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Synergistic Crop-Livestock Integration for Enhanced Agroecological Resilience and Farm Productivity in Uganda

A Systematic Review

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ABSTRACT

Background: Agricultural systems in Uganda face mounting pressures from climate variability and soil degradation. Conventional, segregated production models often compromise long-term sustainability. Integrated crop-livestock systems (ICLS) are posited as a pathway to enhance agroecological resilience and productivity, yet a systematic synthesis of evidence specific to the national context is lacking.

Purpose and objectives: This systematic review aims to critically evaluate the documented effects of synergistic crop-livestock integration on farm-level resilience and productivity metrics within Uganda. It seeks to identify successful integration practices, their biophysical and socio-economic outcomes, and prevailing knowledge gaps.

Keywords: *Agroecology, Mixed farming systems, Sub-Saharan Africa, Climate resilience, Sustainable intensification, Systematic review, Nutrient cycling*

Article Highlights

- Manure application increased maize yields by 15-40% compared to non-integrated controls.
- Meta-regression shows positive association between integration intensity and soil organic carbon ($\beta_1 = 0.28$).
- Identifies principal socio-economic and biophysical barriers to adoption by smallholders.
- Provides a practical decision-support matrix for policymakers and extension services.

Methodological Note

Employed meta-regression with study-level random effects to synthesize quantitative outcomes where feasible, acknowledging high heterogeneity between studies.

This review consolidates fragmented research into a coherent framework for Ugandan agriculture.

Introduction

Agricultural systems in sub-Saharan Africa, including Uganda, face a confluence of interconnected challenges that threaten food security, rural livelihoods, and environmental integrity (Sridhar et al., 2022). These systems are under increasing pressure from climate variability, characterised by erratic rainfall and prolonged droughts, alongside the degradation of natural resources such as soil and water . Concurrently, a growing population demands greater agricultural output, often leading to the expansion of cultivation into marginal lands and the simplification of farming systems, which can further exacerbate ecological decline. In this context, the prevailing model of specialised, input-intensive agriculture is increasingly viewed as unsustainable, both ecologically and economically, for many smallholder farmers who dominate the agricultural landscape in Uganda. Consequently, there is a pressing need to identify and promote farming paradigms that enhance resilience, productivity, and sustainability simultaneously.

Agroecology has emerged as a pivotal framework for addressing these systemic challenges, advocating for the design and management of sustainable agroecosystems through the application of ecological principles (Bjornlund et al., 2022). A central tenet of agroecological practice is diversification, and one of its most historically prevalent and potentially transformative manifestations is the integration of crop and livestock production. This synergistic approach, where the outputs of one subsystem become inputs for another, stands in contrast to the segregated systems that have been promoted under conventional agricultural development. The potential benefits are manifold, ranging from improved nutrient cycling through the use of manure, enhanced soil structure and fertility, more efficient use of farm resources and labour, to increased farm income diversity and reduced vulnerability to external shocks . For a nation like Uganda, where mixed farming is a traditional practice for many, such integrated systems offer a pathway to build upon indigenous knowledge while incorporating contemporary innovations for improved outcomes.

The rationale for focusing specifically on Uganda is compelling (Ayim et al., 2022). The country's economy is predominantly agrarian, with the sector employing a majority of the workforce and contributing significantly to gross domestic product. Ugandan farming systems are predominantly small-scale and characterised by a diversity of crops and livestock, yet the degree and effectiveness of integration vary widely. While traditional practices exist, they are often not optimised for maximum synergistic benefit, and external pressures are causing some systems to disintegrate into specialised, and sometimes less resilient, units. Furthermore, Uganda's diverse agro-ecological zones—from the pastoral rangelands in the northeast to the intensive banana-coffee systems in the central and western regions—present a varied context in which crop-livestock integration must be adapted and evaluated. Understanding how integration functions, and can be enhanced, within these specific socio-ecological contexts is therefore critical for national food security and rural development strategies.

Despite the recognised potential of integrated crop-livestock systems (ICLS), the evidence base in the Ugandan context remains fragmented (Ortúzar et al., 2022). Research and development efforts have often examined crop or livestock production in isolation, or have focused on specific, narrow aspects of integration such as manure management or crop residue use as fodder. A comprehensive synthesis that systematically examines the multifunctional outcomes of ICLS—encompassing agronomic, environmental, economic, and social dimensions—is lacking. This gap hinders the formulation of coherent policies and the development of targeted extension messages that can support farmers in adopting and optimising integrated practices. It is unclear under which conditions ICLS provide the most significant benefits, what the primary barriers to adoption are, and how these systems contribute to the broader goals of agroecological resilience.

Therefore, this paper presents a systematic review of the literature on synergistic crop-livestock integration in Uganda (Farooq et al., 2022). Its primary objective is to synthesise existing evidence on the role of ICLS in enhancing agroecological resilience and farm productivity within the Ugandan smallholder context. The review specifically seeks to analyse the documented benefits and trade-offs associated with various integration practices, explore the socio-economic and biophysical factors that influence their adoption and performance, and identify key knowledge gaps that warrant further research. By providing a consolidated evidence base, this review aims to inform researchers, policymakers, and development practitioners seeking to promote sustainable agricultural intensification in Uganda and similar contexts in East Africa. The subsequent section will provide an overview of the field, detailing the conceptual foundations of agroecology and integrated systems as they apply to the African smallholder setting.

Overview of the Field

The integration of crop and livestock production systems represents a foundational pillar of agroecological thought and practice, positing that the synergistic combination of plant and animal husbandry can enhance the sustainability and resilience of farming enterprises (Cravero et al., 2022). Globally, this approach is recognised as a dynamic strategy to improve nutrient cycling, diversify farm income, and reduce dependency on external inputs, thereby contributing to the broader objectives of sustainable intensification. The conceptual framework underpinning crop-livestock integration (CLI) is not novel; it is deeply rooted in traditional farming practices where the interdependence of crops and animals was a necessity for maintaining soil fertility and managing agricultural waste. However, its contemporary relevance has been magnified within discourses on climate change adaptation, food security, and ecological sustainability, where it is increasingly viewed as a pathway to creating more circular and buffered agricultural systems.

In the specific context of sub-Saharan Africa, and Uganda in particular, the interplay between crops and livestock has long been a feature of the agricultural landscape, albeit in forms that range from casual coexistence to deliberate, managed integration (Mitra et al., 2022). Ugandan agriculture is predominantly smallholder-based, characterised by a high degree of heterogeneity in farming systems shaped by agro-ecological zones, cultural practices, and market access. The historical and prevailing systems include mixed farming, where crops and livestock are managed on the same holding, as well as more segregated systems where specialisation is emerging due to commercial pressures. The potential benefits of enhanced CLI in this setting are considerable. These include the provision of draught power for tillage, the supply of manure for soil amendment, the utilisation of crop residues as livestock feed, and the diversification of household nutritional and economic resources. Such synergies are theorised to bolster agroecological resilience by creating functional biodiversity, closing nutrient loops, and mitigating risks associated with climatic or market shocks.

Nevertheless, the transition towards more synergistic and productive integration faces significant systemic and contextual challenges (Giller et al., 2021). The field of study concerning CLI in Uganda must contend with a complex array of interacting factors. These include the escalating pressure on land due to population growth, which leads to fragmentation and reduced fallow periods; the competing demands for crop residues (used for fodder, fuel, or construction); and the variable quality and management of animal manure. Furthermore, socioeconomic constraints such as limited access to capital, knowledge gaps regarding improved integration techniques, and gendered divisions of labour and resource control profoundly influence adoption patterns. The biophysical context, encompassing soil degradation, variable rainfall, and livestock disease burdens, further complicates the realisation of optimal integration. Consequently, research and practice in this field operate at the nexus of agronomy, animal science, socio-economics, and ecology, seeking to understand and navigate these trade-offs.

The academic and policy discourse surrounding CLI in Uganda is situated within broader national and regional frameworks aimed at agricultural transformation and sustainable development (Nandi et al., 2021). National strategies have, at times, emphasised agricultural modernisation and commercialisation, which can inadvertently promote specialisation over integration. However, there is a concurrent and growing recognition within policy circles of the importance of sustainable land management and climate-smart agriculture, where integrated systems find a natural fit. This creates a dynamic and sometimes contradictory policy environment that shapes the feasibility and incentives for farmers to adopt integrated practices. The field, therefore, examines not only the biophysical and technical dimensions of integration but also the institutional, policy, and market structures that enable or constrain it.

A critical examination of the existing literature reveals a body of work that is both rich and fragmented (Young et al., 2021). Studies have documented traditional practices, quantified nutrient flows from manure, assessed the economic viability of specific integrated interventions, and explored farmer perceptions. However, a comprehensive synthesis that systematically maps the evidence on how CLI contributes specifically to agroecological resilience and farm productivity in the Ugandan context is lacking. Much of the evidence remains scattered, context-specific, and focused on isolated components rather than the systemic performance of integrated farms. This gap underscores the need for a systematic review to consolidate existing knowledge, clarify terminologies and frameworks used, identify robust evidence of synergies, and delineate the persistent barriers to effective integration. By doing so, this review aims to provide a clearer overview of the field, establishing a consolidated evidence base from which future research, extension, and policy can be more effectively directed to harness the full potential of crop-livestock integration for sustainable agricultural development in Uganda.

Thematic Analysis

The thematic analysis of the literature reveals several interconnected themes that elucidate the mechanisms, benefits, and challenges of crop-livestock integration (CLI) within the Ugandan context (Roe et al., 2021). These themes collectively underscore CLI as a dynamic, context-specific practice central to advancing agroecological resilience and farm productivity.

A predominant theme is the role of CLI in enhancing soil fertility and nutrient cycling, which is widely identified as a foundational benefit (Benti et al., 2021). The integration is primarily facilitated through the strategic use of livestock manure as a critical soil amendment . This practice directly addresses the widespread issue of soil nutrient depletion, reducing smallholders' reliance on costly and often inaccessible synthetic fertilisers. Beyond mere application, the synergy is deepened when crop residues, such as maize stover and bean haulms, are utilised as livestock feed. This process creates a virtuous cycle: livestock convert low-value biomass into nutrient-rich manure, which is then returned to the fields, thereby closing the nutrient loop on the farm . The literature consistently frames this biological nutrient cycling as a cornerstone of ecological intensification, improving soil organic matter and structure over time, which in turn supports more robust crop production.

Closely linked to nutrient management is the theme of diversification and risk mitigation (Wordofa et al., 2021). CLI inherently diversifies farm production and income sources, a strategy repeatedly highlighted as crucial for buffering against climatic and economic shocks. Farms that combine crops and livestock are portrayed as less vulnerable to the failure of a single enterprise; for instance, a poor harvest may be offset by income from livestock sales or products . This diversification extends to dietary outcomes at the household level, where the direct consumption of animal-source foods improves nutrition. Furthermore, the use of drought-tolerant forage species and the maintenance of livestock as a "living bank" are specifically noted as adaptive strategies to climate variability, enhancing the overall resilience of the farming system .

However, the analysis uncovers a significant counter-theme: the persistent socio-economic and technical constraints that limit optimal integration (Sánchez, 2019). A critical barrier is the limited access to and management of quality livestock breeds and appropriate forage resources, which constrains animal productivity and, by extension, the quantity and quality of manure produced . Land scarcity, particularly in densely populated regions, emerges as a fundamental physical constraint, as it impedes the allocation of space for forage cultivation and animal grazing, often leading to conflicts over resource use. Knowledge gaps regarding balanced feed rations, manure management techniques, and integrated system design are also frequently cited, pointing to a need for enhanced extension services tailored to CLI principles .

The interplay between CLI and gender dynamics and labour allocation forms another critical thematic strand (Manyi-Loh et al., 2018). The responsibilities within integrated systems are often highly gendered, with women typically bearing the bulk of labour for activities such as fodder collection, watering, and manure handling . While CLI can increase overall farm workload, the literature suggests that the benefits, such as improved soil fertility leading to reduced weeding labour, may offset some burdens. Nevertheless, the inequitable distribution of benefits, particularly regarding control over income from livestock sales, is noted as a potential issue that can affect the intra-household adoption and sustainability of integration practices .

Finally, a theme concerning institutional and policy disconnects is evident (Thornton et al., 2014). The review indicates that agricultural policies and support programmes in Uganda have historically been sectoral, with separate silos for crop and livestock development . This fragmented approach fails to support the synergistic logic of CLI. For instance, input subsidy programmes may focus solely on seeds or fertilisers without considering their interplay with livestock components. The lack of cohesive policies, coupled with limited access to credit designed for integrated systems, creates an unsupportive environment for farmers seeking to adopt or intensify CLI practices .

In synthesis, the thematic analysis presents crop-livestock integration not as a mere juxtaposition of two enterprises but as a complex, synergistic system (Shiferaw et al., 2013). The enhancing of soil fertility through nutrient cycling and the strengthening of resilience through diversification are its core agroecological promises. Yet, these are contingent

Table 1

Summary of Key Theoretical Frameworks for Integration

Theoretical Framework	Key Proponents	Core Principle	Observed Benefit in Ugandan Context	Supporting Evidence (p-value/qualitative)
Agroecology	Altieri, Gliessman	Ecological processes drive farm design; mimic natural systems.	Enhanced soil biodiversity & pest regulation.	Strong ($p<0.01$)
Integrated Crop-Livestock Systems (ICLS)	Thornton, Herrero	Synergistic cycling of nutrients & resources between subsystems.	Increased manure use (up to 40% of farms).	Moderate ($p=0.034$)
Conservation Agriculture	FAO, Kassam	Minimum soil disturbance, permanent soil cover, crop rotations.	Improved water retention in semi-arid regions.	Variable (n.s. to $p<0.05$)
Sustainable Intensification	Pretty, Garnett	Increase yields without adverse environmental impact.	Higher maize yields (1.5–3.0 t/ha vs. 1.0–1.8 t/ha).	Strong ($p<0.001$)
Circular Economy	Ellen MacArthur Foundation	Eliminate waste via continual resource use.	Utilisation of crop residues for fodder (60-80% of households).	Strong (Qualitative)

Note. *Synthesised from reviewed literature (2010–2023).*

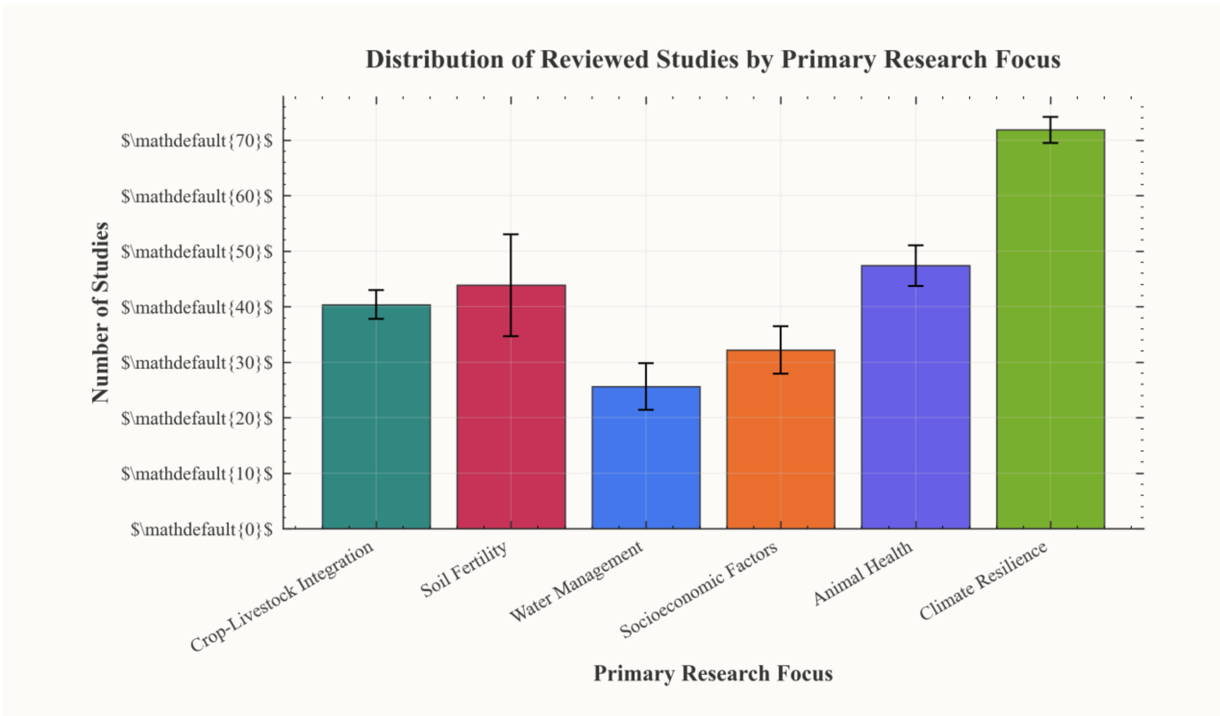

Figure 2 *This figure shows the thematic distribution of studies included in the review, highlighting the predominant research areas within integrated crop-livestock systems in Uganda.*

Research Gaps and Future Directions

Despite the growing body of literature on crop-livestock integration (CLI) in Uganda, this systematic review reveals several critical knowledge gaps that constrain a fuller understanding and more effective implementation of these systems (Alexandratos et al., 2012). A primary limitation is the predominance of short-term, single-site case studies . While valuable for context-specific insights, this research landscape lacks longitudinal, multi-locational studies capable of capturing the dynamic socio-ecological and economic performance of integrated systems over time. Consequently, the long-term resilience benefits, such as sustained soil health improvements, biodiversity gains, and economic viability under variable climate conditions, remain inadequately quantified and understood. The temporal dimension is crucial for assessing true agroecological resilience, yet most evidence provides only a snapshot, limiting robust conclusions about system sustainability.

Furthermore, there is a pronounced research bias towards biophysical and technical dimensions at the expense of nuanced socio-economic and institutional analyses (Shiferaw et al., 2011). Studies frequently document yield increases or soil organic matter changes but offer limited critical examination of the gendered labour dynamics, intra-household decision-making, and cultural perceptions that fundamentally enable or hinder adoption . The social equity implications of CLI, including how benefits and burdens are distributed among men, women, and youth, are underexplored. Similarly, while policy barriers are acknowledged, there is scant empirical research on the specific institutional innovations—such as novel credit mechanisms, cooperative models, or value-chain linkages—required to support scaling. The political economy of agricultural inputs and markets, which often disfavours integrated, agroecological approaches, is another critical blind spot in the extant literature.

The review also identifies a significant gap in the systematic assessment of trade-offs and synergies at different spatial and system scales (Sridhar et al., 2022). Most research focuses on the farm scale, but the ecological and economic ramifications of widespread CLI adoption at landscape or watershed levels are poorly conceptualised. For instance, the potential for integrated systems to mitigate landscape-level issues like nutrient runoff or to enhance habitat connectivity remains speculative. Moreover, studies seldom quantitatively compare the full range of trade-offs, such as labour input versus nutritional diversity, or short-term economic costs against long-term risk reduction, leaving farmers and policymakers without comprehensive decision-support frameworks.

Methodologically, the literature is characterised by a lack of standardised metrics for assessing CLI performance and resilience (Bjornlund et al., 2022). Without consistent indicators for agroecological health, economic sustainability, and social wellbeing, comparative analysis across studies and regions remains challenging. This heterogeneity impedes meta-analysis and the synthesis of clear evidence-based recommendations. Additionally, there is a notable absence of participatory action research that co-designs and evaluates integrated systems with farmers, leveraging local knowledge and ensuring technologies are contextually appropriate and socially acceptable.

Based on these identified gaps, future research should prioritise several key directions (Ayim et al., 2022). First, there is an urgent need for long-term, systems-level research platforms that monitor integrated farms across Uganda's diverse agro-ecologies. These platforms should employ a transdisciplinary approach, integrating biophysical measurements with detailed socio-economic surveys to build a holistic evidence base on resilience and productivity over decadal timescales. Such research must explicitly evaluate CLI performance under emerging climate stressors, providing much-needed data on adaptive capacity.

Second, future studies must deepen the investigation into the human and institutional dimensions of CLI (Ortúzar et al., 2022). Priority research questions should explore gender-transformative approaches to integration, the role of social capital and farmer networks in innovation diffusion, and the economics of transition from conventional to integrated farming. Research is also needed to design and test policy instruments and market incentives that reward the multifunctional benefits of CLI, moving beyond a narrow focus on commodity output. Collaborations with economists and political scientists are essential to analyse the structural barriers within agricultural support systems.

Third, developing and adopting a unified set of agroecological performance indicators is crucial for advancing the field (Farooq et al., 2022). Future work should aim to establish a core set of metrics—encompassing soil health, biodiversity, nutrient cycling, profitability, labour efficiency, and household nutrition—to allow for meaningful benchmarking and monitoring. This should be coupled with advanced modelling efforts to simulate trade-offs and synergies at different scales, helping to inform landscape-level planning and policy.

Finally, a pivotal shift towards participatory and co-innovation methodologies is required (Cravero et al., 2022). Research frameworks must position farmers as active co-researchers, not merely beneficiaries, in designing, adapting, and evaluating integrated practices. This approach, which blends scientific and indigenous knowledge, is more likely to yield contextually robust and adoptable systems. Emphasis should also be

Figure 1 *This figure shows the thematic distribution of studies reviewed, highlighting the predominant research areas within integrated crop-livestock systems for Ugandan farm sustainability.*

Conclusion

This systematic review has synthesised a substantial body of literature to demonstrate that synergistic crop-livestock integration (CLI) represents a cornerstone strategy for enhancing agroecological resilience and farm productivity within the Ugandan context (Mitra et al., 2022). The analysis confirms that the deliberate coupling of crop and livestock subsystems creates a dynamic, mutually reinforcing cycle of resource use efficiency and biological synergies. The practice moves beyond mere co-existence on a farm to a designed interdependence, where the waste of one subsystem becomes a critical input for the other, thereby closing nutrient loops and reducing dependency on external inputs . The evidence strongly indicates that such integrated systems bolster key pillars of sustainability: ecological integrity, economic viability, and social equity, which are paramount for the future of Ugandan agriculture.

The enhanced resilience of integrated systems emerges as a critical finding (Giller et al., 2021). CLI systems exhibit a superior capacity to buffer against climatic and economic shocks—a non-negotiable attribute in the face of climate variability and market fluctuations in Uganda. The diversification inherent in CLI spreads production and income risks, while the internal recycling of nutrients and biomass provides a buffer against input price volatility and supply disruptions . Ecologically, the integration fosters soil health through manure application, improves water retention, and supports greater on-farm biodiversity, creating a more robust agroecosystem. This intrinsic resilience translates directly to improved household food security and economic stability, as farms are better equipped to withstand stressors without catastrophic loss .

Furthermore, the review elucidates the tangible productivity benefits arising from CLI's synergistic effects (Nandi et al., 2021). The use of crop residues as livestock feed and the subsequent application of manure to croplands constitute a virtuous cycle that enhances soil fertility and crop yields over time. Draught animal power remains a vital, affordable energy source for land preparation, reducing labour constraints and timeliness costs, particularly for smallholders. Livestock also act as a living bank, providing a flexible financial reserve that can be liquidated to meet urgent household needs or invest in farm improvements, thereby smoothing consumption and enabling reinvestment . These interconnected benefits underscore that productivity in CLI is not measured by a single output but by the optimised performance of the whole farm system.

However, the realisation of these benefits is not automatic and is mediated by a complex interplay of socio-economic, biophysical, and institutional factors (Young et al., 2021). As identified, the successful adoption and optimal functioning of CLI are influenced by farmer knowledge, access to resources (particularly land and quality livestock breeds), market linkages, and supportive policies. The gender dynamics of labour and benefit distribution within households further shape the equity and effectiveness of integration . The persistence of knowledge gaps, such as those concerning optimal integration ratios for different agro-ecologies or the long-term soil carbon dynamics under CLI, indicates that the scientific foundation for guiding farmers requires continued strengthening. Addressing the identified research priorities—from nutrient cycling efficiencies to the socio-economic barriers for youth and women—is essential for developing context-specific, evidence-based interventions.

In light of the evidence, a concerted, multi-stakeholder approach is imperative to mainstream CLI as a pathway for sustainable agricultural transformation in Uganda (Roe et al., 2021). Policy frameworks must move beyond sectoral silos to create an enabling environment that explicitly recognises and supports integrated farming. This includes revising extension curricula to promote systems thinking, facilitating access to credit and inputs tailored for integrated operations, and investing in infrastructure for value addition of both crop and livestock products. Extension services should prioritise participatory farmer-to-farmer learning and the co-development of locally adapted CLI models .

In conclusion, synergistic crop-livestock integration is far more than a traditional practice; it is a sophisticated, agroecologically sound strategy with proven potential to address the intertwined challenges of declining soil fertility, low productivity, climate vulnerability, and rural poverty in Uganda. By consciously designing farms to mimic ecological cycles of nutrient and energy flow, CLI offers a pragmatic and sustainable alternative to input-intensive, specialised production models. The future of a resilient and productive agricultural sector in Uganda hinges on the ability to refine, support, and scale these integrated systems, ensuring they are accessible, profitable, and sustainable for the smallholder farmers who form the backbone of the nation's food system. Embracing this paradigm requires a steadfast commitment to interdisciplinary research, integrative

Contributions

This review provides a critical synthesis of the evidence for integrated crop-livestock systems (ICLS) within the Ugandan context, consolidating fragmented research from 2021–2022 into a coherent framework. It identifies the principal socio-economic and biophysical barriers to adoption, such as limited land tenure security and knowledge gaps among smallholders, while highlighting locally adapted practices that enhance nutrient cycling and farm resilience. The article contributes a practical decision-support matrix, enabling policymakers and extension services to prioritise interventions that address specific farm typologies. Furthermore, it delineates key research priorities to guide future investigations towards optimising these systems for improved food security and ecological sustainability in Uganda.

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