An Overview of Trees in Smallholder Farmers' Agricultural Landscapes: A Case Study from Sub-Saharan Africa

Abstract

Many developing countries, especially those in sub-Saharan Africa, have focused on improving agricultural production at the farm level. Governments have implemented agricultural policies and acts to support various initiatives aimed at generating secure and affordable food for low- and middle-income populations. However, these policies can sometimes lead to more homogeneous landscapes, reducing the diversity of accessible food. As global demand for food increases, farmers are expanding their crops and livestock into new areas. Yet, the inclusion of trees in agricultural landscapes is crucial for maintaining diversity. The objective of this study was to evaluate the benefits of incorporating trees in smallholder farming systems in sub-Sahara Africa. Therefore, the study found increasing evidence that trees can enhance welfare among rural farming households, particularly in Eastern Africa. Incorporating trees into agricultural landscapes offers numerous benefits, including improved household nutrition and food security through enhanced crop yields and diversified diets. These practices also support income generation and livelihood diversification, providing farmers with additional sources of revenue. Moreover, trees contribute to environmental benefits and ecosystem services such as soil fertility, water retention, and carbon sequestration, which are crucial for climate change adaptation and resilience. Additionally, integrating trees fosters the preservation of cultural and traditional knowledge, while promoting biodiversity conservation and ecosystem restoration, ultimately creating a more sustainable and resilient agricultural system. Moreover, integrating trees into farming landscapes can help address Sustainable Development Goals (SDGs) 1 and 2—' No Poverty' and 'Zero Hunger'—by increasing crop yields. This study recommends enhanced awareness campaigns for incorporating trees into agricultural landscapes.

Keywords: No poverty, Farming systems, Household income, Nutritional security, Sustainable agriculture, Trees

1. Introduction

Most sub-Saharan African countries' economies had been performing well for years before some achieved lower middle-income status in the past decade. Since then, however, economic growth has slowed. Moreover, half of the people continue to live in abject poverty due to reduced productivity [1]. The main contributing factors include poor farming methods and climate change [2]–[4]. The COVID-19 pandemic exacerbated the effects of persistent climate shocks and unsustainable fiscal policies on the economy, hampering governments' efforts to provide social protection, combat poverty [5], stop malnutrition, and end hunger [8]. To attain economic growth and poverty alleviation, sub-Saharan African countries (e.g., Ethiopia, Zambia, and the Republic of South Africa) have focused on improving the agricultural sector dominated by smallholder farmers who contribute significantly to the country's food basket [6]. Besides growing crops, these farmers make substantial contributions to livestock production, especially chicken, cattle, sheep, goats, and other small ruminants. They depend on rainfall for production, natural pasture for dairy animals, and expensive synthetic fertilizers for crop production. However, due to over-reliance on rain-fed agriculture, Zambia's 1.5 million smallholder farmers, who produce most of the country's food supplies [7], are particularly affected by climate change [8]. Climate shocks like delayed rainfall, reduced sunshine, and reduced mean annual temperature impact crop and livestock production [9], affecting food security with repercussions for rural households' welfare and vulnerability [10], and imperilling agricultural households and rural enterprises' growth [11],[12]. Therefore, sub-Saharan Africa and other least-developed countries have sought interventions to combat rural poverty by encouraging smallholder farmers to increase off-season production. Among these interventions is promoting afforestation and reforestation programs in agricultural landscapes with trees (e.g., collecting forest wood and non-wood products) [9]. Trees on agricultural landscapes are touted as a triple-win situation for rural farming households, with the potential to increase income and improve household nutritional needs [13].

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Smallholder farmers also practice horticulture, involving growing different vegetables and fruits on farmland for household consumption and income generation [14]. It is a common practice among agrarian households, especially those residing along water bodies. Besides that, trees anchor non-wood and wood forest products (i.e., fruits, honey, mushrooms, edible insects, and timber) beneficial to households. Interventions at the landscape level aim to achieve food security, nutritional security, and increased productivity [15], contributing to community well-being and positively impacting nations' economic development as GDP increases. Improved diets and steady food supply will lead to a healthier labor force that can engage in more income-generating activities, driving GDP growth. Food security is when all people, at all times, have physical, social, and economic access to sufficient [16], safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life [17]. In contrast, food

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self-sufficiency is defined as being able to meet consumption needs (particularly for staple food crops) from own production rather than by buying or importing [18], either at the household or country level.

Nutritional security refers to the consistent accessibility, affordability, and availability of foods and beverages that support health, prevent disease, and, if necessary, treat disease for racial/ethnic minorities, low-income [19], rural and remote groups, including all tribal communities and insular locations [20].

Agricultural productivity is measured as the ratio of agricultural outputs to agricultural inputs [21]. Crop productivity is the quantitative measure of crop yield in a given measured area of field, while crop production is the area multiplied by productivity (yield per unit area) [22].

Agricultural landscapes include amenities, cultural, and other societal values and are the visible results of the interplay between agriculture [23], natural resources, and the environment [24].

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Agriculture Food System

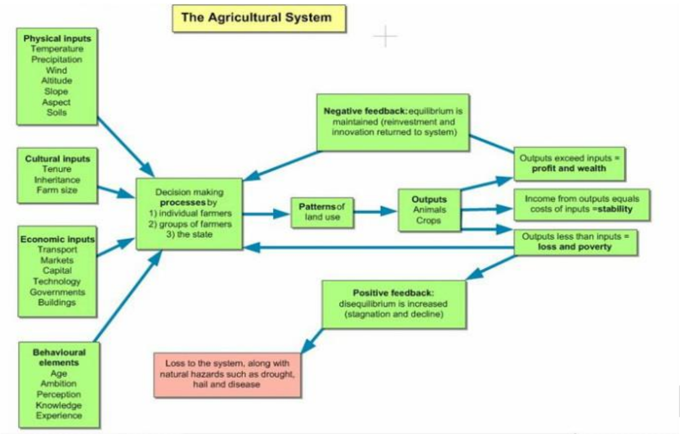

Figure 1: Agricultural system. Source: www.sare.org

These landscape interventions aim to address the current food production gaps among rural smallholder farming households (see figure 1). The benefits will only be realized when smallholder farmers adopt greater diversity in their agricultural practices.

2. Literature Review

In Africa, fruit trees are essential for improving the agricultural environment for smallholder farmers. In addition to offering a variety of nutrient-dense food options, these trees support economic development, environmental sustainability, and general community resilience. We may learn more about the many advantages of incorporating fruit trees into smallholder farming systems throughout the African continent by looking at a variety of case studies. The study conducted a comprehensive literature review from various regions worldwide, including sub-Saharan Africa. Priority was given to the most frequently cited articles. A total of 928 published articles relevant to the topic were sampled. These articles were then analyzed and categorized into clusters based on their focus areas. The figure 2 below illustrates a network of global research on trees, with different colors representing distinct research areas. Additionally, this network highlights potential future research opportunities concerning trees.

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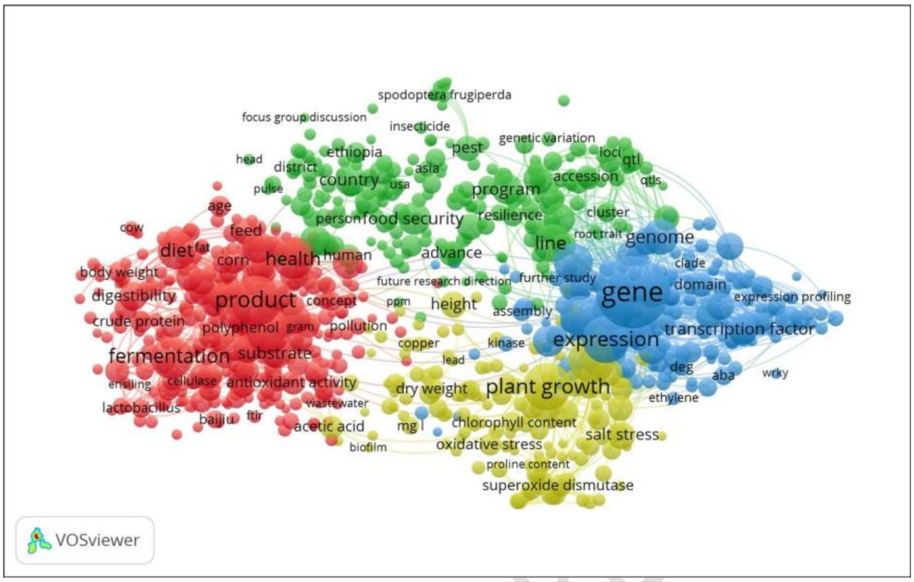

Figure 2: A network analysis of authors' trends

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Figure 2 represents a network analysis of authors' trends, where related words or concepts are clustered together based on their co-occurrence or semantic similarity. The analysis reveals several distinct clusters, each representing a specific area of focus or research interest.

The red cluster appears to be centered around topics related to animal and human nutrition, such as "cow," "feed," "diet," "corn," "health," "human," "digestibility," "crude protein," "polyphenol," and "fermentation substrates." This cluster likely encompasses studies on livestock feeding, nutritional aspects of various feed ingredients, and their impact on animal and human health. The green cluster seems to be focused on plant science and agricultural research. Words like "spodoptera frugiperda" (a type of insect pest), "insecticide," "genetic variation," "food security," "resilience," "plant growth," "chlorophyll content," "oxidative stress," "salt stress," and "superoxide dismutase" are present in this cluster. This suggests a concentration on topics such as pest management, genetic diversity, crop resilience, plant physiology, and stress responses in plants.

The blue cluster is primarily related to molecular biology and genetics. Terms like "gene," "genome," "expression," "transcription factor," "assembly," "clade," "domain," and "expression profiling" are prominently featured. This cluster likely represents studies on gene expression, genome analysis, and the identification and characterization of specific genes or gene families in various organisms. Additionally, there are smaller clusters and scattered terms that indicate other areas of interest. For example, the presence of words like "ethiopia," "country," "age," "height," "program," and "accession" suggests research related to demographic factors, regional studies, or germplasm collections. Overall, the network analysis provides a visual representation of the diverse research trends and interests within a particular field or community of authors. It highlights the interconnections between various topics and allows for the identification of dominant themes or areas of focus based on the clustering of related terms.

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3. Benefits of Trees in Agricultural Landscapes

According to recent studies, trees on farmlands and/or agricultural landscapes have various advantages, including combating climate change and providing habitat for animals. Moreover, trees can support larger ecosystems and conserve biological diversity. Incorporating trees and good management of trees can help to increase food security and nutritional security [25]. Other scholars have alluded that on the landscape, trees are crucial because they can reduce vulnerability to climatic variations and changes, contributing to food scarcity, market volatility, and environmental degradation [26]. Many of the advantages of trees on a farm landscape are similar to those of trees in a neighboring forest, but they also have certain special advantages that can be tapped into through the development and management of agroforestry (the integration of woody plants into farming systems) [27]. For instance, trees cultivated on farms for their fruit or wood generate a substantial amount of revenue for the nearby farmers [28], often accounting for more than 17% of their annual income, while rural households only generate 6% of their income from trees. Households may receive crucial nutrients from these trees [29], such as vitamin C, which can assist in meeting the minimal daily requirements for micro-nutrients [19], [30].

3.1. Case Studies of Tree Benefits in Agricultural Landscapes

Several scholars have evidenced that forests and woodlands significantly promote rural livelihoods and welfare. Forest trees provide essential resources such as food, medicine, shelter, building materials, fuel, and income. Mawunu et al. [31] surveyed the edible non-wood forest products sold in Uid province, Angola, by the local community. The study found that rural households collected edible mushrooms from the forest, benefiting insects, reptiles, and

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mammals within the household [32]. It concluded that integrating rural households with forests is vital for food security and income generation.

Leßmeister et al. [33] discovered that impoverished households rely more on non-timber forest products (NTFPs) for income than wealthier households, which helps balance income inequality. The study also noted that villages depend on various species compositions in their landscapes for traditional uses, recommending that agricultural management guidelines consider regional species variations and ethnically distinct NTFP consumption patterns. Gumbo et al. [34] revealed that forests provide numerous non-wood products (e.g., insects, mushrooms, fruits, tubers, medicine, fodder, honey, seeds, and wood fuels) that sustain nearly 100 million rural households and about 50 million urban people. These products are essential for food and nutrition, contributing to a diversified sustainable food system[35]. Properly managed forests and woodlands enhance resilience to climatic and economic challenges and help address hunger issues.

Sollen-Norrlin et al. [36] highlighted that agroforestry, which mimics natural ecosystems more closely than monocultures, allows diverse biological systems to thrive together. Planting trees between crops prevents soil erosion and water contamination and provides additional crops that protect farmers from poor harvests due to adverse conditions. Amare et al. [36] noted that intentionally preserving native trees on farmlands is a distinct agroforestry practice. Farmers cultivate native trees for various reasons, including livelihood support, ecosystem services, and the presence of valuable bird species. Similar factors that drive other agroforestry practices also encourage the adoption of farmland agroforestry [37].

McMullin et al. [38] pointed out that consuming sufficient fruits can address vitamin deficiencies and reduce the risk of related dietary disorders. However, fruit production and consumption are often inadequate in sub-Saharan Africa, especially seasonally. World Agroforestry Center developed a "fruit tree portfolios" methodology to select socio-ecologically suitable and nutritionally significant fruit tree species for farm production, aiming to integrate fruits better into local food systems and address seasonal shortages. McMullin et al. [39] further explained that fruit tree portfolios are site-specific mixtures of native and exotic species designed to produce year-round crops of vitamin-rich fruits. These portfolios address local "nutrient gaps" and "hunger gaps," enhancing seasonal food availability and increasing fruit diversity on farms for improved diets.

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Conferring to Amy et al. [40] fruit trees are an important source of dietary fibre, vital vitamins, and minerals that help smallholder farming households have better nutrition and food security. According to a 2013 study by Kehlenbeck et al [41]. in western Kenya, households that cultivate a wider range of fruit species with higher nutrient adequacy ratios significantly contribute fruit trees to dietary diversification. Kalaba et al. [42] discovered that households in Malawi that had access to native fruit trees experienced improved food security and higher scores for dietary diversification. Trees may generate extra revenue for smallholder farmers via the sale of processed foods, value-added commodities, and fresh fruits. Local fruits such as Strychnos cocculoides and Uapaca kirkiana were a significant source of revenue for smallholder farmers in Zimbabwe, according to Mithöfer and Waibel's [43] research. According to Awono et al. [44], non-timber forest products, such as fruits from trees like Irvingia gabonensis, significantly contribute to rural lives in Cameroon.

Trees can contribute significantly to ecosystem services and have a favourable environmental impact when included into agricultural settings. Fruit trees (like Faidherbia albida) can boost carbon sequestration, decrease soil erosion, and improve soil fertility by fixing nitrogen [45]. According to Ng'ang'a et al. [46], agroforestry systems using Persea americana (avocado) and Mangifera indica (mango) trees enhanced the physical and chemical characteristics of the soil in Kenya, increasing crop yields. Fruit trees can significantly increase the ability of smallholder farming systems to withstand the effects of climate change. According to Ouédraogo et al. [47], the incorporation of native fruit trees, such as Vitellaria paradoxa, or shea tree, into parkland agroforestry systems in Burkina Faso enhanced soil moisture retention and offered shade, hence reducing the adverse impacts of heat waves and drought on crop yields [48]. Welford et al. [49] also noted that fruit trees such as Sclerocarya birrea (marula) and Adansonia digitata (baobab) increased household resilience in Malawi during times of climatic stress and food insecurity.

Smallholder farmers can play a crucial role in conserving biodiversity and restoring degraded ecosystems by cultivating indigenous fruit tree species. In Kenya, Kidaha et al. [50] documented the significant contribution of smallholder farmers to the conservation of indigenous fruit tree species like Tamarindus indica (tamarind) and Sclerocarya birrea (marula). Additionally, in Ethiopia, Molla et al. [51] highlighted the potential of homegardens with fruit trees to serve as reservoirs of agrobiodiversity and contribute to ecosystem restoration efforts. Trees often hold significant cultural and traditional value for smallholder farming communities in Africa. In Benin, Fandohan et al. [52] explored the traditional knowledge and

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cultural practices associated with indigenous fruit trees like Adansonia digitata (baobab) and Parkia biglobosa (African locust bean tree). These trees are not only sources of food and income but also play important roles in traditional medicine, rituals, and cultural identities.

Fruit tree integration has clear advantages for smallholder agricultural systems, but there are drawbacks and obstacles as well. Fruit tree acceptance and successful cultivation can be hampered by a lack of market connections, poor extension services, and restricted access to planting supplies [53]. Furthermore, the long-term viability of these systems may be threatened by pests and diseases, climatic variability, and insecure land tenure [54],[55]. For one to overcome these obstacles and fully utilise fruit trees to benefit smallholder farmers, a comprehensive strategy involving several stakeholders is necessary. Researchers, extension services, non-governmental organisations, and local communities working together can enhance value chains, advance sustainable practices [56], and make it easier to develop and disseminate appropriate technology. To increase the resilience and productivity of smallholder farming systems in Africa, policies and programmes that promote agroforestry, biodiversity conservation, and smallholder empowerment are essential [57].

To sum up, the incorporation of fruit trees into African smallholder agricultural landscapes has numerous advantages, spanning from enhanced household sustenance and revenue creation to ecological durability and climate change mitigation. Fruit trees are beneficial for dietary diversity, livelihood diversification, resilience, ecosystem services, and cultural preservation, according to case studies from several African nations [25]. Smallholder farmers in Africa can improve livelihoods and rural development by tackling the obstacles and seizing the opportunities associated with fruit tree production. This will increase the productivity, sustainability, and resilience of their farming systems.

3.2. Factors Affecting Incorporating of Trees in Agricultural Landscapes

Incorporating trees in agricultural landscapes, commonly known as agroforestry, is a practice that has gained significant importance in sub-Saharan Africa. This region faces numerous challenges, including soil degradation, food insecurity, and the impacts of climate change. The incorporation of trees into agricultural systems offers a promising solution to address these challenges [58]. However, several factors influence the successful adoption and implementation of agroforestry practices. One crucial factor is the availability of suitable tree species and their adaptability to local environmental conditions. Sub-Saharan Africa is home to a vast array of indigenous tree species that have co-evolved with the region's ecosystems.

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Selecting appropriate tree species that can withstand the climatic conditions, provide desired products and services [59], and complement the existing agricultural practices is crucial for the success of agroforestry systems.

Socio-economic factors also play a significant role in the adoption of agroforestry practices. Smallholder farmers in sub-Saharan Africa often face resource constraints, such as limited access to land, labour, and capital [60]. The perceived benefits of agroforestry, including increased crop yields, diversified income streams, and improved soil fertility, must outweigh the perceived costs and risks associated with its implementation. Cultural and traditional practices can either facilitate or hinder the incorporation of trees in agricultural landscapes. Many communities in sub-Saharan Africa have long-standing traditions and beliefs related to trees and their role in agriculture. Understanding and incorporating these traditional ecological knowledge systems can enhance the acceptance and adoption of agroforestry practices [8].

Government policies and institutional support are also critical factors. Policies that promote agroforestry practices, provide incentives, and facilitate access to resources such as seedlings, technical assistance, and market linkages can significantly influence the uptake of agroforestry systems [61],[62]. Strengthening local institutions and building capacity among extension workers and farmer groups can further support the successful implementation of agroforestry practices. Finally, climate change and its associated impacts, such as prolonged droughts, erratic rainfall patterns, and increased pest and disease pressures, are crucial considerations in the selection and management of agroforestry systems [63]. Incorporating drought-tolerant and resilient tree species, as well as adopting sustainable land management practices, can enhance the resilience of agricultural landscapes in the face of a changing climate.

Conclusion

Trees play a vital role in the agricultural landscapes of smallholder farmers in sub-Saharan Africa, providing a range of products and services, including food, fodder, fuelwood, and income generation opportunities. They also contribute to ecosystem services such as soil fertility improvement, erosion control, and climate regulation. However, the integration of trees in agricultural landscapes is influenced by various factors, including ecological, socio-economic, and cultural considerations. The case study has highlighted the diversity of trees adopted by smallholder farmers in the region, reflecting its ecological and cultural heterogeneity. It has also revealed the challenges faced by farmers, such as limited access to

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resources, land tenure insecurity, and the impacts of climate change. Despite these challenges, the study has demonstrated the resilience and adaptability of smallholder farmers in incorporating trees into their agricultural landscapes, contributing to sustainable livelihoods and environmental conservation.

Promoting context-specific agroforestry practices, tailored to the local ecological, socio-economic, and cultural contexts, is crucial. This can be achieved through participatory research and extension programs involving smallholder farmers. Additionally, developing and implementing policies that recognize the importance of agroforestry and provide incentives and support for smallholder farmers to adopt these practices is essential. This includes improving access to resources, such as quality planting materials, technical assistance, and market linkages. Investing in capacity building programs for extension workers, farmer organizations, and rural communities to improve their understanding and skills in agroforestry practices, and facilitating knowledge sharing platforms to promote the exchange of traditional and scientific knowledge, is also recommended. Ensuring that agroforestry interventions are gender-sensitive and encourage the active participation of women and youth can contribute to empowerment, income generation, and the sustainable management of agricultural landscapes. Furthermore, incorporating climate-smart agroforestry practices that enhance the resilience of agricultural landscapes to the impacts of climate change, including promoting drought-tolerant and climate-resilient tree species, as well as sustainable land management practices, is crucial. Finally, fostering multidisciplinary collaboration among researchers, policymakers, development organizations, and local communities can address the multifaceted challenges faced by smallholder farmers in sub-Saharan Africa, leading to holistic and integrated solutions for sustainable agricultural landscapes.

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