particularly those in the Lake Chad Basin, represent a strategic natural resource for maintaining biodiversity, regulating biogeochemical cycles, and supporting agricultural production (Brady & Weil, 2016). In these constrained environments, the intrinsic properties of the soil strongly influence ecosystem functioning and the sustainability of agropastoral systems. A comparison of cultivated land-use systems in South Sikkim reported differences in soil physicochemical indicators and carbon stocks in relation to management practices (Tamang *et al.*, 2024).

In the Kadzel sub-catchment (Niger), soils evolve under the influence of particularly harsh Sahelian pedoclimatic conditions, characterised by high interannual rainfall variability, elevated temperatures, and pronounced topographic gradients. These factors govern pedogenetic processes, the spatial distribution of land-cover units, and their functional dynamics (Food and Agriculture Organization of the United Nations [FAO], 2015; Buol *et al.*, 2011). In this context, the capacity of soils to perform essential ecological functions such as storing organic carbon, regulating water flows, and supporting plant production serves as a key determinant of the ecological and socio-economic resilience of Sahelian territories (Bationo *et al.*, 2011). A global dryland assessment further found that the factors associated with soil carbon and nitrogen stocks vary with soil depth (Zhou *et al.*, 2024).

However, as in many other parts of the Sahel, the Kadzel sub-catchment is currently experiencing accelerated degradation of its soil resources. This results from a combination of processes, including water and wind erosion, surface crusting, a reduction in vegetation cover, and the intensification of agricultural land use. These degradative dynamics lead to the progressive alteration of the physicochemical and structural properties of soils, resulting in declines in their fertility, water-retention capacity, and structural stability (Lal, 2001). Over time, these transformations compromise agricultural productivity and increase the vulnerability of local socio-ecological systems, particularly with regard to food security (Bationo *et al.*, 2011). Research in southern Mali has identified soil texture and organic carbon content as factors associated with susceptibility to soil surface crusting (Jimenez Jimenez *et al.*, 2025).

Despite the critical nature of these issues, knowledge of the vertical organization of soil profiles and the variability of soil physicochemical properties in the Kadzel sub-basin remains limited. This lack of empirical data hinders a nuanced understanding of degradation processes and the development of sustainable management strategies tailored to different land-use units (FAO, 2015; Buol *et al.*, 2011). Consequently, a thorough characterisation of soil horizons is essential for guiding agricultural practices, improving fertility management, curbing erosion, and strengthening the resilience of agroecosystems in the face of global change. A comparison of land-use systems in Ethiopia likewise identified differences in soil physicochemical properties across land uses and soil depths (Girma *et al.*, 2023).

In this context, the present study aims to characterise the morphological and physicochemical properties of soils, as well as their vertical distribution, across four land-use units (gallery forest, irrigated cropland, steppe, and field-fallow systems) within the Kadzel sub-basin.

2. Materials and Methods

2.1 Study Area

The study was conducted in the Kadzel sub-watershed, located in the south-eastern part of the Manga zone in the Diffa region (Niger). This sub-watershed extends between the communes of Maïné-Soroa to the southwest and N'Guigmi to the northeast, situated around 13°34′ N latitude and 12°71′ E longitude. It covers an area of approximately 7,504.71 km² and is part of the Lake Chad basin hydrographic system.

From a geomorphological perspective, the study area is characterised by a plain with a southward slope, leading toward the Komadougou Yobé valley—the region's primary hydrological outlet. To the east, the landscape is marked by relict formations from the ancient shoreline of Lake Chad, while to the north, the terrain transitions into predominantly desert-like zones. This configuration results in significant spatial heterogeneity in terms of edaphic (soil) and hydrological conditions.

The soils found in the area consist primarily of hydromorphic soils, vertisols, and subarid brown soils, reflecting a diversity of drainage conditions, textures, and hydrological dynamics. These soil substrates support a mosaic of vegetation types characteristic of the Sahelian environment, including shrubby to wooded steppes, degraded steppes, gallery forests, and complex agricultural systems that integrate cultivated fields, fallow land, and grazing areas. The vegetation features a tree layer dominated by species such as *Tamarindus indica*, *Diospyros mespiliformis, Vachellia nilotica*, *Hyphaene thebaica*, and *Salvadora persica*. The shrub layer is dominated by very dense stands of *Prosopis juliflora* and *Bauhinia rufescens*. The soil ranges primarily from sandy to sandy-loam and clayey from the north to the south of the gallery forest; agriculture, livestock farming, and fishing are the main socio-economic activities (Fig. 1).

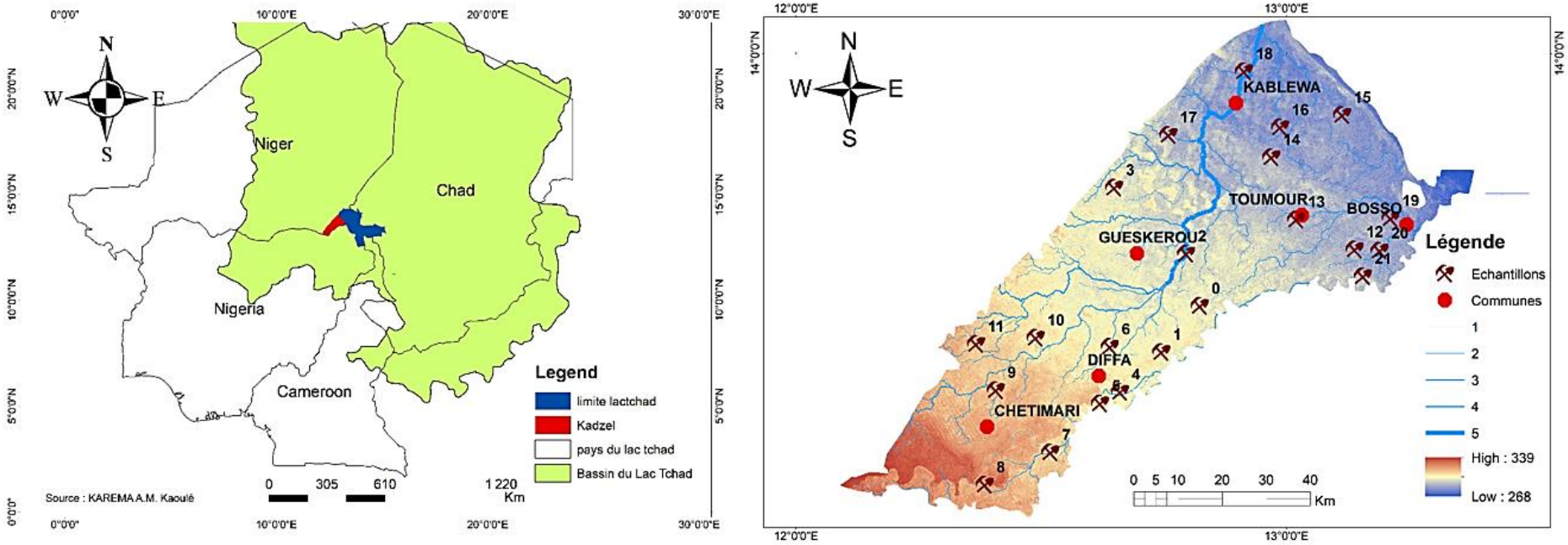


Fig. 1. Location of the study area

The climate of the Kadzel sub-watershed is dry tropical, characterised by a short rainy season and a long dry season. The rainy season lasts, on average, from June to September (4 months); the mean annual rainfall for 2025 was 240.6 mm. The highest mean monthly total, 190.2 mm, (in 2025) was recorded in August. The mean annual maximum temperature ranges between 44.72 °C and 45.96 °C, while the mean annual minimum temperature ranges between 9.85 °C and 10.94 °C (Fig. 2).

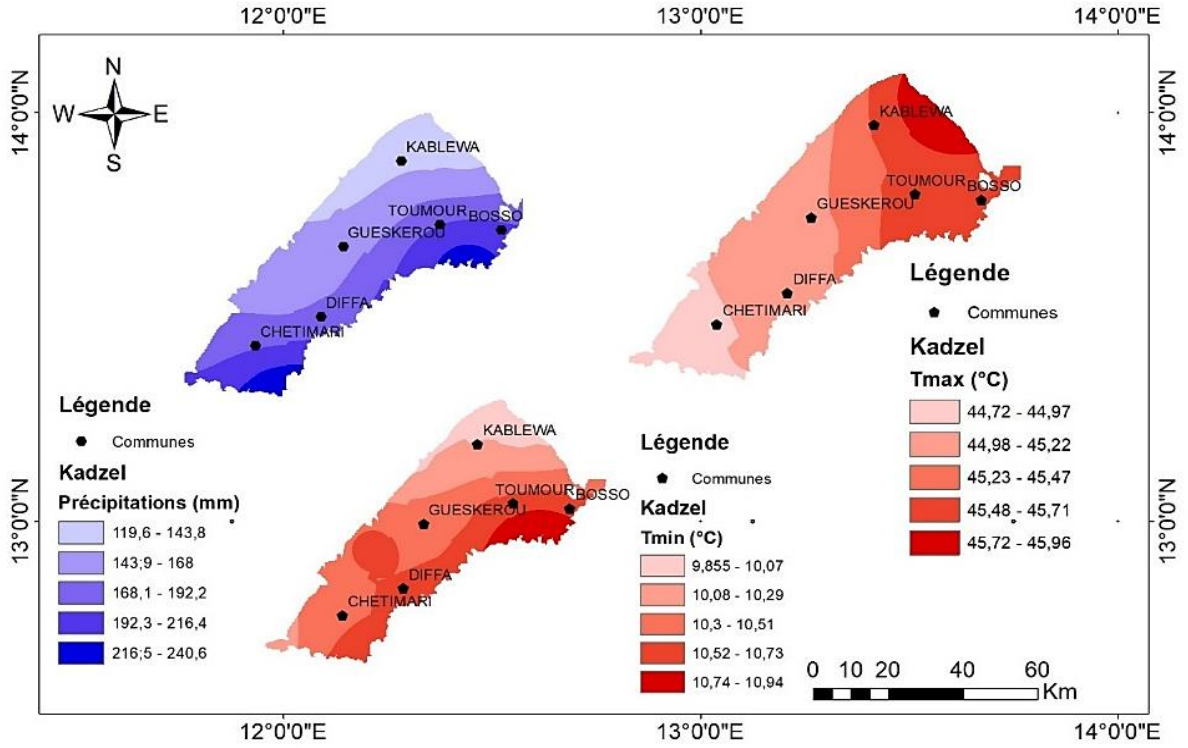


Fig. 2. Annual rainfall and temperature for the Kadzel sub-catchment

2.2 Data Collection

2.2.1 Sampling

In the Kadzel sub-watershed, the sampling strategy was based on a stratified approach according to land cover units, to account for the spatial heterogeneity of ecosystems and land-use practices. Four representative units were selected based on their ecological and socio-economic importance.

A total of 195 individual samples were collected and combined into 13 composite samples. In addition, four soil pits were excavated, one per land cover unit, to describe soil profiles and analyse the vertical distribution of soil horizons. This approach enabled the combination of surface analysis with an understanding of pedogenetic dynamics at depth (Table 1).

Sampling was carried out using an auger to a depth of 0–20 cm, corresponding to the layer most sensitive to human activity and biogeochemical processes. Each composite sample was a homogenized mixture of several individual samples and has an average weight of approximately 500 g.

Table 1. Distribution of soil samples and composite samples according to land use units in the Kadzel sub-watershed

Land use units	Number of samples	Composite samples	Number of soil pits
Gallery Forest	45	3	1
Irrigated farming area	45	3	1
Fallow fields	60	4	1
Shrubby-tree steppe	45	3	1
Total	**195**	**13**	4

2.2.2 Data Analysis

The study of soil chemical fertility parameters was carried out on 13 composite samples from the four land-cover units. The analyses were performed at the Soil, Water, Vegetation and Fertilizer Analysis Laboratory of the National Institute of Agronomic Research of Niger and included the following parameters: pH (measured directly using a pH meter with a soil/extraction solution

ratio of 1/2.5 [FAO, 2006]), C (%), P (%), OM (%), CEC (Meq /100 g), EC (mS /cm) , Ca^{2+} (Meq /100 g), Mg^{2+} (Meq /100 g), Na^{+} (Meq /100 g) and K^{+} (Meq /100 g). The analytical methods were as follows: (i) pH was measured directly using a pH meter with a soil/extraction solution ratio of 1/2.5 [FAO, 2006]; (ii) for the organic carbon (C) content, the method of Walkley and Black (1934) was applied; (iii) phosphorus (P) was determined by nitric acid extraction (Bray & Kurtz, 1945); (iv) exchangeable bases were assessed by spectrometric determination of Ca^{2+} and Mg^{2+} cations by atomic absorption spectrometry, and then of K^{+} and Na^{+} cations by flame emission spectrometry; (v) the cation exchange capacity (CEC) was measured from the extraction solution of the exchangeable bases (Sumner & Miller, 1996).

2.3 Statistical Analyses

Analysis of variance (ANOVA) was performed to compare the chemical characteristics of the soils between the different land cover units. Principal component analysis was conducted to evaluate the relationships between the morphological and physicochemical parameters of the soils and the land cover types. All statistical analyses were performed using R software version 4.3.1.

3. Results

3.1 Analysis of Physicochemical Characteristics

Analysis of physicochemical properties showed significant differences in chemical fertility parameters according to land cover units ($P < 0.05$). The soils exhibited neutral to alkaline conditions, with pH values ranging from 6.84 to 9.56, with the highest values observed in the fallow field (CJ) and shrub-to-tree steppe (Stp3) units. Electrical conductivity was low (< 0.30 mS/cm) in the irrigated crop, fallow field, and shrub-to-tree steppe areas, whereas it was high in the gallery forest (1.25 mS/cm).

The exchangeable cations showed marked differences among units, with high levels of calcium (Ca^{2+} 8.0 meq / 100 g), total exchangeable bases (S ≈ 8.73 meq /100 g), and cation exchange capacity (CEC ≈ 8.83 meq /100 g) in gallery forest (FG). Conversely, these values were low in fallow fields (CJ) (S < 1.30 meq /100 g; CEC < 1.40 meq /100 g) (Fig. 3).

Magnesium (Mg^{2+}) was found at relatively higher levels in the irrigated crop zone (ICZ) and the shrub-to-tree steppe, while sodium (Na^{+}) and potassium (K^{+}) remained low across all units. Available phosphorus exhibited high spatial variability, with high levels in the irrigated zone (ICZ 26.43 ppm) and gallery forest (GF), and lower levels in the fallow fields and shrub-to-tree steppe. Similarly, organic matter and organic carbon levels were higher in the gallery forest (0.70% OM and 0.40–0.42% carb). Overall, gallery forest (FG) and irrigated zone (ZCI) appeared to be the most fertile units, whereas fertility was lower in fallow fields (CJ) and shrubby to tree steppes (Fig. 3).

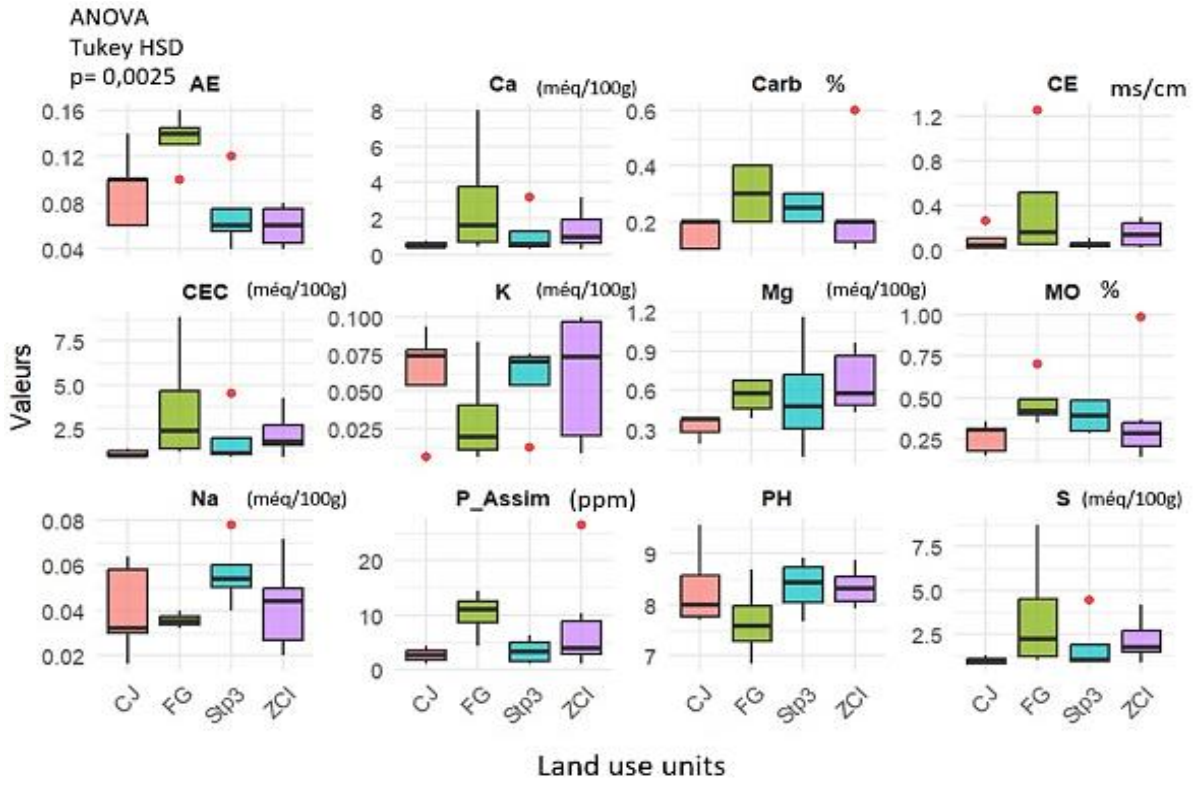


Fig. 3. Analysis of physicochemical characteristics
Legend: CJ: Fallow fields; FG: Gallery Forest; ZCI: Irrigated agricultural area; Stp3: Shrub-tree steppe

3.2 Analysis of Morphological Characteristics

Fig. 4 shows the morphological characteristics of four land cover units (FG, ZCI, STP and CJ) over the first 100 centimetres of depth.

FG: Exhibited a clayey texture throughout almost its entire depth, with a silty texture between 35 and 78 cm. The observed structures are cubic, polyhedral, and oblique plate-like. Very sticky, not very friable, with identifiable plant debris and traces of decomposition. ZCI: Clayey texture from 0 to 68 cm, sandy texture from 68 to 90 cm. The structures are particulate and subangular polyhedral, very sticky, not very friable, with identifiable plant debris from 0 to 70 cm. The uppermost horizon, from 68 to 90 cm, is non-sticky and very friable. STP: Silty texture at the surface (0 to 35 cm), sandy between 35 and 60 cm, and clayey at depth. The structures are massive, lumpy, cubic, and subangular polyhedral, friable on the surface and very sticky at depth with identifiable decomposing plant debris. CJ: Presented a sandy texture from 0 to 55 cm and a silty texture at depth. Massive, lumpy, cubic, and subangular polyhedral structures. Friable, with identifiable decomposing plant debris.

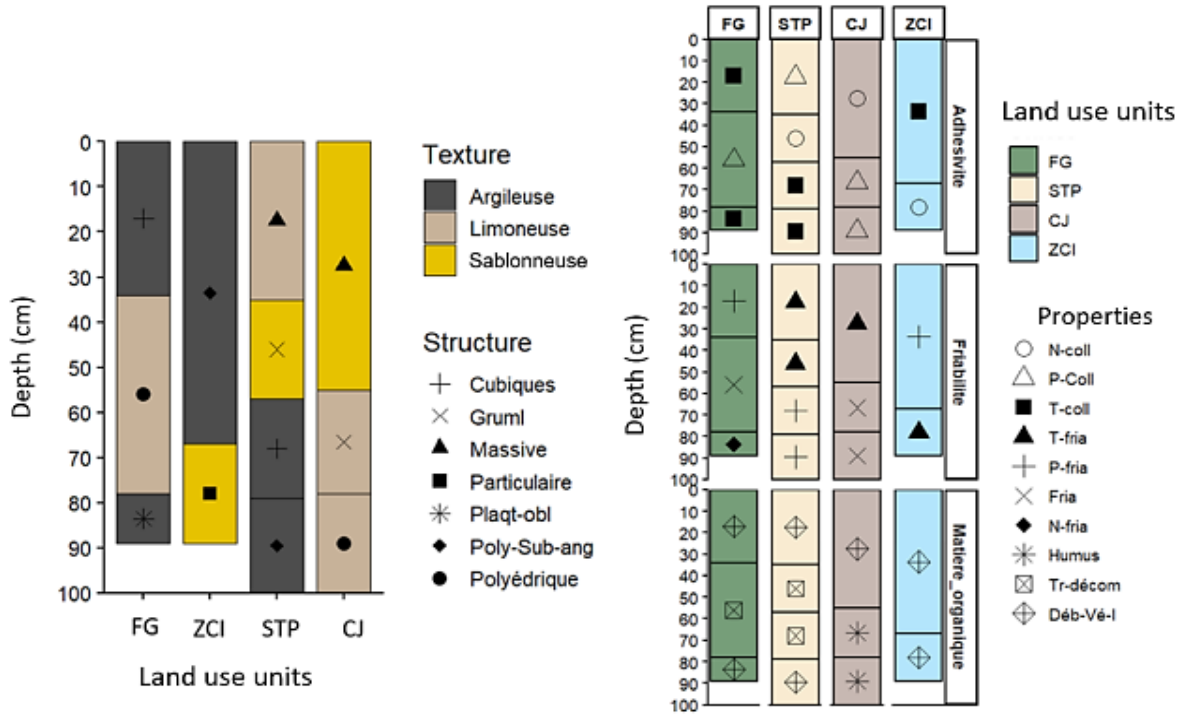


Fig. 4. Analysis of morphological characteristics

Legend: N-coll: Non-sticky; P-coll: Slightly sticky; T-coll: Very sticky; P- fria : Slightly friable; Fria: Friable; N- fria : Non-friaable; Tr-decom : Identifiable trace of decomposition; Deb-Ve-I: Debris of identifiable vegetation

3.3 Textural, Structural and Organic Gradient of Soils under Different Land Uses

Principal component analysis (PCA) carried out on the morphological properties of soils under different land-use units (FG, ZCI, STP and CJ) showed that the first two factorial axes explain 73.4% of the total variance (Dim1 = 39.6%; Dim2 = 33.8%).

Axis 1 contrasted sandy soils, characterised by a loose, friable, and non-adhesive consistency, with clay soils, associated with high plasticity, a sticky consistency, and subangular polyhedral and plate-like structures. Axis 2 highlighted, on the one hand, silty soils, exhibiting granular structures rich in organic matter, and, on the other hand, soils characterised by massive, subangular polyhedral, or particulate structures, associated with lower organic activity (Fig. 5).

Gallery forest (GF) was characterised by clay soils, with a silty transition between 35 and 75 cm depth. These soils exhibited polyhedral, cubic and platy structures, strong cohesion in wet conditions, which resulted in high plasticity, as well as intense biological activity, marked by identifiable traces of decomposition.

The irrigated cultivation zone (ICZ) was characterised by a clayey texture, with a sandy transition between 70 and 90 cm depth. The structures observed were mainly subangular polyhedral and particulate at depth (Fig. 5).

The shrubby to tree steppe (STP) exhibited a contrasting vertical organization. The soils were characterised by a silty-sandy texture at the surface, becoming more clayey at depth. The structure was heterogeneous, evolving from massive to granular, then polyhedral forms. The consistency changed from a friable state at the surface to a highly plastic state at depth, linked to the dynamics of organic matter and biological activity (Fig. 5).

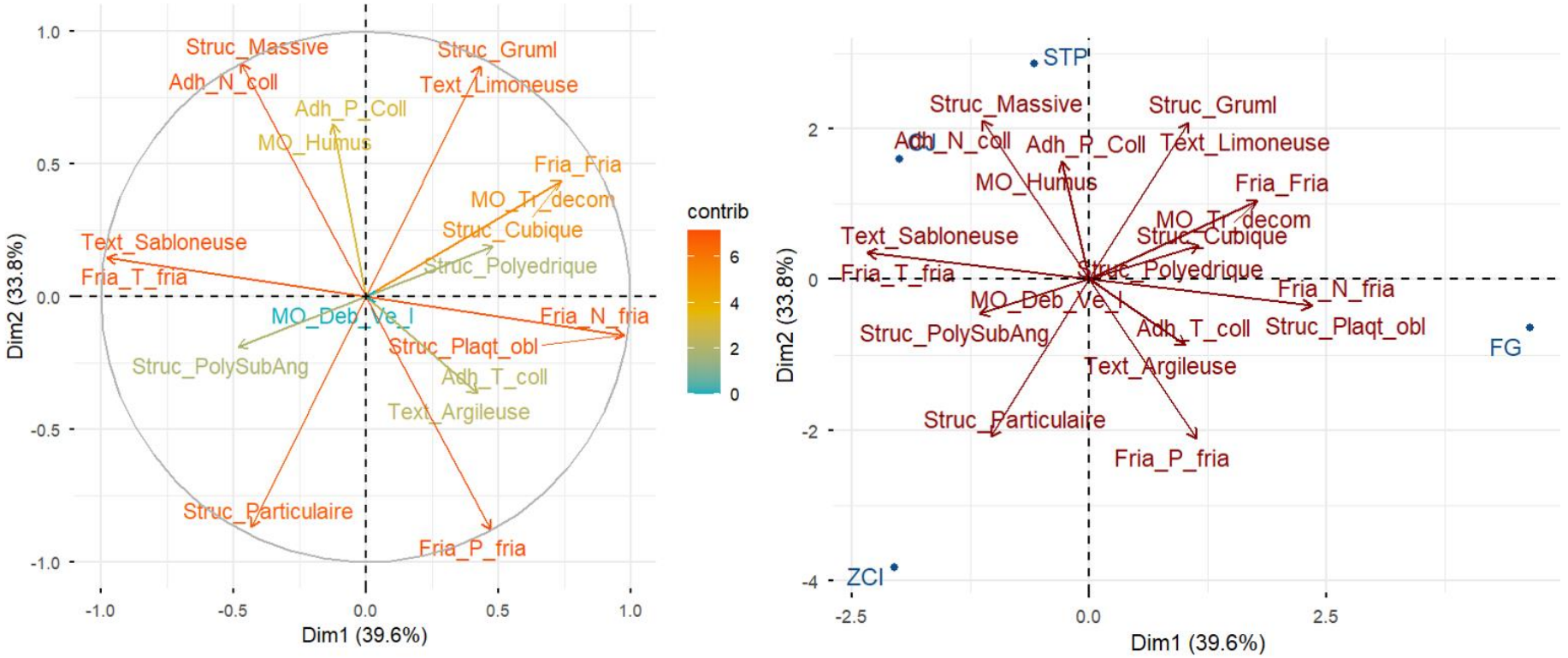


Fig. 5. Textural, structural and organic gradient of soils under different land uses

The Field-Fallow (FF) Complex was characterised by sandy to sandy-loam soils with a poorly developed, massive to granular structure and an overall friable consistency. These characteristics reflected limited structural evolution, despite some incorporation of organic residues into the surface horizons (Fig. 5).

3.4 Vertical Distribution of Soil Water Reserves According to Land Use Units

Fig. 6 shows the vertical variability of soil water reserves across land cover units. Overall, values decreased progressively with depth for all units. The ZCI exhibited the highest water reserves across the entire profile, with values ranging from 220 mm at the surface to 120 mm at 100 cm. Conversely, the fallow field showed the lowest reserves, ranging from 140 mm to 60 mm. The Galleria Forest (FG) and Shrub-to-Tree Steppe (STP) units showed intermediate levels, with relatively high values in the surface horizons (160–180 mm) gradually decreasing to 90–110 mm at depth. Furthermore, water reserve classes changed with depth, with high classes being dominant at the surface, while low to very low classes became predominant in deeper horizons, particularly in unit CJ.

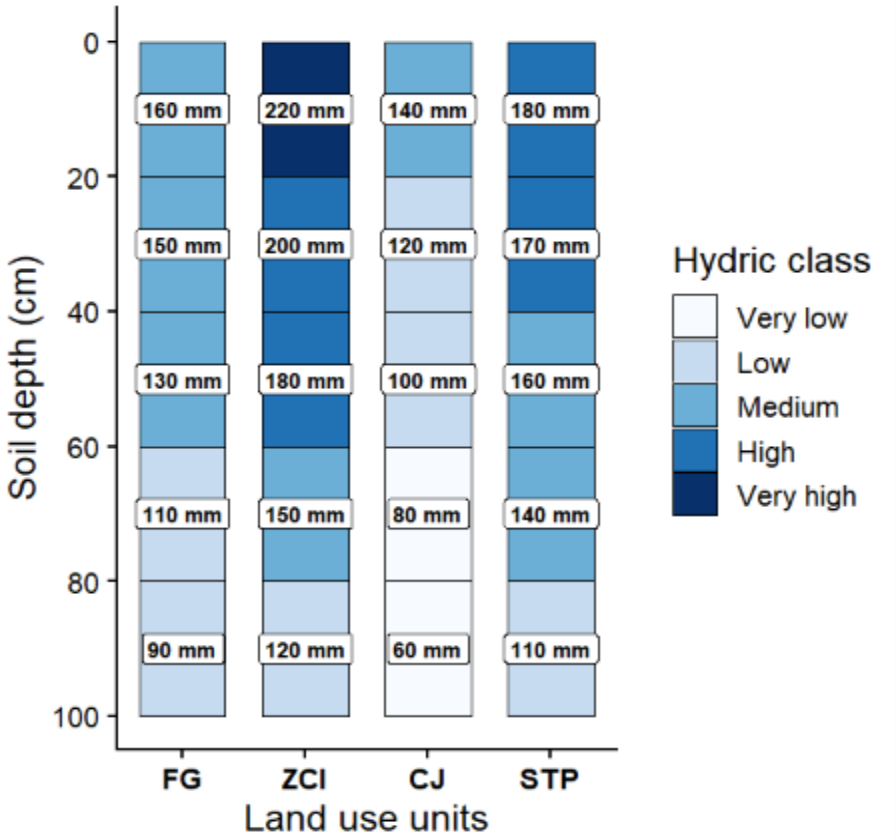


Fig. 6. Vertical distribution of soil water reserves according to land cover units

4. Discussion

The analysis of the physicochemical and morphological properties of soils under different land use units reveals a strong pedological structure controlled by human activities. This organization is not limited to simple differentiation of fertility but reflects distinct ecological trajectories, ranging from resilient systems to advanced states of degradation. Principal component analysis (PCA) identified functional gradients that reflect the interactions between biological, chemical, and physical soil processes. Studies in the Nigerien Sahel have also documented soil and vegetation responses to contrasting land-use pressures (Bationo *et al.*, 2007; Hiernaux *et al.*, 2009; Issoufou *et al.*, 2022).

The observed neutral to alkaline pH range (6.84–9.56) is characteristic of calcareous soils in arid to semi-arid climates, where evapotranspiration exceeds precipitation, leading to an accumulation of exchangeable bases (Brady & Weil, 2016). Soil chemistry studies indicate that salts, carbonates and exchangeable cations can influence soil chemical behaviour in dry environments (Hillel, 2004; Sumner & Miller, 1996). The 2.72 pH unit difference between CJ and FG reflects sodisation processes initiated by capillary concentration under sparse canopy cover, a phenomenon described by Hillel (2004) as characteristic of eroded systems where organic matter no longer plays its buffering role. In comparison, the FG maintains a moderate pH (7.5–8.2) despite its high electrical conductivity (1.25 mS/cm), suggesting a buffering capacity enhanced by clay-humus complexes, a mechanism consistent with organic-matter-mediated aggregation and cation retention (Oades, 1984; Sumner & Miller, 1996). This discrepancy shows that pH is

not an absolute indicator of fertility but must be interpreted in conjunction with cation exchange capacity (CEC) and soil solution composition.

The values recorded for FG, with a CEC of 8.83 meq /100 g and a sum of exchangeable bases of 8.73 meq /100 g, placed this unit in the class of very fertile eutrophic soils, consistent with the important role of organic matter and fine fractions in nutrient retention (Oades, 1984; Six *et al.*, 2002). This is particularly evident in the relatively well-preserved vegetation formations of Niger, notably in the areas of the Gadabedji Biosphere Reserve and certain gallery forests of the Komadougou. More generally, litter inputs and biological activity can support nutrient retention and soil aggregation (Bationo *et al.*, 2007; Oades, 1984). This level was explained by a positive feedback mechanism: abundant litter feeds a high microbial biomass, producing polysaccharides that promote aggregation and protect organic matter (Six *et al.*, 2002, 2006). An organic matter content of 0.70% indicates a likely low C/N ratio (< 12) and high stability, as indicated by its positive correlation with CEC in PCA. By comparison, the ZCI reaches 26.43 ppm of available phosphorus, a value higher than the FG, but this concentration is artificial and not synchronized with plant demand, exposing it to losses through fixation or leaching (Lemming *et al.*, 2019; Sharpley *et al.*, 2018). Research on agricultural phosphorus management shows that repeated nutrient additions can increase residual phosphorus pools and create potential losses (Lemming *et al.*, 2019; Sharpley *et al.*, 2018). In fertile soils, phosphorus is maintained in the slowly mineralized organic compartment, ensuring continuous availability without toxic spikes. The electrical conductivity of 1.25 mS/cm, while exceeding the sensitivity threshold of many legumes (0.75 mS/cm), remains below the problematic salinity criterion (> 2 mS/cm) and reflects a concentration of nutrient solutes in a closed biospheric system, a condition requiring interpretation alongside the soil's exchange characteristics (Hillel, 2004; Sumner & Miller, 1996). Thus, fertile soils constitute a model of self-sustaining fertility, where soil chemistry is subordinate to biology.

The ZCI shared high fertility indicators with the FG, but PCA revealed a fundamental dissociation: these nutrients are dissolved in the soil solution rather than adsorbed onto organomineral complexes. This "hydrodynamic fertility" resulted from massive external inputs: irrigation water laden with salts, phosphate fertilisers, and calcium amendments (Lal, 2004). Studies across managed soils show that changes in land use and nutrient inputs affect soil chemistry and nutrient retention, although the magnitude depends on local conditions (Bationo *et al.*, 2007; Girma *et al.*, 2023). However, the CEC < 1.40 meq /100 g in CJ and the weak correlation between OM and CEC in the ZCI ($r < 0.3$ according to PCA) indicate that retention capacity did not keep pace with inputs. This discrepancy led to agronomic inefficiency: up to 60% of fertilisers can be leached into the sandy horizons of 70–90 cm. Compared with the FG (Flood Grazing), where 80% of phosphorus is organic and stable, the ZCI (Zone of Controlled Isoil) has labile mineral phosphorus, readily available but rapidly lost (Lemming *et al.*, 2019; Sharpley *et al.*, 2018). The high magnesium content in the ZCI can induce a cationic imbalance (Ca/Mg ratio < 2) that is detrimental to soil structure (Brady & Weil, 2016).

The lowest values for CEC (< 1.40 meq /100 g) and available phosphorus (< 5 ppm) placed CJ and STP in the oligotrophic soil class (Bationo *et al.*, 2007; Bielders *et al.*, 2002). This nutrient poverty resulted from convergent degradation: selective wind erosion of fine particles < 50 µm, accelerated mineralisation of organic matter without replenishment, and surface compaction. In Nigerien Sahelian environments, changes in land use, grazing and vegetation cover have been linked to declining productivity and enhanced erosion risks (Hiernaux *et al.*, 2009; Issoufou *et al.*, 2022). The position of CJ on the Na^+ and K^+ side of the PCA suggests increasing saturation of the sites by monovalent cations, an early indicator of sodisation (Hillel, 2004). In comparison, STP exhibits intermediate levels of Mg^{2+}, reflecting slower root biomass mineralisation than CJ, but insufficient to restore CEC. Low available phosphorus (< 3 ppm) is the major limiting factor. PCA thus confirmed that CJ and STP follow a degradation trajectory where structural loss precedes and exacerbates nutrient loss, a phenomenon described by Lal (2004) as "physical degradation inducing chemical degradation."

The dominant clayey texture over 0–100 cm indicates a homogeneous profile, but FG was distinguished by its organomineral cohesion: the cubic and polyhedral structures reflect structuring by root and faunal bioturbation (Dexter, 2004). The role of roots, organic matter and microbial activity in stabilising aggregates and supporting porosity has been described in soil-structure research (Oades, 1984; Six *et al.*, 2002). These structures indicated an aggregate stability index greater than 80% and a transmission porosity favourable to infiltration (Ksat > 10 cm/h) and retention. Compared with the ZCI, where the structure is destroyed by ploughing, FG exhibits a structure "newly formed" by biological processes. The very strong cohesion (very sticky) protected against water erosion and maintained optimal aeration.

The abrupt textural discontinuity at 70 cm is an indicator of anthropogenic soil. Such reworking can accompany repeated cultivation and alteration of soil organic matter and structure (Bationo *et al.*, 2007; Dexter, 2004). The particulate structure results from the fragmentation of aggregates by repeated tillage, reducing the average aggregate size from > 2 mm to < 0.25 mm (Six *et al.*, 2002, 2006). This fragmentation explains the very sticky consistency: the dispersion of clays creates a plastic paste that dries into a surface crust, reducing infiltration by 50 to 70% (Hillel, 2004). Compared with the FG (Flood Grazing), where the polyhedral structure ensures bimodal porosity, the ZCI (Zone of Controlled Irrigation) exhibited reduced unimodal porosity.

The contrasting structure of the soil, with its silty-sandy surface and clayey subsoil, is not a sign of degradation but a functional stratification typical of Sahelian steppe ecosystems. The importance of vegetation and land-use conditions for Sahelian rangeland functioning is also documented in Niger (Hiernaux *et al.*, 2009; Issoufou *et al.*, 2022). The crumbly surface horizon promoted rapid infiltration of torrential rainfall (50–100 mm/h) and limits evaporation. The plastic clayey horizon constituted a capillary water reserve accessible during the dry season. This biphasic architecture, described by Oades (1984) in Mediterranean soils, is optimized for drought but vulnerable to overgrazing. Trampling compacted the friable horizon, reducing infiltration.

The sandy texture and massive structure reflect a pedological evolution that was arrested at a fluvisolic stage. In sandy Sahelian landscapes, exposed soils can be particularly vulnerable to wind erosion and nutrient losses (Bielders *et al.*, 2002; Hiernaux *et al.*,

2009). The friability indicates a lack of organic cementation and susceptibility to slaking under raindrop impact. Compared with STP, CJ exhibits unfavourable textural homogeneity: the low retention capacity (60 mm at 100 cm) and unimodal porosity limit infiltration and water retention. The presence of plant debris without a humic horizon suggests mineralisation that was too rapid (t½ < 6 months) to allow humification (Bationo *et al.*, 2007; Oades, 1984).

5. Conclusion

The analyses showed that gallery forest (GF) represented a stable and resilient system, characterised by high and sustained fertility supported by biocycling and a well-developed structure. Irrigated cultivated areas (ICA) exhibited high but unstable chemical fertility, masked by significant physical fragility linked to textural discontinuity and substantial nutrient losses. Fallow fields (FF) reflected an advanced state of degradation with poor, poorly structured, and severely depleted soil. Shrub-to-tree steppe (STP) maintained vertical soil functionality but remains vulnerable to grazing pressures. Principal component analysis confirmed that soil sustainability depends as much on physical structure as on chemical fertility, and that degradation processes vary across units. Thus, each system requires a specific management strategy: conservation for GF, structural restoration for ICA, intensive rehabilitation for STP, and controlled grazing management for STP. Finally, the study emphasises that soil sustainability relies on replicating natural processes, particularly those observed in gallery forests. It recommends further research using isotopic tracers and field experiments to assess the reversibility of degradation and improve restoration strategies.

6. Limitations

The study was based on 13 composite surface-soil samples and four soil pits, with one pit representing each land-use unit. This sampling design limits the assessment of within-unit variability and the generalisability of profile-level observations. The findings describe the sampled conditions rather than temporal changes or causal effects of land use. Some management implications and mechanistic explanations discussed in the study were not directly tested through field experiments. Additional sampling, repeated measurements and field-based assessment of soil processes would strengthen the interpretation of the observed differences.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. ChatGPT, Claude and Perplexity were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., & Kimetu, J. (2007). Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems, 94*(1), 13–25. https://doi.org/10.1016/j.agsy.2005.08.011

Bationo, A., Waswa, B., Okeyo, J. M., Maina, F., & Kihara, J. (Eds.). (2011). *Innovations as key to the green revolution in Africa: Exploring the scientific facts*. Springer. https://doi.org/10.1007/978-90-481-2543-2

Bielders, C. L., Rajot, J.-L., & Amadou, M. (2002). Transport of soil and nutrients by wind in bush fallow land and traditionally managed cultivated fields in the Sahel. *Geoderma, 109*, 19–39. https://doi.org/10.1016/S0016-7061(02)00138-6

Brady, N. C., & Weil, R. R. (2016). *The nature and properties of soils* (15th ed.). Pearson. https://books.google.com/books?id=x0PFzgEACAAJ

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science, 59*(1), 39–46. https://doi.org/10.1097/00010694-194501000-00006

Buol, S. W., Southard, R. J., Graham, R. C., & McDaniel, P. A. (2011). *Soil genesis and classification* (6th ed.). Wiley-Blackwell. https://www.wiley.com/en-us/soil-genesis-and-classification-6th-edition-p-9780470960608

Dexter, A. R. (2004). Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. *Geoderma, 120*(3–4), 201–214. https://doi.org/10.1016/j.geoderma.2003.09.004

Food and Agriculture Organization of the United Nations. (2006). *Guidelines for soil description* (4th ed.). FAO. https://www.fao.org/3/a0541e/a0541e.pdf

Food and Agriculture Organization of the United Nations. (2015). *Status of the world's soil resources: Main report*. FAO. https://www.fao.org/3/i5199e/i5199e.pdf

Girma, K., Yimer, F., Tamirat, T., & Abdelkadir, A. (2023). Effect of land use change on soil physico-chemical properties under different land use system in Arsi Zone, Oromia Region, Ethiopia. *Journal of Biology and Nature, 15*(1), 57–69. https://doi.org/10.56557/joban/2023/v15i18076

Hiernaux, P., Ayantunde, A., Kalilou, A., Mougin, E., Gérard, B., Baud, F., Grippa, M., & Djaby, B. (2009). Trends in productivity of crops, fallow and rangelands in Southwest Niger: Impact of land use, management and variable rainfall. *Journal of Hydrology, 375*(1–2), 65–77. https://doi.org/10.1016/j.jhydrol.2009.01.032

Hillel, D. (2004). *Introduction to environmental soil physics*. Academic Press. https://www.sciencedirect.com/book/9780123486554/introduction-to-environmental-soil-physics

Issoufou, I., Abdourhamane, T. A., Halarou, N., Rajot, J.-L., Hassane, B., Tidjani, A. D., & Zibo, G. (2022). Vegetation dynamics in a fragile ecosystem in relation to land use: The case of the dune cordon of Namaro, southwestern Niger. *African Journal of Environmental Science and Technology, 16*(7), 264–274. https://doi.org/10.5897/AJEST2022.3115

Jimenez Jimenez, P. A., de Oliveira, E. M., Medeiros, B. M., Borghi, E. J. A., Zinn, Y. L., Avanzi, J. C., Inda, A. V., Cirillo, M. Â., Marques, J. J., Cisse, A., Diakite, M., Curi, N., & Silva, M. L. N. (2025). Factors governing crusting formation in soils in Southern Mali, West Africa: Evaluation of susceptibility indices. *Catena, 248*, 108581. https://doi.org/10.1016/j.catena.2024.108581

Lal, R. (2001). Soil degradation by erosion. *Land Degradation & Development, 12*(6), 519–539. https://doi.org/10.1002/ldr.472

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304*(5677), 1623–1627. https://doi.org/10.1126/science.1097396

Lemming, C., Oberson, A., Magid, J., Bruun, S., Scheutz, C., Frossard, E., & Jensen, L. S. (2019). Residual phosphorus availability after long-term soil application of organic waste. *Agriculture, Ecosystems & Environment, 270–271*, 65–75. https://doi.org/10.1016/j.agee.2018.10.009

Oades, J. M. (1984). Soil organic matter and structural stability: Mechanisms and implications for management. *Plant and Soil, 76*, 319–337. https://doi.org/10.1007/BF02205590

Sharpley, A., Jarvie, H., Flaten, D., & Kleinman, P. (2018). Celebrating the 350th anniversary of phosphorus discovery: A conundrum of deficiency and excess. *Journal of Environmental Quality, 47*(4), 774–777. https://doi.org/10.2134/jeq2018.05.0170

Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil, 241*, 155–176. https://doi.org/10.1023/A:1016125726789

Six, J., Frey, S. D., Thiet, R. K., & Batten, K. M. (2006). Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Science Society of America Journal, 70*(2), 555–569. https://doi.org/10.2136/sssaj2004.0347

Sumner, M. E., & Miller, W. P. (1996). Cation exchange capacity and exchange coefficients. In D. L. Sparks *et al.* (Eds.), *Methods of soil analysis: Part 3—Chemical methods* (pp. 1201–1229). Soil Science Society of America. https://doi.org/10.2136/sssabookser5.3.c40

Tamang, N., Bordoloi, J. B., Singh, L. M., Dkhar, K., Dembalar, A., Walling, I., & Pradhan, B. (2024). Comparative studies on effect of conventional practices on soil quality parameters and carbon stock in common land uses in Namthang Block, South Sikkim. *Asian Journal of Soil Science and Plant Nutrition, 10*(4), 28–43. https://doi.org/10.9734/ajsspn/2024/v10i4379

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science, 37*(1), 29–38. https://doi.org/10.1097/00010694-193401000-00003

Zhou, X., Zhang, S., Chen, Y., Durán, J., Lu, Y., Guo, H., & Zhang, Y. (2024). Environmental drivers of soil carbon and nitrogen accumulation in global drylands. *Geoderma, 451*, 117075. https://doi.org/10.1016/j.geoderma.2024.117075

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