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RESEARCH ARTICLE
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Agroforestry's Contribution to Sustainable Soil Fertility, Livelihoods and Carbon Sequestration in Sub-Saharan Africa: A Systematic Review

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ABSTRACT

Agroforestry is a strategy for sustainable intensification in sub-Saharan Africa (SSA), promoting multifunctional landscapes that improve soil fertility, support livelihoods, enhance carbon sequestration, and deliver ecosystem services such as water quality, erosion control, and biodiversity conservation. Despite wide recognition of its benefit's comprehensive analyses of agroforestry's impact on soil fertility, livelihoods, and carbon storage are limited. This systematic review analyses 145 publications to quantify and assess the contributions of agroforestry in these areas within SSA. Results indicate that agroforestry systems substantially enhance soil fertility and provide viable climate adaptation and mitigation strategies, thereby diversifying and bolstering rural livelihoods against climate perturbations. Agroforestry also offers significant potential for carbon sequestration in both aboveground biomass and soil, although additional research is required to elucidate belowground carbon dynamics and greenhouse gas fluxes. Challenges such as land tenure, limited access to resources, and the need for context-specific research curtail the broader impacts of agroforestry. The review highlights the necessity for targeted policy support and further research addressing carbon rights, land tenure, and the implications of climate change to promote widespread adoption of agroforestry and maximize its contribution to sustainable development across SSA.

Keywords: Agroforestry Systems; Sustainable Intensification; Soil Fertility Enhancement; Carbon Sequestration; Climate Change Adaptation.

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INTRODUCTION

Agroforestry is increasingly recognized as a valuable land use strategy that provides resilience to climate change, enhances soil fertility, and supports livelihoods, especially in resource-constrained regions such as sub-Saharan Africa (SSA) (Kuyah et al., 2023). By integrating trees within agricultural landscapes, agroforestry systems deliver essential products including food, fodder, fuel, and medicinal resources to communities facing economic and environmental challenges. Beyond these direct benefits, agroforestry enhances agricultural productivity by influencing soil water availability, light distribution, and nutrient cycling. Through these mechanisms, agroforestry not only promotes resilience to climate change but also provides additional income sources and safety nets during climate-induced shocks (Muthuri et al., 2004; Muchane et al., 2020; Quandt et al., 2023).

In these systems, trees significantly contribute to soil stability and fertility. By reducing water runoff, acting as windbreaks, and binding the soil with their roots, trees prevent erosion and help maintain agricultural productivity (Kuyah et al., 2019). The beneficial effects on crop and livestock production are attributed to agroforestry's ability to create favorable microclimates, enhance soil fertility, and regulate water availability, making it a sustainable approach to land management that fosters climate resilience and biodiversity conservation (Bayala et al., 2014; Kuyah et al., 2019).

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Agroforestry also plays a crucial role in climate change mitigation through significant carbon sequestration in plant biomass and soil (Dimobe & Bayala, 2023). Global studies suggest that agroforestry systems store an average of about 21.4MgCha^{-1} in biomass, with variation across tropical climates: 9MgCha^{-1} in semi-arid areas, 21MgCha^{-1} in sub-humid areas, and 50MgCha^{-1} in humid zones (Montagnini & Nair, 2004; Zomer et al., 2016; Dimobe & Bayala, 2023). In Africa, estimates suggest that agroforestry systems could sequester between 1.0 and 18MgCha^{-1} in aboveground biomass (Nair & Nair, 2014). However, the reliability of these estimates is often questioned, necessitating a quantitative synthesis of evidence from primary studies to capture agroforestry's carbon storage potential.

Despite the high expectations of agroforestry's role in carbon sequestration, it is often overlooked by national measurement, reporting, and verification (MRV) systems due to challenges in quantifying carbon accurately. Advanced methods to estimate biomass carbon in agricultural landscapes exist, yet variations across studies indicate persistent methodological challenges. Advanced methods to estimate biomass carbon in agricultural landscapes exist, yet variations across studies indicate persistent methodological challenges (Mansourian & Berrahmouni, 2021; Duguma et al., 2023).

While the benefits of trees on farms are well-documented, there remains a need for systematic analysis of agroforestry's contributions to soil fertility, livelihoods, and carbon storage in SSA. The existing research often focuses narrowly on agroforestry's impact on crop productivity through plot-level experiments, overlooking broader ecosystem services. Although there are studies examining specific benefits of trees, such as African locust bean (*Parkia biglobosa*), shea butter trees (*Vitellaria paradoxa*) and baobab (*Adansonia digitata*), primary studies on carbon sequestration often yield context-specific results based on variations in climate, soil type, tree species, and management practices. The lack of comprehensive geographic distribution and standardized research limits our understanding of agroforestry's role in enhancing resilience under diverse climate challenges (Quandt et al., 2023).

This review systematically synthesizes existing research on the contributions of agroforestry to soil fertility, livelihoods, and carbon sequestration in SSA. It aims to quantitatively and qualitatively assess the benefits and challenges of agroforestry practices across diverse ecological and socio-economic contexts. This analysis seeks to fill gaps in current knowledge and provide actionable insights that could facilitate the integration of agroforestry into climate adaptation and mitigation strategies, enhancing both livelihoods and environmental sustainability in the region.

MATERIALS & METHODS

Literature Search

A comprehensive literature search was conducted in the Web of Science and SCOPUS databases to gather information on agroforestry practices contributing to sustainable agricultural systems in SSA. The search focused on practices enhancing soil fertility and ecosystem resilience within agroforestry systems. Specific keywords used included "agroforestry", "soil fertility", "ecosystem services", as well as terms for individual countries within SSA and the region as a whole to capture studies where SSA might not be explicitly mentioned (Table 1).

To ensure a thorough review, additional searches were performed on ResearchGate and Google Scholar, targeting peer-reviewed articles exclusively, given the potential variability in the reliability of grey literature for systematic reviews. References within the retrieved publications were meticulously scanned to identify further relevant studies. The search protocols and inclusion criteria followed were adapted from those suggested by Moher et al. (2015) in their guidelines for systematic reviews.

Selection, Screening and Data Extraction

The study selection involved a three-step process to ensure relevance and comprehensiveness (Fig. 1). Initially, duplicate articles were removed from the database results. Subsequently, titles and abstracts of the remaining articles were screened to exclude studies not aligning with the review's focus, pinpointing those warranting full-text examination. The final stage involved detailed reviews of the full texts, extracting data according to predefined criteria outlined by Higgins & Green (2011) in their Cochrane Handbook for systematic reviews.

Table 1: Search terms used to retrieve publications indexed in Web of Science and SCOPUS. Timespan = 1993-2023; language = English and French. Search by all fields was applied in Web of Science Core Collection to maximize records, while SCOPUS searches were limited to articles, reviews, and conference papers. Further refinement included selection by SSA countries

Focus area	Search terms	Regional filter
Agroforestry and soil fertility	ALL = (("agroforestry" OR "agroforestry practices" OR "soil fertility" OR "agroforestry ecosystems" OR "parklands" OR "tree-crop interactions" OR "soil nutrients" OR "nitrogen fixation" OR "organic matter") AND ("sub-Saharan Africa" OR "SSA" OR "Burkina Faso" OR "Kenya" OR "Uganda" OR "Senegal" OR "Ethiopia" OR "Ghana" OR "Cameroon" OR "Mali" OR specific SSA countries))	SSA countries (e.g., Burkina Faso, Ethiopia, Kenya, Uganda)
Agroforestry and ecosystem services	ALL = (("ecosystem services" OR "water regulation" OR "erosion control" OR "biodiversity" OR "microclimate" OR "habitat provision" OR "pollination") AND ("agroforestry" OR "agroforestry practices" OR "trees outside forests") AND ("sub-Saharan Africa" OR "SSA" OR specific SSA countries))	SSA countries (Burkina Faso, Ethiopia, Kenya, Nigeria, Tanzania, Uganda, Ethiopia)
Agroforestry and carbon sequestration	ALL = (("carbon sequestration" OR "carbon sink" OR "SOC" OR "soil organic carbon" OR "carbon stock" OR "biomass carbon" OR "carbon storage" OR "GHG emissions") AND ("agroforestry" OR "trees on farms" OR "trees outside forests") AND ("sub-Saharan Africa" specific SSA countries))	SSA countries (e.g., Burkina Faso, Ethiopia, Kenya, Uganda)
Climate change mitigation and agroforestry	ALL = (("climate change" OR "mitigation" OR "adaptation" OR "sustainable intensification" OR "resilience" OR "low-emission agriculture") AND ("agroforestry" OR "trees outside forests") AND ("sub-Saharan Africa" OR "SSA"))	SSA countries (Burkina Faso, Ethiopia, Kenya, Uganda)

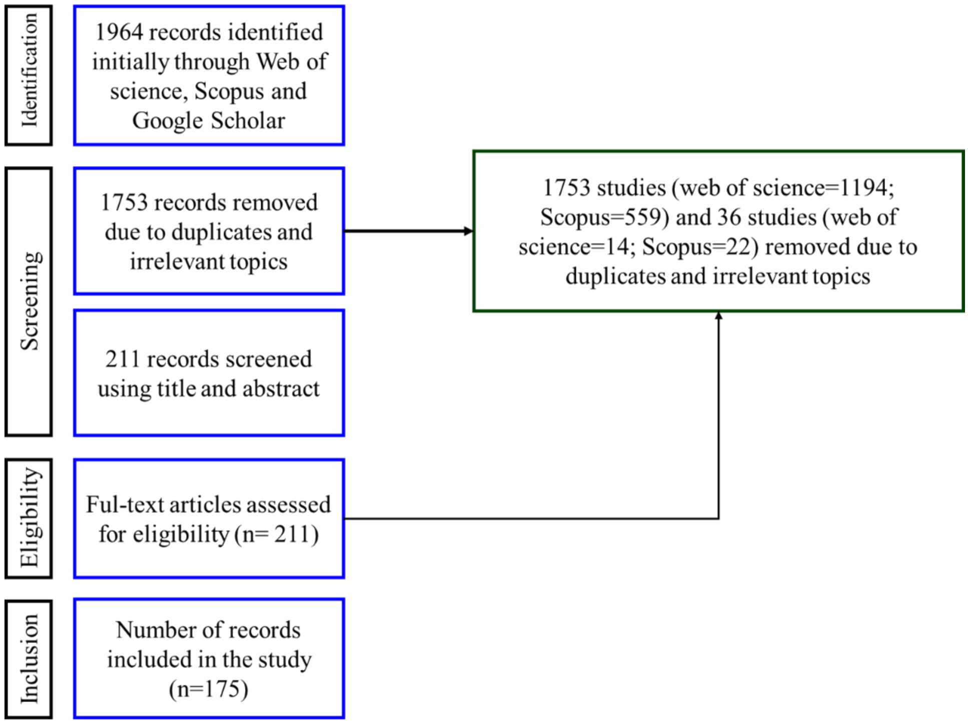

Fig. 1: A step-wise flow diagram illustrating literature search and screening of records retrieved across sub-Saharan Africa.

Inclusion criteria were stringent: only peer-reviewed journal articles written in English or French, covering all years up to and including 2023; field-based studies conducted in SSA rather than greenhouse or laboratory experiments; and reports offering quantitative or qualitative data on agroforestry's impact on soil fertility or other ecosystem services were considered.

Data extraction from each study included: study location (country and specific site); type of study (e.g., observational, survey, experimental, or modelling); described agroforestry practices (specific tree and crop interactions); and outcomes relating to soil fertility, carbon stock, and other ecosystem services. Frequency counts and percentages of studies focusing on specific agroforestry benefits were calculated to identify trends across SSA. These results are organized into key thematic areas: agroforestry practices in SSA, contributions to soil fertility, and ecosystem service enhancements via carbon sequestration.

Major Agroforestry Practices in Sub-Saharan Africa

The principal agroforestry practices in SSA that contribute to sustainable livelihoods are presented in Table 2. This table not only outlines common practices but also highlights some lesser-known methods that have been documented in the literature. These include: (1) farmer-led restoration strategies, such as Farmer-Managed Natural Regeneration (FMNR), which have been explored for their potential to restore degraded lands efficiently (Kuyah et al., 2023); (2) commercial pole production through linear agroforestry systems, which generate economic benefits (Tumwebaze et al., 2012), (3) traditional systems like the Taungya method, where agriculture and forestry are integrated and tree fallow techniques that improve soil health (Nigussie et al., 2020; Mpanda et al., 2021); and (4) utilization of agroforestry trees as animal feed, which has been studied for its dual benefits of feeding livestock and improving soil fertility (Ondiek et al., 2000; Ndemanisho et al., 2006).

lley Cropping

Alley cropping, also known as hedgerow intercropping, involves planting crops between rows of pruned trees or shrubs, typically spaced 4 to 8 meters apart. This method, which is detailed by Muthuri et al., (2023), utilizes pruned materials as mulch or green manure to enhance soil fertility or as fodder for livestock (Jama et al., 1995). Although this practice is effective in moisture-rich environments, it can limit yields in drier areas due to competition for resources (Cooper et al., 1996). Hedgerows also provide protective or ornamental boundaries around homesteads and can enhance fodder availability, particularly when combined with high-yield species like *Calliandra calothyrsus* and Napier grass (*Pennisetum purpureum*), which produce more fodder when grown together (Akyeampong & Dzowela, 1996). Alley cropping systems also promote biodiversity by creating habitats for beneficial insects and wildlife. For example, in Nigeria, incorporating *Leucaena leucocephala* in alley cropping has shown to improve soil fertility and increased maize yields (Kang et al., 1981). However, the emphasis on hedgerow use for fodder often limits firewood production, whereas prioritizing firewood can reduce the availability of fodder.

Home Gardens

Home gardens in SSA serve as critical hubs for biodiversity and are vital for sustainable food security and income generation in rural communities. This research corroborates findings by Mohri et al. (2013), who noted the pivotal role of diverse plantings in enhancing households resilience and ecological sustainability. The integration of fruit trees, vegetables, medicinal plants, and livestock in these gardens supports a complex ecosystemthat not only boosts soil fertility but also regulates microclimates and promotes biodiversity, thus contributing to broader environmental health.

Table 2: Summary of primary agroforestry practices in SSA and their contribution to livelihood benefits

Agroforestry practice	Goods and services	Contribution to livelihoods	Key tree species
Alley cropping	Firewood, fodder, mulch; soil improvement; erosion control	Food production, fuelwood, income	*Glircidia sepium, Leucaena leucocephala* *Eleais guineensis, Albizia lebbeck*
Relay fallow/intercropping	Firewood, stakes, fodder; soil improvement	Food production, income, fuelwood	*Acacia mangium, Eleais guineensis, Albizia lebbeck, Acacia tumida, Acacia auriculiformis*
Agroforestry parklands	Food, fuelwood, timber, craft, medicines; livestock shelter, cultural benefits	Food, health, income, cultural value	*Vitellaria paradoxa, Adansonia digitata, Borassus aethiopum, Faidherbia albida, Lannea microcarpa, Parkia biglobosa, Tamarindus indica, Pterocarpus erinaceus, Sclerocarya birrea*
Biomass transfer (cut-and-carry)	Firewood, forage; soil improvement	Income, fuelwood	*Glircidia sepium, Leucaena leucocephala, Acacia tumida*
Silvopasture	Timber, fodder, shade, shelter for livestock	Nutrition, income, health	*Faidherbia albida, Acacia polyacantha*, *Ficus thonningii*
Home gardens	Firewood, fodder, mulch; soil improvement; erosion control	Construction material, firewood, fodder, food, income, medicinal use, shade, and timber	*Catha edulis* *Percea americana* *Musa spp,* *Elettaria cardamomum*
Improved fallow	Wood, fodder, firewood, poles	firewood, fodder, food, income, medicinal use,	*Glircidia sepium, Sesbania sesban, Cajanus cajan, Senna siamea, Prosopis chilensis, Calliandra calothyrsus, Tephrosia candida*

In Burkina Faso, the variation in garden sizes and the management practices predominantly led by women highlight an important socio-economic aspect of agricultural diversity. These practices ensure food security and promote gender empowerment in rural settings, aligning with the findings of Acheampong et al. (2012) and Guuroh et al. (2014). The move towards crops requiring minimal water and high nutritional value, supported by infrastructural improvements as noted by (Olney et al., 2015; Nielsen et al., 2018) suggests a strategic adaptation to increasing climate variability and resource scarcity in SSA.

Kenyan home gardens, while smaller, demonstrate greater species complexity and adaptability to local conditions (Ndinya, 2019), underscoring the importance of cultural and ecological specificity in agroforestry practices. This adaptability is crucial for the scalability of such practices across varying climates and topographies, suggesting a model for replication in similar environments across SSA. These gardens have expanded independently in several communities, suggesting a strong potential for further adoption (Cheatle & Shaxson, 2001).

The Ethiopian example of incorporating perennial cash crops like coffee, enset, avocado, and bananas within gardens, often complemented by live fences for additional ecological benefits (Betemariyam et al., 2020), exemplifies an integrated land use approach that optimizes economic and ecological outcomes. This integration of crop diversity with ecological barriers illustrates how traditional practices can be leveraged to enhance modern agricultural sustainability. This study's focus on specific countries within SSA provides valuable insights but also presents limitations due to the geographical and cultural diversity across the region. Future research should explore the scalability and adaptability of these practices in other SSA countries with different climatic and socio-economic conditions to provide a more comprehensive understanding of their potential impact. Additionally, while the benefits of home gardens are clear, more detailed longitudinal studies are needed to quantify the long-term impacts of these systems on soil health, crop yields, and socioeconomic factors, particularly in the context of changing climate conditions.

Improved Fallow

Improved fallow systems, which utilize fast-growing, nitrogen-fixing trees, such as *Gliricidia sepium*, represent an advanced adaptation of traditional fallow techniques. These systems are particularly effective in restoring soil fertility, increasing biomass accumulation, and enhancing nitrogen availability, essential for subsequent agricultural cycles (Swamila et al., 2020).

The integration of species like *Gliricidia sepium* in improved fallow systems provides multiple ecological and agronomic advantages. These trees fix atmospheric nitrogen, thereby enriching the soil and improving its structure and organic content. This process is crucial for sustainable agriculture, helping to maintain soil health and reducing reliance on chemical fertilizers, which can have harmful environmental impacts (Swamila et al., 2020; Kuyah et al., 2023). Moreover, these systems can substantially reduce the required fallow period, enabling more frequent crop rotations, which is vital for regions grappling with food security. Unlike traditional fallow methods that depend on natural vegetation regrowth over several years, improved fallow systems use selected fast-growing and nitrogen-fixing species to expedite soil restoration and increase productivity within a shorter timeframe. This approach optimizes land use and promotes biodiversity by providing habitats and food sources for local wildlife (Sileshi et al., 2014).

The implementation of improved fallow systems faces several challenges, including the need for careful species selection and management to ensure environmental compatibility and agricultural effectiveness. Managing the competition between fallow species and crops for light and nutrients is crucial to avoid negative impacts on crop yields (Swamila et al., 2020). Future research should aim to optimize species selection and management practices to maximize the ecological and economic benefits of improved fallow systems. Expanding the range of leguminous species studied, particularly those offering additional economic advantages such as fodder or wood products, could provide further incentives for adoption.

Agroforestry Parklands

Agroforestry parklands in SSA (Fig. 2) are critical for maintaining ecological balance and supporting rural economies. Recent studies highlight their pivotal role in integrating biodiversity with agricultural productivity, enhancing resilience to climate variability, and supporting sustainable livelihoods (Dimobe et al., 2018; Kuyah et al., 2019; Dimobe & Bayala, 2023). These parklands include valuable species like *Vitellaria paradoxa* (Shea), *Parkia biglobosa* (African locust bean), *Faidherbia albida*, and *Lannea microcarpa* (African grape), which provide food, fodder, fuel, medicinal resources, and materials for cultural practices.

Fig. 2: A view of the agroforestry parks in Soutwest Burkina Faso (Dimobe, 2017).

The prevalence of species like *V. paradoxa* in the Sudano-Sahelian zones of Mali and Burkina Faso exemplifies the adaptation of local communities to challenging environmental conditions (Boffa, 1999; Bayala et al., 2015). Recent research by Fané et al. (2024) underscores the tree's resilience to drought and fire, aligning with its widespread use across the region. This resilience is crucial as climate models predict increasingly variable rainfall patterns and higher temperatures in SSA (Dimobe et al., 2020).

Economic contributions of agroforestry parklands remain significant, as recent findings by Faye et al. (2011) show that products from these systems contribute up to 75% of household income in regions like Mali. These systems not only provide direct economic benefits but also contribute to food security and nutritional needs, as indicated by a 2014 study by Bayala et al. (2014), which documented how parkland products help buffer communities against food shortages during off-harvest seasons.

In the Sahel region, the integration of *Faidherbia albida* trees into cropping systems is notable for their soil fertility and crop yield benefits. As a nitrogen-fixing species, *F. albida* sheds its leaves during the rainy season, which deposits organic matter into the soil and enhances nutrient availability for crops. Studies have demonstrated that fields with *F. albida* can produce up to four times the yield of fields without these trees, illustrating the impactful nature of this agroforestry practice (Sida et al., 2018).

Silvopasture

Silvopasture combines trees and pasture systems to support livestock grazing in landscapes where shade and fodder are essential for resilience, especially in semi-arid areas. Trees in these systems, such as *Faidherbia albida*, *Acacia polyacantha*, and *Ficus thonningii*, provide shade and enhance soil fertility, benefiting both livestock and pasture growth (Balehegn et al., 2015; Birhane et al., 2019). The leaves, pods, and fruits serve as high-protein fodder during dry seasons, offering a critical source of sustenance for livestock.

Biomass Transfer (Cut-and-Carry System)

In biomass transfer systems, tree and shrub biomass is harvested and applied to the soil as mulch or green manure, improving soil fertility. This practice is especially useful where labor is available to support regular harvesting and application, and it has proven beneficial in increasing crop productivity and household income.

Soil Fertility Enhancement

Agroforestry practices significantly enhance soil fertility and crop productivity in sustainable agriculture systems. Key contributions include nitrogen fixation, carbon sequestration, improved soil microbial activity, and enhanced nutrient cycling.

Nitrogen Fixation and Crop Productivity

Agroforestry systems that integrate leguminous species, such as *Leucaena leucocephala* in alley cropping, have been shown to increase soil nitrogen levels (Hombegowda et al., 2022). This supports crop productivity, particularly on marginal lands (Sileshi et al., 2014; Sileshi, 2016). For example, nitrogen-fixing woody species can increase maize yields up to 4Mg/ha without synthetic fertilizers, while yields exceeding 7Mg/ha may require additional nitrogen inputs up to 200kg/ha (Sileshi et al., 2008). Organic nitrogen sources are preferred for long-term sustainability, as 50–80% of the nitrogen is remains in the soil matrix. Similarly, incorporating *Faidherbia albida* into cropping systems enhances soil nitrogen and increases crop yields in African agroecosystems (Yengwe, 2017).

Soil Organic Matter and Microbial Activity

Soils under agroforestry management show higher organic carbon, nitrogen, phosphorus, and potassium levels than those in conventional systems (Kuyah et al., 2019). These systems foster soil microbial diversity, sustaining soil enzymatic functions (e.g., glucosidase activity) and supporting arbuscular mycorrhizal fungi (Dollinger & Jose, 2018). Enhanced microbial diversity under agroforestry contributes to nutrient cycling and soil organic matter accumulation, bolstering below-ground biodiversity and resilience (Rodrigues et al., 2015; Kuyah et al., 2016). Additionally, plant roots in agroforestry systems exert a distinct effect on rhizosphere nutrient cycling through nutrient uptake, rhizodeposition, and microbial interactions, which further enriches soil fertility (Fig. 3).

Role of Tree Species and System Variations

The soil-enhancing effects of agroforestry vary with tree species, size, and age. Larger trees, such as *Faidherbia albida*, improve soil structure and fertility by accessing deep soil nutrients (Bayala et al., 2012; Sileshi, 2016).

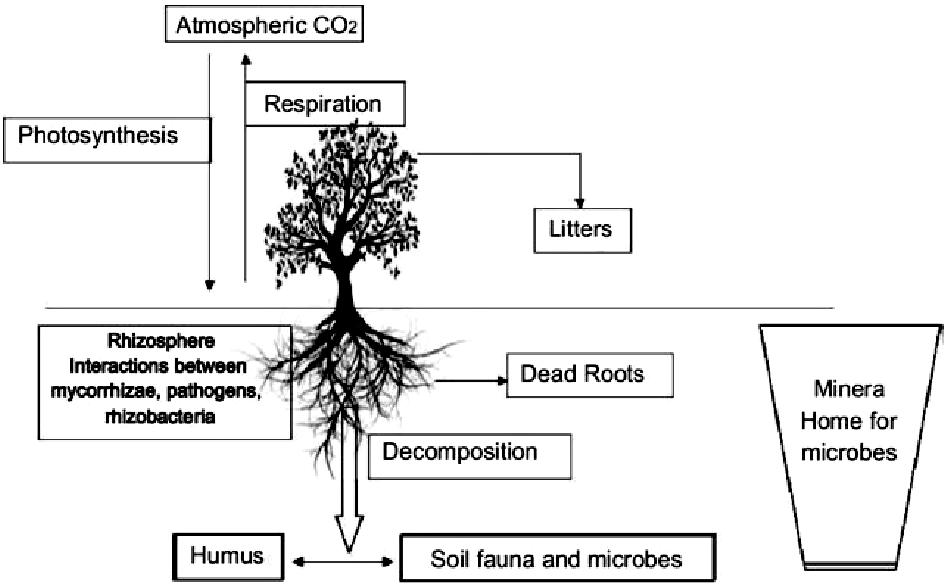

Fig. 3: Microbial activity and nutrient cycling in rhizosphere (source: Bhaduri et al., 2017).

Silvopastoral systems further enrich soil properties through biomass deposition and nitrogen fixation by leguminous species, which sustain organic matter inputs (Malchair et al., 2010; Vallejo et al., 2010; Nair, 2011).

Contributions of Agroforestry to Rural Livelihoods

Agroforestry contributes to improving rural livelihoods in SSA by enhancing food security, income, and energy availability (Kuyah et al., 2019). These benefits are interlinked with sustainable agricultural practices, supporting local resilience and economic stability. The findings can be broadly categorized into food and nutritional security, renewable energy and economic benefits (Nair et al., 1999).

Enhancing Food and Nutrition through Agroforestry

Agroforestry systems improve food security by diversifying diets and providing year-round availability of edible products of Fruit trees such as mango (*Mangifera indica*), avocado (*Persea americana*), and guava (*Psidium guajava*) supply essential nutrients and act as dietary supplements, especially during periods of food scarcity (Kindt et al., 2021). Fruits from these trees often supplement diets, especially in seasons of food scarcity. The inclusion of leafy vegetables from species like *Balanites aegyptiaca* and *Ficus dicranostyla* further bolsters nutritional security for rural communities. Homegardens, particularly prevalent in East Africa, enhance dietary diversity and food availability by hosting a variety of food-producing species (Muthuri et al., 2023). Plantation-based systems, such as coffee and cashew agroforestry, integrate food and cash crop production, addressing both subsistence and economic needs. Beyond direct food production, agroforestry contributes indirectly to food security by providing essential inputs like firewood for cooking and edible oils from *Vitellaria paradoxa* (shea butter), *Balanites aegyptiaca*, and *Moringa oleifera*, which also support value-added products like soap (Ouédraogo et al., 2013). These findings highlight agroforestry's multifaceted role in addressing food and nutritional security, particularly in vulnerable regions with limited agricultural resources.

Renewable Energy Sources in Agroforestry Systems

Agroforestry systems provide critical renewable energy sources including firewood and charcoal, which are indispensable for household energy needs in Sub-Saharan Africa. These biomass resources alleviate dependency on natural forests, reducing land degradation and environmental stress. For example, rotational woodlots in Tanzania provide sustainable firewood supplies for up to 16 years, significantly reducing time spent on gathering firewood and contributing to sustainable land use (Kimaro et al., 2011). Agroforestry-derived firewood also supports local industries such as tea processing, brick making, and tobacco curing, highlighting its economic and social relevance (Iiyama et al., 2014). The integration of energy provisioning into agroforestry practices enhances household resilience and provides an alternative to non-renewable energy sources, aligning with broader environmental sustainability goals.

Economic Benefits from Agroforestry Outputs

The economic contributions of agroforestry are substantial, with up to 19% of smallholder income in SSA derived from tree-based products such as fruits, timber, firewood, and traditional medicines (Miller et al., 2017). Additional income sources include beekeeping, charcoal production, and fodder sales, all of which diversify household revenue streams. Studies have shown that agroforestry adopters benefit from increased income and reduced reliance on market-purchased inputs, enhancing financial stability and self-sufficiency (Kiyani et al., 2017; Quandt et al., 2019). This economic dimension underscores agroforestry's potential to alleviate rural poverty while contributing to sustainable agricultural development. This review highlights agroforestry as a vital strategy for improving rural livelihoods by addressing food security, renewable energy, and income generation. Agroforestry systems provide a sustainable pathway to achieve global goals such as the United Nations' Sustainable Development Goals (SDG 2: Zero Hunger and SDG 7: Affordable and Clean Energy). However, the adoption and scalability of agroforestry practices are constrained by socio-economic and institutional barriers. Addressing these challenges requires targeted interventions, including:

- Policies to incentivize agroforestry adoption through subsidies and technical support.
- Development of markets for agroforestry products, enhancing their economic value.
- Research on long-term ecological and socio-economic impacts to inform adaptive management practices.

Future studies should explore region-specific variations in agroforestry benefits, particularly under different climatic conditions, to optimize its implementation. By integrating agroforestry into national and regional development plans, Sub-Saharan Africa can harness its full potential to support sustainable livelihoods and environmental conservation.

Carbon Sequestration in Agroforestry Systems in Sub-Saharan Africa (SSA)

Agroforestry has been recognized as a viable climate change mitigation strategy due to its potential for carbon sequestration in both tree biomass and soil. As agriculture contributes 10–12% of global greenhouse gas emissions (Vermeulen et al., 2012), the IPCC has highlighted agroforestry as a promising pathway for reducing these emissions. By incorporating trees into agricultural systems, agroforestry can contribute to climate resilience in SSA, where climate change impacts are particularly severe. Trees in these systems capture atmospheric CO_2 and store it in their biomass, while crop residues and tree litter contribute to increased soil organic carbon, thus enhancing soil quality and resilience (Nair, 2012). For example, research has shown that agroforestry systems in SSA can recover up to 35% of the original forest carbon stocks after slash-and-burn practices (Sanchez, 2000). Some agroforestry species, such as *Gliricidia sepium* and *Acacia* species (e.g., *Acacia crassicarpa, Acacia mangium*) have demonstrated a capacity to increase soil organic carbon, with studies in Tanzania reporting significant increases in topsoil carbon under these species (Kimaro et al., 2007). Such species enhance soil fertility while contributing to stable carbon stocks, thereby supporting agricultural productivity and soil resilience. Agroforestry systems also hold promise for inclusion in global carbon trading initiatives, which would provide economic incentives for carbon sequestration and reduce further deforestation and land degradation.

In SSA, agroforestry systems an average of 24.2±2.8MgCha^{-1} in biomass and 98.8±12.2 MgCha^{-1} in soil, indicating substantial carbon storage potential (Muthuri et al., 2023). This combined storage capacity exceeds that of simpler agrosilvicultural systems in Africa's humid tropics (29–53 MgCha^{-1}) but is somewhat lower than high-density, long-lived tree systems found in Southeast Asia. Variations in carbon sequestration across agroforestry practices are influenced by factors such as soil depth and sampling methodologies, as these can significantly affect soil carbon estimations (Schrumpf et al., 2011; Hairiah et al., 2020). For example, complex systems such as home gardens in SSA exhibit particularly high carbon storage capacity, averaging up to 153±23MgCha^{-1}. Such systems often integrate perennial crops with multipurpose trees, promoting prolonged carbon retention and supporting household livelihoods through the production of food, medicinal plants, and timber (Kimaro et al., 2007).

Aboveground Carbon Sequestration

Agroforestry systems like home gardens and perennial tree-crop systems store substantial amounts of aboveground carbon, with typical values around 34.3±7.9MgCha^{-1} in home gardens and 29.9±12.7MgCha^{-1} in perennial systems (Kimaro et al., 2007). Notably, higher aboveground carbon values have been observed in more intensively managed systems, such as enset-coffee agroforestry, which can store between 58.3 and 116.2MgCha^{-1}, reflecting the effects of extended tree rotation periods and complex canopy structures in these systems (Kimaro et al., 2007; Hobbs & Cramer, 2008). Small-scale woodlots in Tanzania, such as Eucalyptus woodlots, display similar benefits, often surpassing carbon stocks found on degraded lands or open cropland, which emphasizes their value for climate mitigation and ecosystem restoration (Nkurunziza et al., 2019).

Soil Carbon Sequestration Potential

Many agroforestry practices, including intercropping and parklands, hold significant potential to increase soil organic carbon in SSA, particularly in sandy soils where water retention is critical. Long-term agroforestry studies in Uganda, such as continuous alley cropping with *Maesopsis eminii*, have demonstrated substantial increases in soil organic carbon over 11 years, underscoring the benefits of sustained agroforestry practices (Hobbs & Cramer, 2008; Tumwebaze et al., 2012). Conversely, studies in Burkina Faso reported limited soil carbon gains in shorter-term alley cropping systems, illustrating the importance of long-term management for maximizing carbon benefits (Baumert et al., 2016). Soil organic carbon stocks are highest in complex agroforestry systems like homegardens and perennial tree-crop systems, particularly in humid and sub-humid zones where tree rotation periods often exceed 20 years (Nair & Nair, 2014). These systems benefit from the continuous input of organic matter through litter, root turnover, and periodic pruning, which enhances soil structure and fertility. Studies in Ethiopia have shown that transitioning from forest to agroforestry systems retains more Soil organic carbon compared to converting land to monoculture crops, demonstrating agroforestry's potential for sustainable land use (Negash et al., 2022).

Boundary systems, while not contributing significantly at the farm level, provide additional Soil organic carbon benefits by enhancing soil carbon in otherwise unused areas. Rotational woodlots, with SOC accumulation rates averaging 29.2±5.5MgCha^{-1} in Tanzania, also play a valuable role in restoring degraded landscapes and promoting long-term carbon retention (Kimaro et al., 2011).

Challenges in Carbon Measurement and Monitoring

Accurately estimating carbon sequestration in smallholder agroforestry systems in SSA presents significant challenges. While these systems contribute substantially to carbon storage, reliable measurement and monitoring of carbon stocks, particularly tree biomass accumulation, remain difficult. The IPCC offers a Tier 1 methodology with global default values for estimating carbon stocks, yet applying these standards locally often leads to inaccuracies (Brown, 1997; IPCC, 2003). . In response, more refined Tier 2 and Tier 3 methods, which incorporate country-specific data and species-specific allometric equations, have improved accuracy. For example, studies in western Kenya have developed local allometric equations for Eucalyptus species, estimating live tree biomass at 24.4±0.01Mg/ha, equivalent to 11.7±0.01Mg of carbon per hectare (Kuyah et al., 2013). Such local adaptations help reduce estimation bias by accounting for regional tree characteristics, but more studies are required to develop equations that reflect variations in tree architecture and wood density across different species.

The diversity of species, management practices, and environmental conditions in SSA further complicates accurate carbon quantification. Most studies use generalized equations that risk over- or underestimating carbon stocks. While agroforestry is effective in sequestering CO_2, the integration of nitrogen-fixing trees and livestock introduces potential emissions of nitrous oxide (N_2O) and methane (CH_4), respectively. For agroforestry to remain a net carbon sink, effective mitigation strategies are essential to balance carbon sequestration with these emissions.

Developing Species-Specific Allometric Equations

Developing accurate allometric equations for local tree species is crucial for effective biomass estimation. Species-specific equations help account for differences in tree architecture and wood density, which vary significantly among species. Several studies in SSA have focused on constructing these equations, particularly for agroforestry species common in parklands. Findings indicate that bias in biomass estimates often arises from inaccuracies in the equations used for smaller trees, which play a critical role in overall biomass estimates. Research has shown that the biomass of smaller trees is often overestimated, impacting the precision of carbon stock assessments (Pérez-Cruzado & Rodríguez-Soalleiro, 2011). To address these issues, tailored equations that consider variables such as DBH, height, and wood density can improve the reliability of carbon estimates in agroforestry systems, enabling a more accurate assessment of their climate mitigation potential.

Conclusion

This review highlights the significant role of agroforestry practices in SSA in advancing sustainable agricultural development, enhancing livelihoods, and contributing to climate mitigation efforts. The diversity of agroforestry practices in SSA, including alley cropping, home gardens, improved fallows, agroforestry parklands, and silvopasture—reflects the adaptability of these systems to different ecological and socio-economic conditions across the region. Each practice contributes uniquely to environmental sustainability, from enhancing soil fertility and conserving biodiversity to providing valuable ecosystem services and promoting resilience against climate shocks. The analysis demonstrates that agroforestry practices are integral to sustainable livelihoods in SSA, providing essential goods such as food, fuelwood, medicinal resources, and livestock fodder, while also generating income. Practices like home gardens and alley cropping directly support household food security and economic stability, particularly for rural communities with limited access to alternative resources. Moreover, by improving soil structure, increasing organic matter, and supporting nitrogen fixation, agroforestry significantly enhances soil fertility, which is critical for long-term agricultural productivity in marginal soils. In terms of climate mitigation, agroforestry in SSA holds considerable potential for carbon sequestration in both biomass and soil. While the carbon sequestration rates vary depending on the specific agroforestry system and the local ecological context, practices such as home gardens and perennial tree-crop systems show high storage capacity, effectively contributing to carbon stock conservation. However, accurate assessment and monitoring of these carbon stocks remain a challenge due to variations in species composition, management practices, and environmental conditions. The development and application of species-specific allometric equations and country-tailored methodologies are essential for precise carbon stock assessments. In conclusion, agroforestry systems in SSA present a holistic approach to sustainable land use, aligning with both environmental conservation and socio-economic development goals. By supporting food security, renewable energy sources, income generation, and carbon sequestration, these systems offer an integrated solution to address the complex challenges faced by rural communities in SSA. Future research should focus on refining carbon monitoring techniques and developing locally relevant allometric equations to enhance the accuracy of carbon sequestration assessments, enabling these practices to be more fully integrated into national climate mitigation strategies and global carbon trading frameworks.

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REFERENCES

Acheampong, E., Guuroh, R.T., & Holm, U. (2012). Homegardens as a Source of Income for Rural Households—A Case Study of Bieha District, Southern Burkina Faso. *Journal of Agricultural Science and Technology*, 10, 798–813.

Akyeampong, E., & Dzowela, B.H. (1996). Fodder production from associations of leguminous shrubs and grasses on contour bunds in the highlands of Burundi. *Tropical Grasslands*, *30*, 330–334.

Balehegn, M., Eik, L.O., & Tesfay, Y. (2015). Silvopastoral system based on Ficus thonningii: an adaptation to climate change in northern Ethiopia. *African Journal of Range & Forage Science*, *32*(3), 183–191. 10.2989/10220119.2014.942368

Baumert, S., Khamzina, A., & Vlek, P.L.G. (2016). Soil organic carbon sequestration in Jatropha curcas systems in Burkina Faso. *Land Degradation & Development*, *27*(8), 1813–1819. https://doi.org/10.1002/ldr.2310

Bayala, J., Sanou, J., Teklehaimanot, Z., Kalinganire, A., & Ouédraogo, S.J. (2014). Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa. *Current Opinion in Environmental Sustainability*, *6*, 28–34. https://doi.org/10.1016/j.cosust.2013.10.004

Bayala, J., Sanou, J., Teklehaimanot, Z., Ouedraogo, S.J., Kalinganire, A., Coe, R., & van Noordwijk, M. (2015). Advances in knowledge of processes in soil–tree–crop interactions in parkland systems in the West African Sahel: A review. *Agriculture, Ecosystems & Environment*, *205*, 25–35. https://doi.org/10.1016/j.agee.2015.02.018

Bayala, J., Sileshi, G.W., Coe, R., Kalinganire, A., Tchoundjeu, Z., Sinclair, F., & Garrity, D. (2012). Cereal yield response to conservation agriculture practices in drylands of West Africa: a quantitative synthesis. *Journal of Arid Environments*, *78*, 13–25. https://doi.org/10.1016/j.jaridenv.2011.10.011

Betemariyam, M., Negash, M., & Worku, A. (2020). Comparative analysis of carbon stocks in home garden and adjacent coffee based agroforestry systems in Ethiopia. *Small-Scale Forestry*, *19*(3), 319–334. https://doi.org/10.1007/s11842-020-09439-4

Bhaduri, D., Pramanik, P., Ghosh, S., Chakraborty, K., & Pal, S. (2017). Agroforestry for improving soil biological health. *Agroforestry for Increased Production and Livelihood Security. New India Publishing Agency, New Delhi*, 465–491.

Birhane, E., Teklay, R., Gebrehiwet, K., Solomon, N., & Tadesse, T. (2019). Maintaining Acacia polyacantha trees in farmlands enhances soil fertility and income of farmers in North Western Tigray, Northern Ethiopia. *Agroforestry Systems*, *93*, 2135–2149. https://doi.org/10.1007/s10457-018-0328-1

Boffa, J.-M. (1999). *Agroforestry parklands in sub-Saharan Africa*. FAO Conservation Guide 34. Rome, Italy.

Brown, S. (1997). *Estimating biomass and biomass change of tropical forests: a primer* (Vol. 134). Food & Agriculture Org. USA.

Cheatle, R.J., & Shaxson, T.F. (2001). Keynote: Conservation is for Business-Self-Help Groups in Kenya. *2001. Sustaining the Global Farm. Selected Papers from the 10th International Soil Conservation Organization Meeting Held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory*, 68–74.

Cooper, P.J.M., Leakey, R.R.B., Rao, M.R., & Reynolds, L. (1996). Agroforestry and the mitigation of land degradation in the humid and sub-humid tropics of Africa. *Experimental Agriculture*, *32*(3), 235–290. http://dx.doi.org/10.1017/S0014479700026223

Dimobe, K., & Bayala, J. (2023). Séquestration du carbone et fourniture d'autres services écosystémiques des parcs agroforestiers à karité au Burkina Faso. *Bois et Forêts Des Tropiquesrets*, *356*, 67–80. https://doi.org/10.19182/bft2023.356.a36903

Dimobe, K., Ouédraogo, A., Ouédraogo, K., Goetze, D., Stein, K., Schmidt, M. & Thiombiano, A. (2020). Climate change reduces the distribution area of the shea tree (Vitellaria paradoxa CF Gaertn.) in Burkina Faso. *Journal of Arid Environments*, *181*, 104237. https://doi.org/10.1016/j.jaridenv.2020.104237

Dimobe, K., Tondoh, J.E., Weber, J.C., Bayala, J., Ouédraogo, K. & Greenough, K. (2018). Farmers' preferred tree species and their potential carbon stocks in southern Burkina Faso: Implications for biocarbon initiatives. *PloS One*, *13*(12), 1–21. https://doi.org/10.1101/344408

Dollinger, J., & Jose, S. (2018). Agroforestry for soil health. *Agroforestry Systems*, *92*(2), 213–219. https://doi.org/10.1007/s10457-018-0223-9

Duguma, L.A., Minang, P.A., Watson, C., Nath, A.J., Muthee, K.W., van Noordwijk, M., Mutune, J.M. & Sileshi, G.W. (2023). Agroforestry as a key intervention to achieve nationally determined contribution (NDC) targets. In *Agroforestry for sustainable intensification of agriculture in Asia and Africa* (pp. 641–664). Springer. http://dx.doi.org/10.1007/978-981-19-4602-8_19

Fané, S., Agbotui, D.K., Graefe, S., Sanou, L., Sanogo, S., & Buerkert, A. (2024). Adoption of agroforestry systems by smallholders' farmers in the Sudano-Sahelian zones of Mali and Burkina Faso, West Africa. *Agroforestry Systems*, 12, 1–12. http://dx.doi.org/10.1007/s10457-024-01020-8

Faye, M.D., Weber, J.C., Abasse, T.A., Boureima, M., Larwanou, M., Bationo, A. B., Diallo, B.O., Sigué, H., Dakouo, J.-M., Samaké, O., & Diaité, D.S. (2011). Farmers' Preferences for Tree Functions and Species in the West African Sahel. *Forests, Trees and Livelihoods*, *20*(2–3), 113–136. https://doi.org/10.1080/14728028.2011.9756702

Guuroh, R.T., Uibrig, H., & Acheampong, E. (2014). How does homegarden size affect input and output per unit area?–a case study of the Bieha District, Southern Burkina Faso. *International Journal of Agriscience*, *4*(3), 196–208.

Hairiah, K., van Noordwijk, M., Sari, R.R., Saputra, D.D., Suprayogo, D., Kurniawan, S., Prayogo, C. & Gusli, S. (2020). Soil carbon stocks in Indonesian (agro) forest transitions: Compaction conceals lower carbon concentrations in standard accounting. *Agriculture, Ecosystems & Environment*, *294*, 106879. http://dx.doi.org/10.1016/j.agee.2020.106879

Higgins, J., & Green, S. (2011). *Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0 (updated March 2011)*. http://handbook.cochrane.org/. http://dx.doi.org/10.1002/9780470712184

Hobbs, R.J., & Cramer, V.A. (2008). Restoration ecology: interventionist approaches for restoring and maintaining ecosystem function in the face of rapid environmental change. *Annual Review of Environment and Resources*, *33*(1), 39–61. http://dx.doi.org/10.1146/annurev.environ.33.020107.113631

Hombegowda, H.C., Adhikary, P.P., Jakhar, P., & Madhu, M. (2022). Alley cropping agroforestry system for improvement of soil health. In *Soil Health and Environmental Sustainability: Application of Geospatial Technology* (pp. 529–549). Springer. http://dx.doi.org/10.1007/978-3-031-09270-1_23

Iiyama, M., Neufeldt, H., Dobie, P., Njenga, M., Ndegwa, G., & Jamnadass, R. (2014). The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. *Current Opinion in Environmental Sustainability*, 6, 138–147. http://dx.doi.org/10.1016/j.cosust.2013.12.003

IPCC, (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. *Institute for Global Environmental Strategies, Kanagawa, Japan*, 590 p.

Jama, B.A., Nair, P.K.R. & Rao, M.R. (1995). Productivity of hedgerow shrubs and maize under alleycropping and block planting systems in semiarid Kenya. *Agroforestry Systems*, *31*, 257–274. http://dx.doi.org/10.1007/BF00712078

Kang, B.T., Wilson, G.F., & Sipkens, L. (1981). Alley cropping maize (Zea mays L.) and leucaena (Leucaena leucocephala Lam) in southern Nigeria. *Plant and Soil*, *63*, 165–179. http://dx.doi.org/10.1007/BF02374595

Kimaro, A.A., Isaac, M.E., Chamshama, S.A.O. (2011). Carbon Pools in Tree Biomass and Soils Under Rotational Woodlot Systems in Eastern Tanzania. In: Kumar, B., Nair, P. (eds) Carbon Sequestration Potential of Agroforestry Systems. Advances in Agroforestry, vol 8. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-1630-8_7

Kimaro, A.A., Timmer, V.R., Mugasha, A.G., Chamshama, S.A.O. & Kimaro, D.A. (2007). Nutrient use efficiency and biomass production of tree species for rotational woodlot systems in semi-arid Morogoro, Tanzania. *Agroforestry Systems*, *71*, 175–184. http://dx.doi.org/10.1007/s10457-007-9061-x

Kindt, R., Dawson, I.K., Lillesø, J.-P. B., Muchugi, A., Pedercini, F., Roshetko, J., van Noordwijk, M., Graudal, L., & Jamnadass, R. (2021). The one hundred tree species prioritized for planting in the tropics and subtropics as indicated by database mining. *World Agroforestry*, 312, 01-21.

Kiyani, P., Andoh, J., Lee, Y., & Lee, D.K. (2017). Benefits and challenges of agroforestry adoption: a case of Musebeya sector, Nyamagabe District in southern province of Rwanda. *Forest Science and Technology*, *13*(4), 174–180. http://dx.doi.org/10.1080/21580103.2017.1392367

Kuyah, S., Buleti, S., Dimobe, K., Nkurunziza, L., Moussa, S., Muthuri, C. & Öborn, I. (2023). *Farmer-Managed Natural Regeneration in Africa: Evidence for Climate Change Mitigation and Adaptation in Drylands*. In

Agroforestry for sustainable intensification of agriculture in Asia and Africa (pp. 53-88). Singapore: Springer Nature Singapore. http://dx.doi.org/10.1007/978-981-19-4602-8_3

Kuyah, S., Dietz, J., Muthuri, C., van Noordwijk, M. & Neufeldt, H. (2013). Allometry and partitioning of above- and below-ground biomass in farmed eucalyptus species dominant in Western Kenyan agricultural landscapes. *Biomass and Bioenergy*, *55*, 276–284. https://doi.org/10.1016/j.biombioe.2013.02.011

Kuyah, S., Öborn I., Jonsson M., Dahlin A. S., Barrios E., Muthuri C., Malmer A., Nyaga J., Magaju C., Namirembe S., Nyberg Y. & Sinclair F. L. (2016). Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa, *International Journal of Biodiversity Science, Ecosystem Services & Management*, 12(4), 255-273. http://dx.doi.org/10.1080/21513732.2016.1214178

Kuyah, S., Whitney, C.W., Jonsson, M., Sileshi, G.W., Öborn, I., Muthuri, C.W., & Luedeling, E. (2019). Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa. A meta-analysis. *Agronomy for Sustainable Development*, 39(5), 1–18. http://dx.doi.org/10.1007/s13593-019-0589-8

Malchair, S., De Boeck, H. J., Lemmens, C. M. H. M., Ceulemans, R., Merckx, R., Nijs, I., & Carnol, M. (2010). Diversity–function relationship of ammonia-oxidizing bacteria in soils among functional groups of grassland species under climate warming. *Applied Soil Ecology*, 44(1), 15-23. https://doi.org/10.1016/j.apsoil.2009.08.006

Mansourian, S., & Berrahmouni, N. (2021). *Review of forest and landscape restoration in Africa 2021*. Accra. FAO and AUDA-NEPAD. https://doi.org/10.4060/cb6111en

Miller, D.C., Muñoz-Mora, J.C., & Christiaensen, L. (2017). Prevalence, economic contribution, and determinants of trees on farms across Sub-Saharan Africa. *Forest Policy and Economics*, *84*, 47–61. http://dx.doi.org/10.1596/29520

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A. & Group, P.-P. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, *4*, 1–9. http://dx.doi.org/10.1186/2046-4053-4-1

Mohri, H., Lahoti, S., Saito, O., Mahalingam, A., Gunatilleke, N., Hitinayake, G., Takeuchi, K., & Herath, S. (2013). Assessment of ecosystem services in homegarden systems in Indonesia, Sri Lanka, and Vietnam. *Ecosystem Services*, *5*, 124–136. http://dx.doi.org/10.1016/j.ecoser.2013.07.006

Montagnini, F., & Nair, P.K.R. (2004). Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems*, *61–62*(1–3), 281–295. https://doi.org/10.1023/B:AGFO.0000029005.92691.79

Mpanda, M., Kashindye, A., Aynekulu, E., Jonas, E., Rosenstock, T.S., & Giliba, R.A. (2021). Forests, farms, and fallows: The dynamics of tree cover transition in the southern part of the uluguru mountains, Tanzania. *Land*, *10*(6), 571. http://dx.doi.org/10.3390/land10060571

Muchane, M.N., Sileshi, G.W., Gripenberg, S., Jonsson, M., Pumariño, L., & Barrios, E. (2020). Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis. *Agriculture, Ecosystems & Environment*, *295*, 106899. http://dx.doi.org/10.1016/j.agee.2020.106899

Muthuri, C.W., Kuyah, S., Njenga, M., Kuria, A., Öborn, I., & van Noordwijk, M. (2023). Agroforestry's contribution to livelihoods and carbon sequestration in East Africa: A systematic review. *Trees, Forests and People*, *14*, 100432. https://doi.org/10.1016/j.tfp.2023.100432

Muthuri, C.W., Ong, C.K., Black, C.R., Mati, B.M., Ngumi, V.W., & van Noordwijk, M. (2004). Modelling the effects of leafing phenology on growth and water use by selected agroforestry tree species in semi-arid Kenya. *Land Use and Water Resources Research*, *4*, 1-11. 10.22004/ag.econ.47874

Nair, P.K.R. (2011). Methodological Challenges in Estimating Carbon Sequestration Potential of Agroforestry Systems. In: Kumar, B., Nair, P. (eds) Carbon Sequestration Potential of Agroforestry Systems. Advances in Agroforestry, vol 8. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-1630-8_1

Nair, P.K.R. (2012). Carbon sequestration studies in agroforestry systems: a reality-check. *Agroforestry Systems*, *86*, 243–253. http://dx.doi.org/10.1007/s10457-011-9434-z

Nair, P.K.R., & Nair, V.D. (2014). 'Solid–fluid–gas': The state of knowledge on carbon-sequestration potential of agroforestry systems in Africa. *Current Opinion in Environmental Sustainability*, *6*, 22–27. https://doi.org/10.1016/j.cosust.2013.07.014

Nair, P.K.R., Buresh, R.J., Mugendi, D.N., & Latt, C.R. (1999). Nutrient cycling in tropical agroforestry systems: Myths and science. In *Agroforestry in sustainable agricultural systems* (pp. xx-xx). CRC Press. Boca Raton, FL, USA.

Ndemanisho, E.E., Kimoro, B.N., Mtengeti, E.J., & Muhikambele, V.R.M. (2006). The potential of Albizia lebbeck as a supplementary feed for goats in Tanzania. *Agroforestry Systems*, *67*, 85–91. http://dx.doi.org/10.1007/s10457-005-2648-1

Ndinya, C.A. (2019). The Genetic Diversity of Popular African Leafy Vegetables in Western Kenya. In: Nandwani, D. (eds) Genetic Diversity in Horticultural Plants. Sustainable Development and Biodiversity, vol 22. Springer, Cham. https://doi.org/10.1007/978-3-319-96454-6_5

Negash, M., Kaseva, J., & Kahiluoto, H. (2022). Perennial monocropping of khat decreased soil carbon and nitrogen relative to multistrata agroforestry and natural forest in southeastern Ethiopia. *Regional Environmental Change*, *22*(2), 38. http://dx.doi.org/10.1007/s10113-022-01905-3

Nielsen, J.N., Olney, D.K., Ouedraogo, M., Pedehombga, A., Rouamba, H., & Yago-Wienne, F. (2018). Process evaluation improves delivery of a nutrition-sensitive agriculture programme in Burkina Faso. *Maternal & Child Nutrition*, *14*(3), e12573. http://dx.doi.org/10.1111/mcn.12573

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Tsubo, M., Ayalew, Z., & Abele, S. (2020). Economic and financial sustainability of an Acacia decurrens-based Taungya system for farmers in the Upper Blue Nile Basin, Ethiopia. *Land Use Policy*, *90*, 104331. http://dx.doi.org/10.1016/j.landusepol.2019.104331

Nkurunziza, L., Chirinda, N., Lana, M., Sommer, R., Karanja, S., Rao, I., Romero Sanchez, M.A., Quintero, M., Kuyah, S., & Lewu, F. (2019). The potential benefits and trade-offs of using sub-surface water retention technology on coarse-textured soils: Impacts of water and nutrient saving on maize production and soil carbon sequestration. *Frontiers in Sustainable Food Systems*, *3*, 71–78. https://doi.org/10.3389/fsufs.2019.00071

Olney, D.K., Pedehombga, A., Ruel, M.T., & Dillon, A. (2015). A 2-year integrated agriculture and nutrition and health behavior change communication program targeted to women in Burkina Faso reduces anemia, wasting, and diarrhea in children 3–12.9 months of age at baseline: a cluster-randomized controlled trial. *Journal of Nutrition*, *145*(6), 1317–1324. http://dx.doi.org/10.3945/jn.114.203539

Ondiek, J.O., Tuitoek, J.K., Abdulrazak, S.A., Bareeba, F.B., & Fujihara, T. (2000). Use of Leucaena leucocephala and Gliricidia sepium as nitrogen sources in supplementary concentrates for dairy goats offered Rhodes grass hay. *Asian-Australasian Journal of Animal Sciences*, *13*(9), 1249–1254. http://dx.doi.org/10.5713/ajas.2000.1249

Ouédraogo, A., Lykke, A.M., Lankoandé, B., & Korbéogo, G. (2013). Potentials for promoting oil products identified from traditional knowledge of native trees in Burkina Faso. *Ethnobotany Research & Applications* 11, 71-84.

Pérez-Cruzado, C., & Rodríguez-Soalleiro, R. (2011). Improvement in accuracy of aboveground biomass estimation in Eucalyptus nitens plantations: Effect of bole sampling intensity and explanatory variables. *Forest Ecology and Management*, *261*(11), 2016–2028. http://dx.doi.org/10.1016/j.foreco.2011.02.028

Quandt, A., Neufeldt, H., & Gorman, K. (2023). Climate change adaptation through agroforestry: opportunities and gaps. *Current Opinion in Environmental Sustainability*, *60*, 101244. http://dx.doi.org/10.1016/j.cosust.2022.101244

Quandt, A., Neufeldt, H., & McCabe, J.T. (2019). Building livelihood resilience: what role does agroforestry play? *Climate and Development*, *11*(6), 485–500. http://dx.doi.org/10.1080/17565529.2018.1447903

Rodrigues, R.C., Araújo, R.A., Costa, C.S., Lima, A.J.T., Oliveira, M.E., Cutrim Jr, J.A.A., Santos, F.N.S., Araújo, J.S., Santos, V.M., & Araújo, A.S.F. (2015). Soil microbial biomass in an agroforestry system of Northeast Brazil. *Tropical Grasslands-Forrajes Tropicales*, *3*(1), 41–48. http://dx.doi.org/10.17138/TGFT(3)41-48

Sanchez, P.A. (2000). Linking climate change research with food security and poverty reduction in the tropics. *Agriculture, Ecosystems & Environment*, *82*(3), 371–383. http://dx.doi.org/10.1016/S01678809(00)00238-3

Schrumpf, M., Schulze, E.D., Kaiser, K., & Schumacher, J. (2011). How accurately can soil organic carbon stocks and stock changes be quantified by soil inventories? *Biogeosciences*, *8*(5), 1193–1212. http://dx.doi.org/10.5194/bg-8-1193-2011

Sida, T.S., Baudron, F., Kim, H., & Giller, K.E. (2018). Climate-smart agroforestry: Faidherbia albida trees buffer wheat against climatic extremes in the Central Rift Valley of Ethiopia. *Agricultural and Forest Meteorology*, *248*, 339–347. http://dx.doi.org/10.1016/j.agrformet.2017.10.013

Sileshi, G., Akinnifesi, F.K., Ajayi, O.C., & Place, F. (2008). Meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa. *Plant and Soil*, *307*, 1–19. http://dx.doi.org/10.1007/s11104-008-9547-y

Sileshi, G.W. (2016). The magnitude and spatial extent of influence of Faidherbia albida trees on soil properties and primary productivity in drylands. *Journal of Arid Environments*, *132*, 1–14. http://dx.doi.org/10.1016/j.jaridenv.2016.03.002

Sileshi, G.W., Weldesemayat, M., Mafongoya, P., Akinnifesi, F.K., Phiri, E., Chirwa, P., Beedy, T., Makumba, W., Nyamadzawo, G., Wuta, M., & Nyamugafata, P. (2014). Agroforestry: Fertilizer trees. In *Encyclopedia of Agriculture and Food Systems* (pp. xx-xx). https://doi.org/10.1016/B978-0-444-52512-3.00022-X

Swamila, M., Philip, D., Akyoo, A.M., Sieber, S., Bekunda, M., & Kimaro, A.A. (2020). Gliricidia Agroforestry Technology Adoption Potential in Selected Dryland Areas of Dodoma region, Tanzania. *Agriculture*, *10*(7), 306-320. http://dx.doi.org/10.3390/agriculture10070306

Tumwebaze, S.B., Bevilacqua, E., Briggs, R., & Volk, T. (2012). Soil organic carbon under a linear simultaneous agroforestry system in Uganda. *Agroforestry Systems*, *84*, 11–23. http://dx.doi.org/10.1007/s10457-011-9448-6

Vallejo, V.E., Roldan, F. & Dick, R.P. (2010). Soil enzymatic activities and microbial biomass in an integrated agroforestry chronosequence compared to monoculture and a native forest of Colombia. Biol Fertil Soils 46, 577–587. https://doi.org/10.1007/s00374-010-0466-8

Vermeulen, S.J., Aggarwal, P.K., Ainslie, A., Angelone, C., Campbell, B.M., Challinor, A.J., Hansen, J.W., Ingram, J.S.I., Jarvis, A., & Kristjanson, P. (2012). Options for support to agriculture and food security under climate change. *Environmental Science & Policy*, *15*(1), 136–144. http://dx.doi.org/10.1016/j.envsci.2011.09.003

Yengwe, J. (2017). *Soil carbon and nitrogen dynamics, soil quality and crop yield levels in Faidherbia-maize agroforestry systems in Zambia* (Doctoral dissertation, Ghent University, Belgium).

Zomer, R.J., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., Van Noordwijk, M., & Wang, M. (2016). Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets. *Scientific Reports*, *6*(1), 29987. http://dx.doi.org/10.1038/srep29987