

CROPLAND INTENSIFICATION, SOIL FUNCTIONAL DECLINE, AND PATHWAYS TO SUSTAINABLE CLIMATE-SMART AGRICULTURE, AND FOOD SECURITY IN SOUTHWESTERN NIGERIA: A BIOGEOPEDOLOGICAL APPRAISAL

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ABSTRACT

Cropland intensification has become a dominant feature of land use in Southwestern Nigeria, driven by population growth, food demand, and urban expansion. However, the sustainability of this intensification is increasingly questioned due to its adverse effects on soil functional attributes. This review examines how cropping patterns and land use transitions are affecting soil biogeochemistry and pedology in the region's diverse agroecological landscapes. Findings reveal that continuous cropping, monocultures, reduced fallow cycles, and indiscriminate agrochemical use are leading to severe organic matter loss, nutrient imbalance, acidification, and microbial suppression. These biogeochemical disruptions reduce soil fertility, carbon storage, and resilience. Pedologically, intensification causes horizon truncation, profile simplification, erosion, and eventual reclassification of soils from Alfisols and Ultisols to less developed forms. Urban and peri-urban farming also introduces salinity and heavy metal concerns. Despite these challenges, integrated systems—such as agroforestry, legume rotations, and organic input use—offer viable pathways to restore soil functionality. However, research gaps remain in regional-scale assessments, long-term monitoring, and farmer-inclusive soil management. The review concludes by emphasizing the need for soil-informed land use planning and integrated restoration strategies to ensure sustainable intensification and long-term land productivity in Southwestern Nigeria.

Keywords: Cropland intensification, Soil functional decline, Biogeochemistry, Pedogenesis, Land use change, Southwestern Nigeria

INTRODUCTION

Cropland intensification has emerged as both a critical strategy and a growing challenge in the context of sustainable agriculture in tropical regions, particularly in Southwestern Nigeria. Soils are not just inert media for plant growth; they are dynamic, living systems that regulate water infiltration, nutrient cycling, carbon sequestration, and biological productivity (FAO, 2021; Akinbile *et al.*, 2021). These soil functions are highly sensitive to human-induced land use changes and agricultural pressures. As food security demands rise, the pressure to intensify land use without adequate regard for soil resilience continues to threaten the sustainability of soil systems (Ogunwale *et al.*, 2021; Falade *et al.*, 2023).

Southwestern Nigeria, comprising Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo states, is characterized by a humid tropical climate and predominantly ferruginous soils—mainly Alfisols, Ultisols, and Inceptisols (Akinbola and Adediran, 2021). Historically, traditional bush fallow systems with minimal external inputs allowed for natural soil regeneration and equilibrium between land use and soil health (Adeyolanu *et al.*, 2022). However, this equilibrium is rapidly shifting due to increased population pressure, shortened fallow periods, mechanized land preparation, and the shift toward monoculture and cash cropping (Oladapo *et al.*, 2023).

MATERIALS AND METHODS

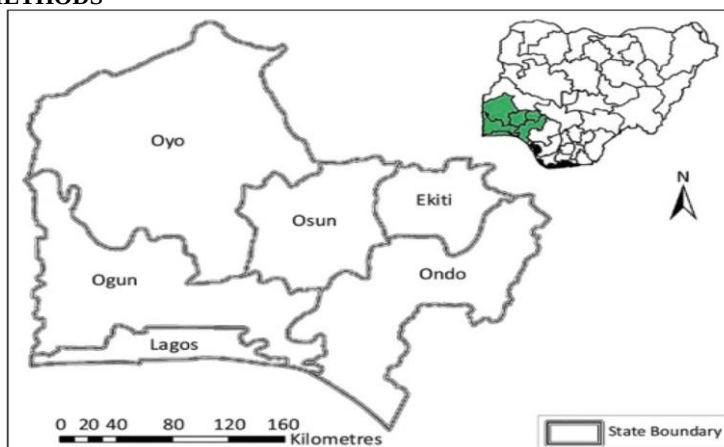


Figure. 1: Study Map

The consequences of such intensification include reduced soil organic matter (SOM), increased erosion, nutrient depletion, compaction, and alteration of natural pedogenic pathways (Adewole *et al.*, 2022; Lamidi *et al.*, 2022). Furthermore, inappropriate use of agrochemicals, irrigation with polluted water, and topsoil stripping have worsened the biogeochemical and structural integrity of soils in both upland and lowland areas (Akinbode *et al.*, 2024). Pedologically, these alterations are leading to the loss of horizon differentiation, erosion of surface horizons, and reclassification of formerly well-developed soils into less evolved forms (Aweto, 2023).

This review adopts a biogeopedological perspective to assess how cropland intensification is driving soil functional decline in Southwestern Nigeria. It integrates current knowledge on biogeochemical nutrient dynamics, soil structure, microbial shifts, and morphological degradation across various cropping patterns and land use types. Ultimately, this work seeks to inform sustainable intensification practices and promote adaptive land management policies to protect soil health in the region.

Cropland Intensification Trends in Southwestern Nigeria

The intensification of cropland in Southwestern Nigeria has evolved over the last four decades due to a combination of demographic growth, urbanization, economic restructuring, and climate variability. Historically, farmers in this region practiced rotational bush fallow systems and intercropping of tubers, legumes, and cereals. These practices allowed for a period of soil regeneration and helped to conserve soil structure and fertility (Adeyolu *et al.*, 2022; Aweto, 2023). Economic incentives and increasing food demand have transitioned many farmers from subsistence to market-driven intensification. High-value crops like amaranth, tomato, maize, and cassava are now cultivated year-round, often on marginal land with minimal soil fertility input or erosion control (Akinbola and Ayoola, 2022; Ogunwole *et al.*, 2021). In areas surrounding Lagos, Ibadan, and Akure, vegetable farms operate under intensive irrigation systems, often using wastewater, which enhances production but increases soil salinity and contamination (Oladapo *et al.*, 2023).

Traditional fallow periods, once lasting 10–15 years, have been reduced to 1–3 years or eliminated entirely in many farming systems. Falade *et al.* (2023) reported that over 75% of arable lands in Osun and Oyo States now experience continuous cultivation without restorative measures. This accelerates soil nutrient depletion, weakens microbial resilience, and increases erosion risk—particularly on the gentle slopes of Ondo and Ekiti States.

Mechanization, while limited to larger farms and government schemes, has grown over the last decade. Tractor use and ploughing disrupt natural soil horizons, promote compaction of subsoils, and remove surface litter—exposing topsoil to erosion (Lamidi *et al.*, 2022). In forest-to-farm conversion, bulldozing and burning of biomass destroy soil microhabitats and alter infiltration and drainage properties (Adewole *et al.*, 2022).

Intensified farming has also led to increased application of synthetic fertilizers and herbicides. Yet, indiscriminate use without soil testing or nutrient balancing often leads to soil acidification and leaching of essential nutrients (Akinbode *et al.*, 2024). Ogunwole *et al.* (2021) observed that smallholder farms in Ekiti and Ogun States apply nitrogen-heavy fertilizers while neglecting potassium and micronutrients, resulting in skewed soil fertility status and long-term productivity decline.

Urban expansion further compounds the problem, with peri-urban zones witnessing high turnover of land from residential to farming and vice versa. In Lagos and Abeokuta, land scarcity has forced farmers to cultivate marginal wetlands, where poor drainage, pollution, and heavy foot traffic degrade soil quality rapidly (Oladapo *et al.*, 2023).

In summary, cropland intensification in Southwestern Nigeria is spatially heterogeneous but commonly characterized by shortened rest cycles, mechanical disruption, excessive input use, and ecological simplification. These trends collectively contribute to a decline in soil functionality and long-term land productivity.

Soil Functional Attributes and Agricultural Land Use

Soil functions are the ecosystem services provided by soils to support plant growth, environmental regulation, and nutrient flow. These include water retention, nutrient cycling, root support, microbial habitat, and carbon sequestration (FAO, 2021). The alteration of land use systems and cropping intensity directly impacts these functions through changes in soil chemical, physical, and biological properties.

Soils under forest and long-term fallow regimes in the region generally show good aggregate stability and infiltration capacity. However, continuous tillage in vegetable-based systems has led to compaction and reduced porosity, increasing the risk of runoff and waterlogging, particularly in clay-rich Inceptisols of Oyo and Ogun (Lamidi *et al.*, 2022; Akinbile *et al.*, 2021). Structural degradation limits rooting depth and water availability, reducing drought resilience.

In intensively cropped soils, there is often a mismatch between nutrient uptake and replacement. Loss of organic matter and cation exchange capacity (CEC) weakens the soil's ability to retain nutrients. Adewole *et al.* (2022) found that continuous maize and cassava cultivation on Alfisols in Osun State reduced CEC by up to 40% within a decade.

Soil organic carbon is a key driver of biological productivity and nutrient availability. Its decline is accelerated by low residue return and the absence of organic amendments. Studies in Ekiti and Ondo States indicate that soils under intensive vegetable production lose 15–30% of their organic carbon content compared to adjacent forest soils (Falade *et al.*, 2023). This reduction directly affects microbial respiration, nitrogen mineralization, and SOM stability.

Soil microbial diversity and enzymatic activity are essential for maintaining nutrient cycling and disease suppression. Urban and peri-urban farming systems in Lagos and Ibadan often rely on polluted water and chemical inputs, which reduce microbial richness and increase pathogen susceptibility (Oladapo *et al.*, 2023; Akinbode *et al.*, 2024). Lack of microbial diversity also limits nutrient mineralization and weakens soil resilience.

The ability of soils to recover from disturbance is referred to as functional resilience. This attribute is rapidly eroding in Southwest Nigeria's intensively cropped soils. Akinbola and Ayoola (2022) reported that continuously farmed Alfisols showed irreversible degradation of topsoil, especially where land management was poor. Such degradation translates into declining yields and higher fertilizer dependency over time.

Soil functionality in Southwestern Nigeria is being significantly undermined by unsustainable land use practices. Reversing this trend requires biogeopedological monitoring, improved organic input strategies, and a return to soil-informed land planning.

Biogeochemical Effects of Cropping Systems

Cropping systems are one of the most powerful anthropogenic determinants of soil biogeochemistry. In Southwestern

Nigeria, land use intensification through specific cropping arrangements—such as monocropping, intercropping, and rotational farming—has caused significant shifts in soil organic carbon (SOC), nitrogen mineralization, microbial functioning, and nutrient retention (Adewole *et al.*, 2022; Akinbile *et al.*, 2021).

One of the clearest biogeochemical effects of intensification is the decline in soil organic carbon (SOC) stocks. Continuous cropping with minimal organic input reduces biomass return to the soil, thereby impairing carbon cycling. Falade *et al.* (2023) found that in vegetable farms in Oyo State, SOC dropped by 35–45% compared to nearby fallowed lands. This loss reduces nitrogen mineralization capacity and weakens plant-available nitrogen.

Additionally, the disruption of microbial biomass under intensive cropping interferes with the decomposition and mineralization of organic matter. Ogunwole *et al.* (2021) observed that under maize monoculture systems, microbial nitrogen turnover declined significantly, requiring higher synthetic N inputs for yield compensation.

Acidification is a major concern in intensively farmed Alfisols and Ultisols of the region. The repeated use of nitrogenous fertilizers, particularly urea and ammonium-based compounds, contributes to increased hydrogen ion concentration in soils. Akinbode *et al.* (2024) reported that pH levels in cassava and maize fields declined from 6.2 to 5.1 over six seasons of continuous cropping in Ekiti State. This pH drop not only affects nutrient availability but also reduces microbial enzyme efficiency, phosphorus solubility, and base saturation.

Cropping patterns also influence nutrient uptake and cycling rates. Monocultures of cassava and maize extract large amounts of potassium and magnesium from the soil. However, replenishment is often uneven or absent. Adeyolanu *et al.* (2022) found that in Ogun and Osun states, more than 60% of sampled plots under continuous cassava had exchangeable potassium below critical thresholds.

Micronutrient depletion, particularly of zinc, copper, and boron, is increasingly reported due to exhaustive cropping without tailored fertilization. These deficiencies are particularly acute in sandy Inceptisols, which have low buffering and retention capacities (Lamidi *et al.*, 2022).

In peri-urban systems, especially around Lagos and Abeokuta, irrigation using untreated or semi-treated wastewater introduces salt and toxic ion loads into the soil. This leads to increased electrical conductivity (EC), affecting plant nutrient uptake and soil microbial ecology. Oladapo *et al.* (2023) documented EC values over 4 dS/m in lettuce farms irrigated with urban effluents, along with reduced microbial respiration rates.

Cropping intensity affects soil biology. Reduced organic input and increased chemical disturbance led to lower microbial biomass carbon (MBC) and nitrogen (MBN). Enzymes like dehydrogenase, phosphatase, and urease, which mediate nutrient transformations, become inhibited. Akinbile *et al.* (2021) reported significantly lower enzymatic activity in continuously cultivated maize fields than in cocoa-agroforestry systems across Ekiti and Ondo States.

Agroforestry and intercropping with legumes (e.g., cowpea, pigeon pea) help stabilize soil carbon and nitrogen through biomass addition and symbiotic nitrogen fixation. Akinbola and Ayoola (2022) demonstrated that cocoa and oil palm plantations under mixed tree-crop systems in Osun State stored up to 22% more SOC than monocropped systems, confirming the biogeochemical advantage of diversified cropping.

In summary, the biogeochemical functioning of soils in Southwestern Nigeria is highly responsive to cropping design, intensity, and input management. Unsustainable intensification depletes carbon, disturbs nutrient cycling, and destabilizes microbial ecosystems, while integrated systems offer better soil health outcomes.

Pedological Responses to Agricultural Intensification

Agricultural intensification does not only impact soil chemistry and biology—it also alters the physical and morphological development of soils. From a pedological standpoint, continuous cultivation, mechanical disturbance, erosion, and compaction accelerate horizon truncation, reduce profile differentiation, and modify classification boundaries (Aweto, 2023; Adewole *et al.*, 2022; Babatunde *et al.*, 2025). Natural pedogenesis in tropical soils under forest cover leads to well-differentiated horizons (A–Bt–BC), often with argillic or cambic features. However, under continuous tillage, the A horizon is shallow or absent, and subsoil layers are exposed due to erosion or plowing. Akinbile *et al.* (2021) documented an average 9–13 cm loss of topsoil in maize fields under 10 years of continuous cultivation, especially on sloped lands.

In many areas of Ekiti and Ondo States, soils once classified as Alfisols now exhibit features of Inceptisols due to diminished illuviation and clay translocation—signs of interrupted or regressive pedogenesis (Ogunwole *et al.*, 2021).

Soil structure is another pedological attribute that responds to intensification. Repeated cultivation breaks down aggregates and increases the bulk density of the subsoil (Babatunde *et al.*, 2025). Falade *et al.* (2023) measured bulk densities of 1.65–1.72 g/cm³ in vegetable fields compared to <1.4 g/cm³ in adjacent fallow lands. Compaction restricts root growth, reduces infiltration, and increases susceptibility to runoff and erosion.

Prolonged waterlogging, often a by-product of poor drainage and compacted soils, alters soil color and redox status. In rice and vegetable plots around Abeokuta, poorly drained soils developed grayish, mottled horizons and iron depletion features (gleying), indicating deteriorated oxygen status (Lamidi *et al.*, 2022). Such features modify classification and indicate environmental stress in the pedosphere.

Selective erosion removes fine particles from the surface and redistributes them downslope, altering the texture of both eroded and depositional soils. Adeyolanu *et al.* (2022) observed that sandy loam topsoils evolved into loamy sand or sandy textures after 5–10 years of intensive use without erosion control.

In long-term cultivated areas, natural horizonation becomes less distinct, often simplified into A–C or Ap–C profiles. This not only affects pedon morphology but also soil classification. Lamidi *et al.* (2022) suggested that some profiles previously identified as Typic Kandistalfs now meet the criteria for Lithic or Entic subgroups due to shallow depth and loss of argillic horizons.

Changes in morphological attributes translate into changing land capability classes. Akinbola and Ayoola (2022) reported that over 40% of previously Class II soils in Osun State were downgraded to Class IV or V under the USDA Land Capability Classification due to compaction, erosion, and fertility decline.

Pedologically, intensification not only accelerates degradation—it rewrites the developmental history of soils. These changes reduce soil productivity, alter classification boundaries, and demand revised land use planning and conservation strategies.

Pathways to Sustainable Land Use, Climate-Smart Agriculture, and Food Security in Southwestern Nigeria

The challenges of cropland intensification and soil functional decline in Southwestern Nigeria are not a dead end but a critical juncture requiring a strategic pivot towards integrated land management. The region's agricultural future hinges on implementing synergistic pathways that address soil degradation while simultaneously increasing productivity, building climate resilience, and ensuring food security. A biogeopedological perspective is essential here, as it recognizes that effective solutions that must be rooted in an understanding of the intrinsic soil-landscape relationships (geopedology) and the biological processes that drive ecosystem functions (biogeochemistry). The following pathways, supported by empirical evidence, provide a framework for this transition.

Adoption of Climate-Smart Conservation Agriculture

A primary pathway involves the widespread adoption of Climate-Smart Agriculture (CSA) principles, particularly conservation agriculture (CA) built on minimum soil disturbance, permanent soil cover, and crop diversification. In the context of Southwestern Nigeria's cropping systems, this translates to a shift away from conventional tillage that exacerbates soil erosion and organic matter mineralization on already degraded lands. Research has demonstrated that practices like no-till farming, combined with the use of organic mulch covers, significantly improve soil aggregate stability, enhance water infiltration, and reduce surface runoff, thereby directly countering the physical aspects of soil functional decline (Bhan & Behera, 2014). Furthermore, the integration of leguminous cover crops into rotations serves a dual purpose: it provides the necessary soil cover and contributes to biological nitrogen fixation, improving soil fertility and reducing the need for synthetic fertilizers (Jat et al., 2022). This aligns with the CSA pillar of sustainably increasing productivity and incomes while enhancing resilience.

Implementation of Integrated Soil Fertility Management (ISFM)

Addressing the region's specific nutrient depletion requires a move beyond blanket fertilizer recommendations to a precise, integrated approach. Integrated Soil Fertility Management (ISFM) — the combined application of inorganic fertilizers and locally available organic amendments — is a critical pathway for restoring soil chemical and biological functions. The combined use of organic amendments (like composted farmyard manure or crop residues) and tailored mineral fertilizers has been shown to be more effective than either input alone in improving soil organic carbon, cation exchange capacity, and nutrient-use efficiency in West African soils (Vanlauwe et al., 2015). For the acid-sensitive soils of the region, this should be coupled with targeted liming to ameliorate aluminium toxicity and unlock phosphorus fixation, making applied nutrients more available to crops. This strategy directly tackles the yield penalties associated with soil functional decline, thereby contributing directly to food security.

Development of Predictive Land Use Planning and Sustainable Intensification Zones

A biogeopedological appraisal provides the scientific basis for spatial planning to avoid further degradation. This pathway involves using soil and landscape data to create sustainable land use plans that designate areas for controlled intensification, conservation, and restoration. By classifying

land based on its inherent capability and vulnerability, policymakers and farmers can avoid cultivating highly erodible slopes or soils with low resilience, instead focusing intensification efforts on more robust land units (Dixon et al., 2020). This spatial approach is a cornerstone of sustainable land use, ensuring that agricultural production does not undermine the natural resource base upon which it depends. It facilitates what is known as sustainable intensification, that is, producing more food from the same area of land while reducing environmental impacts—which is fundamental to long-term food security in a region with limited scope for agricultural expansion.

Enhancement of Soil Carbon Sequestration for Climate Mitigation and Adaptation

A crucial pathway that bridges climate action and food production is the active management of agricultural lands for soil carbon sequestration. The degraded soils of Southwestern Nigeria have lost significant portions of their native soil organic carbon. Implementing practices that rebuild this carbon stock—such as agroforestry (integrating trees with crops), application of biochar, and the CA practices mentioned above—serves multiple functions. From a climate perspective, it mitigates global warming by drawing down atmospheric CO₂. From a local soil health perspective, increased soil organic carbon is the primary driver for improving soil structure, water retention, and nutrient cycling (Lal, 2015). This enhanced resilience to both drought and heavy rainfall is a key adaptation strategy, making farming systems more robust in the face of climate variability.

RESULTS AND DISCUSSION

Research Gaps and Management Implications

Despite numerous studies on soil degradation, cropping systems, and land use in Southwestern Nigeria, several critical research gaps remain. Firstly, most available studies are plot-specific or location-bound, lacking regional-scale synthesis of soil functional decline across varying agroecological belts. A geospatially integrated approach that combines pedological mapping with land use monitoring is urgently needed to predict soil change trajectories under intensification.

Secondly, very few studies have examined the long-term biogeochemical implications of continuous cropping under changing climate regimes. Interactions between soil organic matter loss, carbon sequestration potential, and microclimatic shifts have not been holistically explored. In particular, the potential for soil carbon restoration through agroforestry, cover cropping, and organic residue recycling needs more empirical support.

Thirdly, there is limited attention to the socio-ecological feedbacks between land users and soil health. Farmers' perceptions, land tenure security, and economic incentives often dictate land use decisions, yet these are rarely integrated into soil conservation research. Bridging this science-practice divide could unlock more sustainable land management behaviors.

From a policy standpoint, land use planning in Southwestern Nigeria needs to move beyond mere zoning and embrace soil-informed decision-making. Extension services should prioritize training on integrated nutrient management, erosion control, and biogeochemical restoration. Pedological and biogeochemical assessments must become part of land capability evaluation frameworks at local and state levels.

CONCLUSION

Cropland intensification in Southwestern Nigeria is reshaping the region's soils in ways that jeopardize both productivity

and sustainability. This review has shown that intensified cropping patterns—marked by monoculture, reduced fallow, and chemical dependency—significantly degrade soil functional attributes, from organic matter loss and nutrient imbalance to microbial suppression and morphological simplification. Biogeochemically, these systems reduce nutrient cycling efficiency and carbon sequestration, while pedologically, they truncate soil horizons, alter classification, and diminish land capability.

However, alternative systems such as agroforestry, legume intercropping, and organic soil management show potential for reversing degradation trends and restoring functional integrity. The challenge lies in translating scientific insight into land use policy, farmer behavior, and landscape-level management. Navigating away from the detrimental cycle of cropland intensification and soil functional decline requires a concerted effort to implement these interconnected pathways. There is no single solution; rather, the integration of climate-smart practices, integrated nutrient management, spatial land use planning, and carbon sequestration strategies offers a viable route to achieving sustainable land use, climate-resilient agriculture, and lasting food security in Southwestern Nigeria. Success will depend on supportive policies, capacity building for farmers, and investments in context-specific research that continues to refine these approaches based on a deep understanding of the local biogeopedology.

Ultimately, the future of food security and environmental resilience in Southwestern Nigeria hinges on whether land use systems can evolve to respect soil limitations, restore its functions, and enhance its regenerative potential. A multidisciplinary, soil-aware approach to land use intensification is not just desirable—it is essential.

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