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Agroforestry practices: a necessity for improving agricultural productivity and soil fertility in different agroecological zones of Ethiopia

Prácticas agroforestales: una necesidad para mejorar la productividad agrícola y la fertilidad del suelo en diferentes zonas agroecológicas de Etiopía

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Article Data

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Abstract

In many parts of Ethiopia, there are serious problems of soil fertility loss and increasing land degradation. This study examines how agroforestry practices affect soil fertility and agricultural production in various agroecological zones in Ethiopia. Various agroforestry practices were employed across the country, including scattered trees in rangelands, forest parks, hedgerows, alley cropping, intercropping, and shifting cultivation. This article reviewed these practices by collecting secondary data from published articles, books, and journals on agroforestry practices that improve agricultural productivity and soil fertility in different agroecological regions of Ethiopia. The study findings suggest that agroforestry practices have a positive impact on agricultural production and soil fertility in various agroecological zones. Furthermore, they help reduce soil erosion, water loss, and organic matter depletion, thereby contributing to increased agricultural productivity. Soil fertility loss poses a serious threat to agricultural crop growth, impacting social well-being and sustainable economic development. The study notes that soil fertility and agricultural productivity can be significantly improved by adopting agroforestry techniques.

Resumen

En muchas partes de Etiopía, existen graves problemas de pérdida de fertilidad del suelo y creciente degradación de la tierra. Este estudio examina cómo las prácticas agroforestales afectan la fertilidad del suelo y la producción agrícola en diversas zonas agroecológicas de Etiopía. Se emplearon diversas prácticas agroforestales en todo el país, incluyendo árboles dispersos en pastizales, parques forestales, setos vivos, cultivos en hileras, cultivos intercalados y agricultura migratoria. Este artículo revisó estas prácticas mediante la recopilación de datos secundarios de artículos, libros y revistas publicados sobre prácticas agroforestales que mejoran la productividad agrícola y la fertilidad del suelo en diferentes regiones agroecológicas de Etiopía. Los hallazgos del estudio sugieren que las prácticas agroforestales tienen un impacto positivo en la producción agrícola y la fertilidad del suelo en diversas zonas agroecológicas. Además, ayudan a reducir la erosión del suelo, la pérdida de agua y el agotamiento de la materia orgánica, lo que contribuye a una mayor productividad agrícola. La pérdida de fertilidad del suelo representa una grave amenaza para el crecimiento de los cultivos agrícolas, impactando el bienestar social y el desarrollo económico sostenible. El estudio señala que la fertilidad del suelo y la productividad agrícola pueden mejorarse significativamente mediante la adopción de técnicas agroforestales.

Introduction

Agroforestry, the integration of trees and shrubs into agricultural landscapes, is increasingly recognized as a vital practice for sustainable land management worldwide. It enhances biodiversity, improves soil fertility, and boosts crop yields while mitigating climate change through carbon sequestration[1]. In sub-Saharan Africa, where land degradation and food insecurity are prevalent, agroforestry systems such as alley cropping and silvopasture have shown promise in restoring degraded soils and increasing farm productivity[2,3]. However, challenges such as limited access to quality tree seedlings, land tenure issues, and competition for resources between trees and crops hinder widespread adoption[4]. Despite these constraints, agroforestry remains a key strategy for resilient farming systems, particularly in regions vulnerable to environmental degradation.

In Ethiopia, where over 80 % of the population relies on agriculture for their livelihood, agroforestry presents a viable solution to address the challenges of land degradation, soil fertility loss, and food insecurity. Integrating trees into farming systems has been shown to improve soil health, enhance crop productivity, and provide additional income sources for smallholder farmers. Successful agroforestry initiatives in regions such as Southern Ethiopia, Tigray, Oromia, and Amhara demonstrate the potential of these practices to restore degraded lands and strengthen food security. For example, integrating trees into farming systems has led to improved crop productivity and strengthened food security, particularly in regions prone to soil erosion and nutrient depletion[5,6], and agroforestry contributes to soil health enhancement and environmental sustainability, especially in degraded highland areas[7]. These findings suggest that agroforestry not only mitigates land degradation but also supports the livelihoods of small holder farmers by diversifying income sources and increasing resilience to climatic shocks.

However, scaling up these successes requires concerted efforts from the government and stakeholders to provide necessary support and resources. Key challenges in Ethiopia are rapid population growth, per capita food output reduction, and environmental deterioration. Due to the need for agricultural intensification and population growth, impoverished farmers must expand their operations to marginal and hilly areas[8]. The highlands of Northern Ethiopia are home to a dense population, small land holdings, and concurrent soil degradation[9]. This is also the case in Southern Ethiopia, where there is deforestation, steeper slope farming, tiny household land holding sizes, and high population density[10].

This population density quickens the pace of land degradation due to a combination of diminishing soil fertility, pressure for limited natural resources, and resource neglect[11]. Believe that the efficiency of crops in agriculture is primarily determined by soil fertility, with a decline in soil fertility serving as the primary cause of low agricultural output. Declining soil fertility and land degradation are emerging as major barriers affecting agricultural output and human welfare in tropical Africa[12]. By estimations, 37 Sub-Saharan African (SSA) countries' 200 million hectares of cultivated land have lost an average of 660 kg of nitrogen (N), 75 kg of phosphorus (P), and 450 kg of potassium (K) ha^{-1} over the past 30 years[13].

The State that agroforestry is one strategy for preventing land degradation and enhancing soil fertility, particularly in the woodland regions[14]. Agroforestry, is described as a collective term for land-use systems in which woody perennials (bushes, shrubs, and many others) are grown in affiliation with herbaceous plant life (crops, pastures), or cattle, in a spatial association, a transient association on the same piece of land, for both ecological and economic advantage[15]. It comprises cultivating arable vegetation and tree species on an equal area of land, resulting in special ecological interactions and optimized financial gains. Suggesting that the best place to start when considering agroforestry choices is with the species that farmers are most familiar with[16,17]. To motivate individual farmers to plant trees, approaches to enhancing smallholder crop productivity should first recognize the benefits and drawbacks of the existing indigenous farming methods[18].

Additionally, *Ficus thonninigii* (blume), an indigenous species of tree that offers year-round animal feed, money, medicine, timber, and soil and water conservation, is cultivated and managed by the people of the Ahferom district in the Tigray region[19]. Fundamentally, *Faidherbia albida* is a multipurpose tree that is planted across Ethiopia to increase soil fertility and provide rural populations with fuel and food[20]. Aside from scattered trees on farms, many farmers in Ethiopia's distinct agroecology zones undertake various agroforestry practices. Even though local communities in Ethiopia's diverse agro-ecological zones recognize agroforestry activities as crucial for boosting soil fertility and crop yields, there is a scientific knowledge fissure surrounding these techniques. As a result, this study aimed at conducting a review of the role of agroforestry in improving agricultural productivity and soil fertility across Ethiopia's varying agro-ecologies.

Development

Agroforestry plays a crucial role in enhancing agricultural productivity and maintaining soil fertility, especially in diverse agro-ecological zones like those found in Ethiopia. By integrating trees with crops and livestock, agroforestry systems improve soil structure, increase nutrient cycling, and offer protection against erosion and land degradation. This synergy not only boosts farm yields but also strengthens the resilience of agricultural landscapes to climate variability. Given Ethiopia's dependence on agriculture for livelihoods and food security, promoting agroforestry practices is essential for sustainable land management and long-term agricultural development.

Agroforestry techniques. Provide practical strategies for utilizing a range of specific skills and knowledge to build robust rural production systems. Trees are a preferred land use that offers both products and environmental benefits[21]. Report that in addition to the obvious environmental benefits, trees also have social and economic benefits[22]. Traditional agroforestry practices that are common in tropical climates include scattered trees on crop fields, homestead tree planting, multistory home gardens, woodlots, home gardens, coffee shade-based scattered trees on farms, and trees on grazing grounds.

Agroforestry, which is practiced by several local groups in Ethiopia, is crucial for a variety of reasons, including food security, the enhancement of the microclimate, economic advantages, environmental protection, home energy, household utensils, cultural values, traditional medicines, and fodder. Agroforestry techniques assist in the adaptation and mitigation of climate change, which contributes to the achievement of the United Nations Millennium Development Goals. The approaches' use of agroforestry-based soil fertility and land management strategies has helped in the fight against hunger. While food supply has improved in developing countries, the average number of individuals experiencing food insecurity has decreased globally[23].

Soil fertility. The inherent ability of soil to supply plants with the proper ratios and amounts of nutrients for growth, free from harmful concentrations of any element, and where the quality of the soil serves as an indication for assessing soil fertility[24]. Soil nutrients are lost from the system in form of erosion, gaseous form, and crop harvesting, and leaching. The primary reason behind African farmers' low earnings and food insecurity of the depletion of soil fertility, 22 kg of nitrogen, 2.5 kg of phosphorus, and 15 kg of okay are lost annually from agricultural soils in the surrounding South African area[25]. Nevertheless, it's crucial to distinguish from terrible soil fertility brought on by outside factors and declining soil fertility as a result of past land usage while setting up the supply of poor crop yields[26].

Nutrient cycling. The theory behind agroforestry argues that tree roots can reach portions of the soil outline that annual crop root systems would not be able to, and tree crops can then take up nutrients from these regions of the profile[27]. The aboveground plant components (leaves, twigs, stems, etc.) and a significantly larger root mass in the surface horizons subsequently absorb these nutrients. The primary ways that trees affect soil qualities are through their roots and through the accumulation of aboveground organic matter through litter fall and trimming.

One important benefit of agroforestry systems is the release of nutrients through the breakdown of tree litter and roots, especially when nitrogen-fixing plants are present[28]. Because they promote recycling and stop erosion, the trees increase the number of inputs (organic matter, nitrogen fixation, nutrient uptake) and decrease the losses (organic matter, nutrients). They also have a good effect on soil biological activities and enhance the physical characteristics of the soil, such as its capacity to retain water[29].

Soil fertility improvement by agroforestry practices. Revealed that trees increase soil fertility after evaluating how they preserve and enhance soil productivity[30]. Agroforestry practices such as hedgerow intercropping, windbreaks, planted tree fallow, shifting cultivation, Taungya, trees on croplands, plantation crop combinations, and trees for soil conservation have all demonstrated an overall increase in soil productivity[31]. The primary results unequivocally show that shifting cultivation is a sustainable system so long as the length of fallow is adequate to return soil conditions to their pre-cultivation and pre-fallow conditions stages.

However, discovered that two-year-old *Sesbania sesban* followed quadrupled maize yields over six years when compared to continuous unfertilized maize production, despite going two years without crop output while the plant was growing[32]. If the fallow period can be shortened without compromising crop productivity or soil fertility. Studies have shown that enriching the soil is one of the functions of shade trees in plantation crop combinations[33]. Numerous investigations on the modifications of soil parameters in hedgerow intercropping have been carried out. Intercropping hedgerows alters the characteristics of the soil[34].

Found that boosting moisture content and cereal crop productivity increased with nearest to the tree trunk[35]. As bulk density increases along the distance from the tree trunk. The results of this study, which compared maize grain yield under and outside of the canopy phase, show the impacts of dispersed *Faidherbia albida* and *Croton macrostachyus* trees on the physical and chemical qualities of the soil. For instance, the study by Manjur et al.[35] demonstrated that both *Faidherbia albida* and *Croton macrostachyus* trees positively influenced soil physical properties and maize yield. Under the canopy of *F. albida*, bulk density decreased (0.9-1.01 g cm^{-3}) and soil moisture content was higher (20.89-24.09 %) compared to outside the canopy, resulting in increased maize grain yields ranging from 64.87 to 76.20 qt ha^{-1}. Similarly, soils under *C. macrostachyus* trees showed lower bulk density (0.92-1.05 g cm^{-3}), higher moisture content (15.01-19.81 %), and enhanced maize yields (68.02-81.56 qt ha^{-1}) relative to open fields (Manjur et al.[35].

Process of soil improvement under agroforestry practice. In an agroforestry system, atmospheric fixation, trimming of woody compounds, and leaf litter all contribute nutrients. Tree roots may assist in bringing nutrients into the system from deeper soil layers that are typically thought to be unavailable to crops since they are situated below the rooting zone of annual crops[36]. Trees can replenish nutrients through dead organic matter (leaves, branches, twigs, fruits, and flowers), which improves the topsoil layer that is available for crops. Thus, an increase in soil structure and nutrient availability may be the biggest benefits of trees for soil[37].

Nutrient recovery. By transporting nutrients from the soil to the earth's top through leaf shedding and other organic wastes, trees enrich the soil with more nutrients. To restore the soil's organic matter, sub-humid and semi-arid environments require 4 and 2 t of dry matter (above-ground leftovers) per hectare per year, and 8 and 2 t p yr^{-1}, respectively[38]. To analyze, legume trees grown in alley cropping systems could yield up to 20 t of dry matter annually[39]. These pruning's could contain up to 358 kg of nitrogen, 28 kg of phosphorus, 232 kg of potassium, 144 kg of calcium, and 60 kg of sulfur.

Impact of agroforestry practice on soil fertility and cereal crop productivity. The effects of agroforestry practices on soil fertility and yearly crop productivity are explained in terms of the customs followed by the local population in various regions. Ethiopia has distinct agro-ecological zones by nature, and adaptation practices differ depending on these zones. He listed nine different agroforestry practices with varying ecological and social benefits across Ethiopia[40]. Under *Faidherbia albida***,** sorghum yields in Ethiopia rose by 36 %[20,41], also found that the production of barley was significantly influenced by both the distance from the center of the *F. albida* stem and the land use regime.

Agroforestry can take various forms in different parts of Ethiopia, such as enset-coffee, tree-spice-based, poem fruit trees, bamboo cumen vegetable farming.

Additionally, agroforestry is based on conservation with multiple perennial crops, including bamboo and cereal crops. Although the Enset-coffee agroforestry systems in southern Ethiopia also aim to generate money, the primary goal of these agroforestry systems is to meet household food demands[42].

Parklands agroforestry practice. It is expressed as deliberate management of multipurpose trees on farmland for economic gain and environmental benefit. Such, Agroforestry techniques have a direct effect on the physical, chemical, and organic content of the soil, which can either raise or lower agricultural production. It is known that agroforestry techniques, such as the bio recycling of minerals, changes in the environment (such as thermal and moisture regimes), and the distribution of trees on croplands, can modify the microclimate, floral and faunal composition, and other ecosystem elements[35].

An additional finding reports that the presence of *F. albida* greatly increased nitrogen and phosphorus utilization efficiencies, which in turn caused a considerable increase in wheat grain yields[43]. This particular tree species provided around 64 kg ha^{-1} yr^{-1} of mineral N. Wheat grown beneath *F. albida* has twice the P usage efficiency of wheat grown in open fields. Other findings also report that nutrient inputs can be boosted through nitrogen fixation, wasteful nutrient losses can be reduced through leaching and erosion, and enhanced biological activity can be fostered by supplying biomass and a conducive environment[44]. Furthermore, yield improvement and increased soil fertility under irregular tree canopies[45].

Another study conducted in Burkina Faso states that sorghum grain yields in improved by 14 % when grown beneath the shade of *Cordia africana* trees[46]. Furthermore, according, *Acacia* inhibits soil fertility and crop yield[47]. According to the study report that the soil bulk density rose from 0.19 to 0.26 as we proceeded from under-to-under tree cover, even though soil pH values varied from 5.5 under trees to 4.62 in open cultivated regions. Additionally, they discovered that when the distance from the tree stem to the open ground increases under the Acacia decurrens tree species, total N and C/N greatly change.

Alley-cropping is an agroforestry practice. Alley-cropping, according study by is an agroforestry system in which crops are grown in the gaps between hedgerows of trees and/or bushes[48]. Hedgerow trees and bushes are pruned down at planting and then again at regular intervals throughout the cropping season to minimize competition with food crops and prevent shadowing. The benefit of alley cropping is that it improves soil fertility, which increases crop productivity. Several studies have been conducted to assess the alley-cropping practices' potential for nutrient cycling. Some of the initial experiments on alley cropping were conducted, which discovered that 25-alley cropping raised agricultural yield and enhanced soil fertility[49].

In one trial, they found that the mean dry matter additions as mulch fell between 5.85 and 7.09 mg ha yr^{-1}, and the average nitrogen yield from pruning *Leucaena leucocephala* ranged from 171 to 208 kg ha yr^{-1}. These trials also showed that applying fertilizer at the start of the cropping season can improve the system's ability to cycle nutrients such as nitrogen and dry matter. However also reviewed that total soil nitrogen was higher in the alley cropping treatment than in the other treatments, bulk density in the treatment showed a difference, even if it was not statistically significant, with only three repetitions[50].

Alley cropping practices were conducted across different agro-ecology zones of Ethiopia and adapted by the local community for severe benefits such as soil erosion control, enhancing fuel wood, fodder, and soil fertility, etc. To that, soil organic carbon was higher in alley-cropped plots than in the control plots at both 0-10 and 10-30 cm depths[51]. On average, organic carbon was lower by over 20 % and 10 % in the control and Gliricidia plots, respectively, compared to Acacia plots.

Home garden agroforestry practice. In many tropical places, home gardens are essential to the subsistence economy as a result of their diverse range of crops and trees[52]. These places typically have high human population densities and landholdings that are smaller than one hectare on average. Due to their appropriate agroclimatic conditions for home garden agroforestry, Ethiopia's south and southwest were more defined by home garden agroforestry than any other location. Agroforestry in home gardens helps smallholders diversify their sources of income and control the productivity of the soil on a small plot of land surrounding the homestead.

This strategy included a variety of soil fertility management techniques, such as applying chemical fertilizer, applying animal manure, applying a combination of animal manure and chemical fertilizer, or applying neither manure nor fertilizer. These management techniques, which include intercropping with perennial trees and shrubs like maize, sorghum, and cash crops like chat and coffee in home gardens, also boost soil fertility and crop productivity. Home garden agroforestry techniques also increase the productivity of various vegetables. Determined that 60 agroforest farms in the Gedeo zone are home to 58 woody species, representing 49 genera and 30 families[53]. Comparably, 32 woody species from 19 groups were identified in a study done in Gununo Wolayita[54]. In a 100 m^2 home garden in the Gedeo zone, 50 plant species from 35 families were recorded[55].

Considering there are many trees and shrubs in home gardens, agroforestry practices have a significant potential for sequestering carbon while also promoting food and nutrition security.

Intercropping agroforestry practices. Around the world, intercropping, the simultaneous growth of two or more crop species in a single field area under a range of tree species, is a widely used technique[56]. Different studies have shown that intercropping practices have a noticeable effect on preserving soil organic matter, lowering soil surface evaporation due to leaf fall mulch, providing cover for plants that require shade, like coffee, and providing shade for people when they are working on the farm. According to intercropping gives a profit advantage when the overall plant density is higher than that of either of the sole crops[57]. Intercropping maize with the Gora faba bean variety at a 50% density resulted in a 13% increase in total grain yields, a 42% rise in economic return, and a 38% improvement in land equivalent ratio compared to growing maize alone[58].

In Ethiopia's several agro-ecological zones, intercropping of different fruit trees is rather common. For example, bananas and mango trees can be grown together. The broad canopy of the mango trees will lessen wind speed and lessen competition for resources since these plants have a different rooting system that enables them to acquire soil nutrients and water from the various strata of the soil profile. Another important main crop grown in the area, maize, is also grown using this technique. This method's nitrogen-fixing trees will also aid in nutrient recycling, enabling production in a cost-effective and ecologically friendly way[47].

While agroforestry has proven effective in improving soil fertility and agricultural productivity, alternatives such as conservation agriculture, integrated soil fertility managemen, and organic farming also offer viable solutions. Conservation agriculture, which emphasizes minimal soil disturbance, permanent soil cover, and crop rotation, can reduce erosion and enhance soil structure. Integrated soil fertility management promotes the combined use of mineral fertilizers and organic inputs to optimize soil health and crop yields. Moreover, organic farming systems, by emphasizing composting and biological soil enrichment, offer environmentally sustainable paths to restoring degraded soils. Nonetheless, these approaches often require substantial technical support, farmer training, and initial investment, which can be challenging for smallholder farmers. Thus, integrating agroforestry with these complementary practices can offer a holistic and practical solution to Ethiopia's ongoing challenges of land degradation and declining soil fertility.

Conclusion

This study emphasizes that agroforestry practices are essential for improving soil fertility and agricultural productivity across Ethiopia's diverse agro-ecological zones. By reviewing existing literature, the findings of this study show that integrating trees into agricultural systems enhances soil organic matter, reduces erosion, and supports sustainable crop production. Agroforestry practices such as home gardens, alley cropping, scattered trees on croplands, and intercropping not only contribute to environmental sustainability but also strengthen rural livelihoods and food security. The findings highlight that agroforestry remains a practical, multifunctional solution to the pressing issues of land degradation, soil nutrient depletion, and climate change impacts. Continued support for and expansion of agroforestry practices are critical for achieving long-term agricultural resilience and environmental conservation in Ethiopia.

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Ethical considerations

I hereby declare that the review conducted is original, has not been published elsewhere, and has been duly approved by all source materials.

Research limitations

The author declares that there were no research limitations.

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Not applicable.

Generative Artificial Intelligence

No generative artificial intelligence was used in this reperch.

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