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Review Article

Enhancing carbon sequestration through tropical forest management: A review

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Article Info

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Abstract

Soil absorbs a lot of carbon dioxide (CO2). Soil organic carbon (SOC) is understudied in tropical regions despite its importance. This study examines how forest management might increase SOC sequestration and restore degraded tropical ecosystems. Sequestering soil organic carbon could enhance soil fertility and reduce land degradation and greenhouse gas (GHG) emissions. Soil structure, aggregation, infiltration, faunal motion, and nutrient (C, N, P and S) cycling are improved. Forest ecosystem management improves C sequestration, climate change mitigation, and degraded land rehabilitation. When combined with organic residue managing and nitrogen-fixing plants, afforesting or reforesting marginal or degraded lands enhances C storing in biomass and soil and supports soil condition, food productivity, land refurbishment, and greenhouse gas reduction. Sequestered C increases biological, physical, and chemical fertility, improving soil health.

Keywords: Tropical forest; Soil carbon; Forest management; Climate change; Soil fertility

1 Introduction

From 1990 to 2015, forestry spanned 3999 million hectares, down 33% from 4128 million. The tropics account for 45 percent, or 728 million hectares, of the globe's forests, followed by the boreal, temperate, and subtropical domains. (FAO, 2020). Yet, research reveals that tropical deforestation is caused by farming and industry (Raihan, 2023a), particularly in South America and Africa (FAO, 2020). Between 2010 and 2020, Africa lost 3.9 million hectares of forests. South America followed with 1 million hectares (FAO, 2020). Pan et al. (2011) found that the forest sink is comparable to the terrestrial sink from fossil fuel emissions. Forests store 80% of aboveground C and 70% of soil organic C (Raihan et al., 2021a). Forest management is essential for carbon sequestration, soil rejuvenation, and GHG emission reduction (Ontl et al., 2020; Raihan et al., 2022a). Forest ecosystem C management involves dynamics, pool size, and chemical forms.

Silviculture (tree species selection and rotation times), gaps (number of trees planted at once), turbulence (pest influxes, wind pitch, and wildfires), air contamination, and water management all affect forest management and carbon sequestration (Raihan et al., 2019). Modeling predicted forest expansion over ten European landscapes over the next century showed how European forest management affects ecosystem services including carbon sequestration, biodiversity, and sustainable timber output (Biber et al., 2020). The study found that climate change- related storms and droughts should be considered. In the eastern US, Community Land Model 4.5 prioritizes forest area for preservation by considering drought and fire vulnerability and relativizing the C priority to biodiversity, unlike in the west (Buotte et al., 2020)Preserved temperate forests (with medium to high C storage capability) in the western US appear to be equivalent to 27-32 percent of the worldwide worldwide mitigation capacity previously found for boreal and temperate forests, enough to absorb fossil fuel emissions for around 8 years (Buotte et al., 2020). The US forest inventory lists 1.4 trillion plants from over 130,000 federal forestlands, demonstrating that tree planting can enhance C sequestration capacity and reduce CO2 emissions (Domke et al., 2020). Tropical forests store carbon underground and above (Raihan and Tuspekova, 2023). They store the most carbon (91 tha-1) and produce the most wood (121 m3ha-1) of any ecosystem. Carbon-rich boreal forest soils lack them (Pan et al., 2011). Tropical woods can gather and store the most C because they have the greatest C concentration (Raihan et al., 2018; Raihan, 2023b). Figure 1 simplifies the global C cycle in tropical forest ecosystems. Their potential to sequester atmospheric C has increased the greatest during the past two eras, making them decisive to climate change mitigation (Fernández-Martnez et al., 2019). MACC-II and Jena CarboScope atmospheric inversion models and 10 dynamic universal plants models assessed this capacity. The findings suggest that ecosystems' carbon dioxide absorption may fight against global warming and climate change (Raihan et al., 2022b). Therefore, forest management is vital for C sequestration, land restoration (destroyed woodlands and additional domains), climate change mitigation, natural forest preservation, and biodiversity (Raihan and Tuspekova, 2022a).

By 2020, global forest C was predicted to reach 662 Gt (or 163 tha-1) (FAO, 2020). Forest soils contain 50% of terrestrial ecosystems' organic carbon (Mayer et al., 2020; Raihan and Said, 2022). Tropical forest soils contain three times more carbon (C) than air or plants. Forest biogeochemical cycles of carbon (C), water, and other factors affect global climate (Malhi et al., 2020). Forest ecosystems need adaptability and resilience to survive climate change (Begum et al., 2020; Raihan and Tuspekova, 2022b; Raihan et al., 2023a). Tropical forests fear climate change may dry them off. Yet, during the past two decades, they have gotten even better at sequestering atmospheric C, improving their ability to mitigate climate change (Fernández- Martnez et al., 2019; Raihan et al., 2022c). Malhi et al. (2020) discovered that land-use alteration, including habitation loss and overexploitation, affects ecosystems more than climate change. Rising population, soil fertility decline, and food shortages cause land degradation, which worsens the consequences of climate change on forest ecosystems in tropics (Jaafar et al., 2020; Raihan and Tuspekova, 2022c; Raihan et al., 2023b). The UN and other international initiatives (such as the "Bonn Challenge" and the "UN-Decade on Ecosystem Restoration" [2021-2030]) have been calling for land dilapidation detachment and the UN-Sustainable Development Goals for years. Natural or human-caused soil deterioration has four main types: chemical (salinization, acidification, leaching, pollution, nutrient depletion, etc.); biological (drop in soil organic material, damage of soil biodiversity, demise of soil C sink bulk, etc.); physical (compaction, runoff and erosion, desertification, etc.); ecological (nutrient cycling disruption, hydrological cycle perturbations, input use efficiency decline, etc.). Forest management and tree planting on degraded land increase soil and ecosystem C pools (Raihan and Tuspekova, 2022d). Studies on SOC have increased during the previous two decades (Mayer et al., 2020; Ali et al., 2022). Most publications and articles discuss SOC and its function in nutrient cycling, soil fertility, crop production, climate change, and

land restoration (Lal, 2013). The "4 per 10000 Initiative," also known as Soils for Food Security and Climate Change, was proposed at the 21st Conference of the Parties (COP) of the UNFCCC, drawing worldwide attention to soil (Soussana et al., 2019). Climate change and land degradation threaten agriculture, forestry, food production, and sustainability (Raihan and Tuspekova, 2022e). Therefore, the 22nd COP focused on fertilizer usage and manure management for sustainable and resilient agriculture. However, SOM serves as a reservoir for nutrients and is commonly utilized as an indicator for assessing soil fertility, as well as soil health in terms of its chemical, physical, and biological properties. SOC comprises 50-99% of the total amount of SOM. The pool of SOM is relatively stable and has a mean residence time of several decades. Therefore, it may take more than 2 years to accurately evaluate changes in SOC. Nevertheless, alterations in the biodegradability of SOM or the biomass of microorganisms can be easily observed within a shorter timeframe. Soils are a crucial reservoir of carbon, serving as both a source and sink of carbon (Raihan et al., 2022d). The factors influencing this include climate, soil texture, soil acidity, vegetation cover, biomass inputs, management practices, as well as soil depth, initial carbon levels, and soil type (Marin- Spiotta and Sharma, 2013; Akpa et al., 2016). The quality of SOM is improved through the process of SOC accretion, particularly when it is safeguarded by fine soil fractions (Eclesia et al., 2012; Sang, 2013). The decline in SOM quality is attributed to increased carbon mineralization resulting from climate, management practices, or edaphic factors (Bonfatti et al., 2015; Cook et al., 2016). Soil carbon sequestration has the potential to enhance soil fertility, increase crop production, and mitigate climate change by reducing greenhouse gas emissions (Paustian et al., 2016; Raihan, 2024a). The storage of SOC plays a crucial role in controlling, mitigating, and halting land degradation (Raihan, 2023c). Shimamoto et al. (2018) conducted a global meta-analysis on the restoration of ecosystem services in tropical forests. They found that restoration efforts were particularly effective in enhancing biodiversity protection in degraded former pasture land, as well as in increasing carbon storage in degraded former agricultural plots. The authors posited that the appropriate approach expands the restoration of ecosystem services in degraded tropical forests. Research on SOC should prioritize monitoring and assessment in areas with accelerated decomposition, such as tropical forest ecosystems experiencing land degradation exacerbated by large stocks and climate change (FAO, 2020; Raihan and Tuspekova, 2022f). Sustainable soil management, specifically through carbon sequestration, is a crucial component for restoring and sustaining soil health, as well as mitigating climate change and restoring land (FAO, 2020; Raihan et al., 2023c). Therefore, the present study will primarily focus on SOC management in tropical forest ecosystems, which are currently the most threatened forest ecosystems. This research aims to address both climate change mitigation and land degradation prevention/restoration. Afforestation on agricultural, grassland, or city-edge property may affect the ecology and economics. Introducing nitrogen-fixing species and managing organic wastes promote SOC sequestration and nutrient cycling, which help forest ecosystems thrive. Tropical soil organic carbon (SOC) amounts and qual-

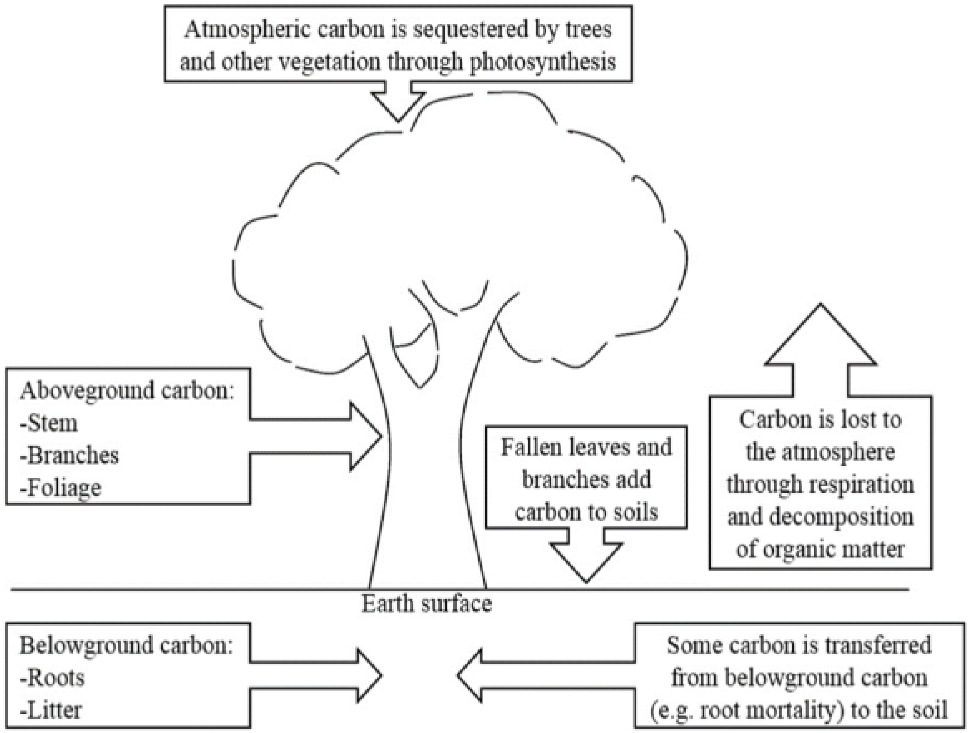

Figure 1: Carbon sequestration in forests.

ity have been understudied, despite their potential to promote C sequestration and avoid land degradation through their links to nitrogen (N) and phosphorus (P). This study explores the influence of SOC quantity and quality (i.e., SOC connected with N or P cycles, C stocks, stable versus labile C forms) on land rehabilitation in tropical forest ecosystems. Reforestation and afforestation of marginal and degraded tropical forest ecosystems may improve soil healthiness, climate change, and land degradation.

2 Methodology

2.1 Systematic literature review

An extensive literature review was performed to delve into the relationships between land restoration, SOC, and other elements in tropical forest ecosystems, and soil carbon management and storage. This helped to reveal how crucial forest management is to the quality and quantity of carbon sequestered and land recovered in tropical ecosystems. As can be seen in Figure 2, the review adhered to the tenets of the systematic review methodology. By deconstructing the research questions into their component concepts, it is possible to develop a set of search terms that would allow to conduct a thorough and representative search of the literature on the topic of handling soil C and its relation to climate change plus land refurbishment in tropical forest ecosystems. Database classification terms have also been taken into account, along with synonyms, single and plural models, broader terms, alternative spellings, and more specific terms.

2.2 Criteria for Inclusion and Exclusion

This study conducted a systematic literature review to address the potential relationships between adaptation to climate change and resiliency in tropical forest ecosystems, the interplay between SOC and other nutrient pedaling, and the associations to land refurbishment. All of the retrieved publications and papers were evaluated based on a set of encoded measures for insertion and elimination of primary research paper. This investigation included primary examinations that assess SOC managing in the context of mitigating climate change or rehabilitating degraded land in tropics. The qualitative and quantitative secondary literature on forests in tropics is also discussed. After conducting a comprehensive search of the relevant literature, 86 articles published between 1990 and 2022 were chosen for further analysis. The papers came from the academic aggregators Google Scholar, Scopus, and Web of Science (WOS). To build a paradigm for future forest research and management that takes into account both carbon sequestration and land degradation restoration, this paper provides an overview of the links between these two processes in forests in tropics over the extended period.

This study solely used research articles published in peer-reviewed journals to assure the quality of the results, which provide a foundation for future tropical forest research and management taking into account carbon sequestration and land degradation restoration. These papers were then reviewed to determine if their primary topic was similar to that of the current investigation.

Figure 2: The procedure of systematic review conducted by the study.

2.3 Extraction of Data and Evaluation of Quality

Even though no precise instrument for quality valuation was utilized, the review safeguarded that evidence mined from the research papers (meeting the insertion conditions) was applicable (useful), and legal (close to the actuality) by evaluating the research etiquette and queries, foundations of information, and the choice of the appraisal.

3 Results and Discussion

3.1 Enhancing Soil Carbon through Tropical Forest Management

Owing to their vital function in the universal C sequence and various ecosystem provisions, incorporating C sequestration (in biomass and soil), forests require careful management to increase sequestration of C and approve soil vigor (Raihan, 2023d). According to Fernández-Martínez et al. (2019), tropical forest ecosystems have improved in this regard during the past two decades due to their increasing capability to sequester carbon. Depending on how the forest is managed, sequestration of C may occur in tropical forests. Table 1 presents a glance of sequestration of C in some tropical forests. The rate of SOC sequestration is controlled by the tree species, type of soil and environment, climate and geographic factors, and has been examined extensively (Mayer et al., 2020). C sequestration in biomass and soil is a common result of managing forest ecosystems through afforestation and reforestation, but the efficacy of these practices is highly dependent on edaphic parameters in addition to those listed above (Dou et al., 2016; Raihan, 2023e).

Soil C storage has been improved, especially in macroaggregates (>2000 m), as a result of afforestation of large uncultivated regions in central China with woodland, shrubland, and agricultural plants (Dou et al., 2016). In compared to pure acacia and eucalypt stands, which contained 16.7 and 15.9 tha^{-1}, respectively, the soil carbon stocks in the top 25 cm of the mixed-species stands, which contained 50% acacia and 50% eucalypt, increased to 17.8 $\pm$ 0.7 tha^{-1}, after afforestation of native tropical savannas. Carbon stock under A. mangium plantations in Malaysia increased from year 1 (74.9 tha^{-1}) to years 3 (89.9 tha^{-1}) and 5 (138.9 tha^{-1}) by 15 tha^{-1} and 64 tha^{-1}, respectively, despite the soil type being loamy siliceous with low fertility (Lee et al., 2015). A framework for long-term sequestration of C in the Makiling forest reserve and the Philippines was given by Camacho et al. (2009). The authors recommended reforestation, especially of fast-growing and high-timber species, to increase C sequestration. Strategies for reforestation and afforestation, such as the introduction of fast-growing Natural fertilizer substitutes (NFS) or bacteria that fix nitrogen, or the leaving of organic residues on the field after harvesting wood, can enhance SOC stocks additionally in coarse-textured soils that have a high rate of SOC decomposition (Dubliez et al., 2018; Mayer et al., 2020). This is because the introduction of fresh organic residues or N-rich organic matter alters microbial activity and/or bacterial makeup (Bini et al., 2018; Pereira et al., 2018). Carbon and nitrogen accumulation in soil microbes demonstrate that after 27 months, combined plantation of acacia and eucalyptus had exceeded those of pure or treated stands. Plants that fix N can promote soil fertility and carbon sequestration in tropical forest plantations by interacting with biota and nutrient availability (Bini et al., 2018; Raihan and Bijoy, 2023).

There was a significant difference between the climate mitigation capability of secondary spontaneously regenerated forest and managed forest plantations of 42 to 47 years old Aucoumea klaineana, Tarrietia utilis, Cedrela odorata, and Terminalia ivorensis in Ghana's moist and wet zones (Brown et al., 2020). For C sequestration and storage purposes, natural forests continue to excel (Raihan, 2023f). An analysis published in support of developing forest management techniques to improve C sequestration in forest soils found a total of 23.48 million metric tons of carbon with a C sequestration capability of 4 tC $ha^{-1}yr^{-1}$ (Chinade et al., 2015). Soil carbon (C), which accounts for 36-46% of the Malaysian forest ecosystem, was not factored in (Chinade et al., 2015). The SOC has been considered in different settings (Forest Survey of India, 2017; Joshi et al., 2020). The total amount of SOC, the largest pool, rose from 3,968 million tons in 2015 to 3,979 million tons in 2017; the total amount of aboveground C stock rose from 2,220 million tons in 2015 to 2,238 million tons in 2017; and the total amount of belowground C stock fell from 695 million tons in 2015 to 699 million tons in 2017. Joshi et al. (2020) also evaluated SOC sequestration in damaged and undisturbed community forests in Nepal's Terai region close to the city of Kanchanpur. The non-degraded community forests sequestered 54.21 $\pm$ 3.59 tha^{-1} of SOC and had a total carbon stock of 301.08 $\pm$ 27.07 tha^{-1}, while the degraded community forests se-

Table 1: Sequestration of carbon in some tropical forests.

Location	Forest type	Sequestrated C	Sources
Panama	Teak plantation	3-41 Mg C ha^{-1}	Derwisch et al. (2009)
Colombia	Mixed forest	122-141 Mg C ha^{-1}	Saatchi et al. (2011)
Venezuela	Mixed forest	118-139 Mg C ha^{-1}	Saatchi et al. (2011)
Bolivia	Mixed forest	84-94 Mg C ha^{-1}	Saatchi et al. (2011)
Myanmar	Mixed forest	146-157 Mg C ha^{-1}	Saatchi et al. (2011)
Papua New Guinea	Mixed forest	147-153 Mg C ha^{-1}	Saatchi et al. (2011)
Vietnam	A. mangium and Eucalypt plantation	11.5 t C $ha^{-1}yr^{-1}$	Sang et al. (2013)
Indonesia	Production forest	46.32 t C ha^{-1}	Situmorang et al. (2016)
Cameroon	Mixed forest	318 t C ha^{-1}	Zapfack et al. (2016)
India	All types of forests	3979 million tons	Indian State of Forest (2017)
Brazil	Eucalypt and A. mangium plantation	C accretion	Pereira et al. (2018)
Ghana	Plantation forests	56-70 Mg Cha^{-1}	Brown et al. (2020)
Nepal	Community forests	301 tha^{-1}	Joshi et al. (2020)
Peru	Agroforestry	106 Mg C ha^{-1}	Aragón et al. (2021)
Thailand	Teak plantation	45-82 Mg C ha^{-1}	Chayaporn et al. (2021)
Costa Rica	Natural forest	18210 tons	Paniagua-Ramirez et al. (2021)
Malaysia	All types of forests	157.5 t C ha^{-1}	Raihan et al. (2021b)
Congo	Peatland	634 Mg C ha^{-1}	Crezee et al. (2022)

questered only 42.55 ± 3.10 tha^{-1} of SOC and had a total carbon stock of 152.68 ± 22.95 tha^{-1}. A study of forest management in a 35-year-old teak plantation in western Thailand emphasized the plantation's ability to absorb C in aboveground biomass and help to reducing the impacts of climate change (Chayaporn et al., 2021). The annual CO_2 sequestration ranking was found to be between 28 and 43 tons CO_2 $ha^{-1}yr^{-1}$, with an average of 36.7 tons CO_2 $ha^{-1}yr^{-1}$ when the net ecosystem exchange in a Thai rubber tree plantation (Hewea brasiliensis Müll.Arg.) was measured using the eddy covariance method (Satakhun et al., 2019). Over 24.9 kilograms of carbon dioxide were stored in the soil for every kilogram of natural-rubber latex harvested from these plants, according to the study.

Yet, SOC sequestration is not necessarily the result of managing forest ecosystems. One factor that may limit the amount of SOC that can be sequestered in forest ecosystems is their advanced age. The San Luis Campus (Monteverde) in Costa Rica found that secondary woods are more able to absorb carbon (C) through tree growth than primary forests (Paniagua-Ramirez et al., 2021). Three short eucalypt plantation rotations (only 6-8 years) after decades of agricultural output and pasture in Brazil depleted soil carbon stocks along a large geographical gradient (Cook et al., 2016). The ability of forest ecosystems to restore damaged lands and mitigate climate change may be compromised by conditions that either boost or inhibit C sequestration (Malhi et al., 2020; Raihan, 2023g). The soil, weather, and plants are all elements that have a role. Sayer et al. (2019) found that 15 years of litter stores in a mature lowland tropical forest in Panama did not raise C stocks. In humid tropics, SOC storage depends on soil mineral stability. After three rotations, 21 years after planting, a sand-based eucalypt plantation in the Congolese coastal plains lost C accretion (Epron et al., 2015). Carbon accretion was observed at the completion of the first phase of eucalyptus and acacia plantings after 7 years in one length of the Congolese coastline, but the percentage of C in POM decreased at 5 relatives to two years into the second rotation. Due to the plantation's fresh organic waste's high N content and sandy soils' low C saturation capacity, SOM turnover is predicted to increase (Epron et al., 2015).

High decomposition rates slow C sequestration. Environment (drought, extended dry season), management (leaving organic leftovers on the field after wood collection), and reforestation cause this (Epron et al., 2015; Akpa et al., 2016; Raihan, 2023h). Marin-Spiotta and Sharma (2013) analyzed soil carbon data from 510 tropical afforestation and reforestation sites in 32 nations and territories. The study found that climate change, not land use or forest age, drives soil C variability in successional and forest plantation environments. This study demonstrated that soil C reserves in tropical forest plantations were not correlated with forest age. Campo et al. (2016) conducted a study comparing the soils of Mexico's tropical forests under different precipitation patterns, and they hypothesized that soils exposed to longer drought periods might have a higher content of resistant biopolymers, resulting in an accumulation of organic matter due to selective preservation. It may take decades for forest ecosystems to recover from the potential loss of SOC if this resource has been diverted. It took more than two decades, according to research by Cook et al. (2014) in Southeast Brazil, for soil SOC stores of native forests to return to pre-conversion levels after they were converted from mature forests to forest plantations and grasslands. In their study of primary and secondary seasonally dry tropical forests in central Mexico, Saynes et al. (2005) found that complete reinstatement of soil C and N dynamics did not occur until 60 years into secondary succession. Thirty years after establishing a plantation or pasture at 27 locations in South America (Brazil, Argentina, and Uruguay), researchers noticed a shift in SOC levels (Eclesia et al., 2012).

There are a variety of obstacles that make it difficult, if not impossible, for tropical forest ecosystems to absorb C, uphold land refurbishment, and moderate climate change (Raihan, 2023i). Possible causes include the knowledge gap and measurement error in some areas, as well as socioeconomic influences (correlated to social, economic, environmental, and political contexts). Kalimantan's degraded forests, which are threatened by palm oil plantations and peatland fires, have a storing prospective of between 0.8 and 1.1 PgC, according to emission aspects assessed using lidar or a random forest map (Ferraz et al., 2018). Kalimantan's damaged forests, the authors reasoned, had a much greater storage potential than South America's second-growth forests (35.33 Mg Cha^{-1}).

3.2 SOC and Land Degradation Restoration in Tropical Forests

Nutrients like nitrogen and phosphorus can affect the total amount and longevity of SOC that is sequestered. Nitrogen availability is linked to carbon dioxide storage (Liu et al., 2018). Several studies on soil C dynamics suggest that N deposition can enhance soil C sequestration through various mechanisms. These mechanisms include reducing the decomposition of plant litter and soil organic matter, inhibiting soil respiration, and altering microbial enzymatic activity (Lu et al., 2021). N-fixation enables C to accumulate in mixed-species plantations, which has been linked to high rates of C sequestration (Bauters et al., 2015; Dubilez et al., 2018). By increasing plant development below and above ground, raised soil N levels can increase SOC accumulation (Fornara et al., 2013). N-fixing plants may potentially enhance SOM permanency by inducing biotic alterations facilitated by the incorporation of N-rich litter (Bini et al., 2018; Pereira et al., 2018). In two tropical forest soils, Cusack et al. (2010) found that N additions increased SOC stores in Puerto Rico. Although nitrogen deposition and climate change are mentioned as global change agents affecting the stability of sequestered SOC in forest ecosystems in the tropics, the authors conclude that much is yet understood.

Sequestration of SOC is simultaneous to phosphorus (P), a key ingredient for vegetation growth, lumber expansion, and agricultural output. Access to phosphorus is linked to SOC mineralization in tropical forests, despite the fact that phosphorus is a limiting element in many of these ecosystems (Bachega et al., 2016). Decomposer starvation/inhibition and low microbial biomass/activity resulted from the stoichiometric (N:P) imbalance brought by low P concentrations in the litter of A. mangium, a natural fertilizer substitutes (Santos et al., 2017). Compared to the soil and the material they break down, microbial communities have low C:N:P ratios and hence require high amounts of N and P. As a result, bacteria can only store so much nitrogen and phosphorus before they begin to release it (Schleuss et al., 2020). Soil nitrogen (N) availability is low, whereas phosphorus (P) demand is considerable (Schleuss et al., 2020). Synergistic effects between P and C accumulation are typically observed in diversified species stands with Sensitive types, as compared to monoculture plantation.

The superiority of sequestered SOC is also affected by the presence of animals and microorganisms in the soil (Bini et al., 2018; Pereira et al., 2018; Santos et al., 2017). Litter decomposition in monocultures was regulated by water-soluble components and lignin concentration, but in tropical forests, decomposer activity was limited by energy or P availability. A change in the makeup of soil microorganisms and bacteria is associated with increased microbial endeavor in litter and soil, indicating more effective nutrient cycling (Bini et al., 2018). In two N-rich tropical forest soils, C cycling was affected by microbial community composition, enzyme capabilities, and soil C chemistry in Puerto Rico (Cusack et al., 2010). It shows how microorganisms improve SOC sequestration and relate SOM to nutrients like nitrogen and phosphorus. Tropical forest soil processes produce stable, less mineralized C, which helps mitigate climate change and restore land (Baccini et al., 2017; Raihan, 2023j). Figure 3 shows how established sequestered SOC connected to additional nutrients besides good soil elements can uphold SOC sequestration and related co-benefits.

Stable segregated SOC and its subsidies on land restitution are augmented by the dynamics of additional nutrients including N, P, and S. The connection between C and N, P, and S for improved physical (cluster) and chemical (N, P, and S disposal) properties, as well as to turn volatile C from agricultural and animal leftovers into stable SOM (Lal, 2013). The accessibility of inorganic nutrients like N, P, and S is decisive to the sequestration of C hooked on the further settled agreed segment of the SOM consortium, and this is true regardless of soil type or C responses. McDonald et al. (2018) shown robust interactions between decomposition proportions, photosynthesis, and soil's capacity to hold carbon, nitrogen, and phosphorus. This partially addresses the second question given by the review by showing that there is a relationship between the quality of the SOC that has been sequestered (its linkage to other N, P nutrients), land retrieval, and the long-term assistances in forest tropical ecosystems.

Degraded Brazilian woods have been turned into carbon-sequestering restored areas with the help of legume vegetation, nitrogen-fixing microbes, and arbuscular mycorrhizal fungus (Macedo et al., 2008). Assuming the deforested area had identical C stocks to the restored area, the authors discovered a 23 Mg ha^{-1} increase in soil C stock and a 1.7 Mg ha^{-1} rise in N stock after 13 years of legume tree planting (Macedo et al., 2008). Natural fertilizer substitutes (NFS) are often utilized to restore agriculturally unsuitable or marginal soils by increasing chemical fertility (Raihan, 2024b). Increasing nitrogen (N) contents and carbon (C) status both contribute to this goal (Wang et al., 2010; Chen et al., 2011). Restoration of southern Chinese soils with Acacia mangium and A. auriculiformis enhanced carbon and nitrogen cycling (Wang et al., 2010). Chen et al. (2011) observed that in Guangdong Province, Southern China, Acacia crassicarpa stands demonstrated bigger carbon sinks and greater SOC stocks than Eucalyptus urophylla stands (330$\pm$76 C m^2 yr^{-1} vs 1960$\pm$178 g C m^{-2} yr^{-1}). Comparing A. mangium and E. urophylla plantings, resultant woods, and meadows across Vietnam's edaphic and climatic gradients reveals a favorable correlation between aboveground biomass output and soil C, N, and P levels (Sang et al., 2013; Raihan, 2023k). Ahmed et al. (2010) in Malaysia found that total C and P concentrations rose from ages 0 to 6, 12, and 17. Carbon and phosphorus can be absorbed by forests that have been restored with native trees, according to studies.

Unexpected events have the potential to prevent the utilization of NFS plantations for C sequestration and land restoration. The soil's clay content, annual precipitation, and average temperature all have an effect on soil C stocks in Brazilian eucalypt plantations; this may

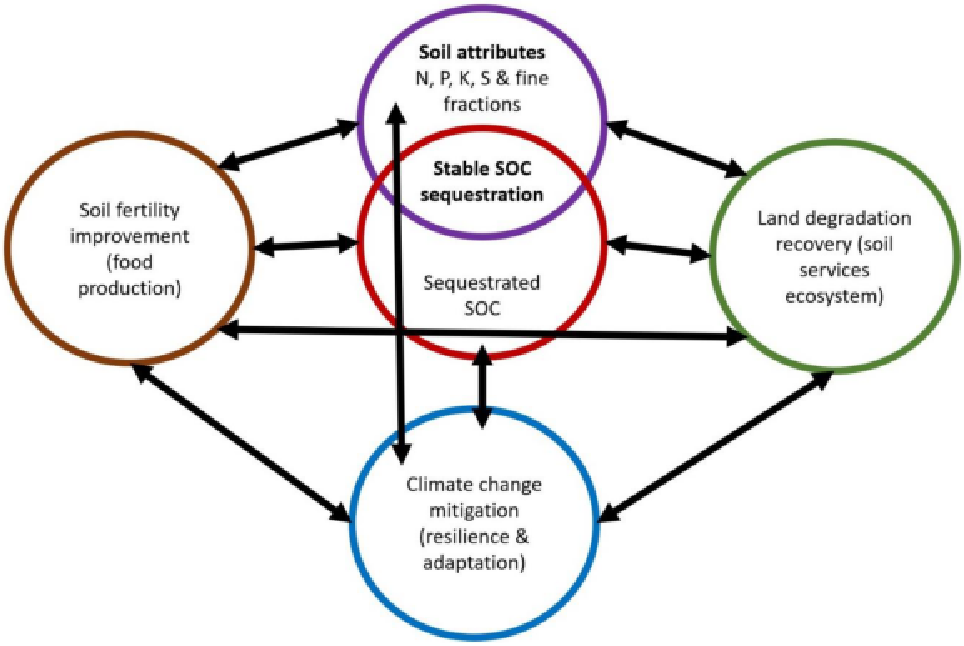

Figure 3: Conceptual framework of stable SOC sequestration and its co-benefits.

be true for other species as well (Cook et al., 2014). From a depth of 0-30 cm beneath 18-26 years old eucalypt planting, Cook et al. (2014) observed that SOC stock diminishes with planting age in tropical and subtropical contexts, reporting a fall from an average of 29 Mg ha^{-1} (0.87 Mg ha^{-1}yr^{-1}). The present study's findings show that SOC sequestration occurs as a result of the managing of organic deposits or the introduction of NFS in the restoration or refurbishment developments of tarnished lands or forests.

4 Conclusions

This review focused on forest management, specifically methods that boost sequestration of SOC and restoration of land, in order to improve the condition of SOC sequestered in tropical forest ecosystems (interactions to other nutrients driven by soil biota). However, due to the fact that it is dependent on edaphic and additional influences like land-use record, climate, ecosystem, and even intrinsic features, SOC sequestration may not always occur. This is because of the fact that it is possible for SOC to be sequestered in a system. C sequestration management is essential if one wishes to restore degraded lands in tropical ecosystems, mitigate the effects of climate change, and preserve the health of the soil. In the process of sequestering carbon, soil biota plays an essential part and have significant connections to other soil fractions and nutrients (including nitrogen, phosphorus, and sulfur). The management of forest ecosystems (planting or natural) associated with specific methods (initiating NFS, overseeing organic deposits, etc.) that generally increase sequestration of SOC and its superiority can result in long-term benefits for the mitigation of climate change and the restoration of land. These benefits can be achieved through the management of forest ecosystems (balanced C, connection to N, P, and soil segments).

Conflict of Interest

The author declares no conflict of interest.

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Research Article

Current status, Threats and Strategic solutions for Ethiopia's Biosphere Reserves

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Abstract

The biosphere is where all life forms and biotic environments live and interact. Biosphere reserves have different ways in which people live, work and interact with each other and with nature. The main objective of this paper was to assess the current status, risks and develop plans to ensure the longevity of Ethiopia's biosphere reserves. These reserves, recognised by UNESCO's Man and the Biosphere (MAB) programme, are designated areas that promote and showcase the balanced coexistence of humans and nature. Since 2010, Ethiopia has established five biosphere reserves, which are monitored globally by UNESCO. Sheka, Majang, Kafa, Yayu and Lake Tana are home to a wide variety of biological species, with 779,381ha representing just 0.1% of the world's biosphere reserves. These reserves play a key role in resolving conflicts between different stakeholders in a particular landscape through their involvement, participation and cooperation. They are also places where people can access information on sustainable development. Ethiopia's biosphere reserves face challenges such as land use change, deforestation, degradation, logging, agricultural expansion, investment, overgrazing, fuelwood, charcoal and other impacts. The sustainability problems in Ethiopia's biosphere reserves stem from the lack of an effective management strategy and insufficient ownership by the various stakeholders. The government and the community should prioritise the promotion and development of biosphere reserves and establish a management plan for each one. Ethiopia's biosphere reserves play a crucial role in conserving biodiversity. It is important that the government and local communities work together to promote development, establish management plans, involve local people, balance conservation and sustainable use, and provide incentives. In the future, institutional restructuring will need to address issues related to lack of ownership.

Keywords: Biosphere, Biosphere Reserves, Man and the Biosphere, Sustainable Development

1 Introduction

A biosphere reserve is defined as a place where humans and nature coexist and interact for mutual benefit (Verlag and Jentzsch-Cuvillier, 2009). The biosphere refers to all living things on Earth, the space they inhabit and the life-supporting systems (atmosphere, hydrosphere) necessary for sustainable life as we know it (Huggett, 1999; Levit, 2011). The biosphere is where living organisms exist and interact. People live, work and interact within biosphere reserves, influencing resource use and future prospects. Cultural diversity is linked to biodiversity (Bridgewater and Babin, 2017; Article, 2017; Pool-Stanvliet and Coetzer, 2020). Ethiopia is rich in biodiversity resources, traditional knowledge and centres of origin and diversity of many biodiversity crops and others. Some of the reasons for diversity are found in Ethiopia's altitude range (116m to 4,620m asl).

The biosphere reserve is a legally protected area where limited human activities are allowed, designated by UNESCO's Man and the Biosphere Programme (MAB). In 1974, a task force of the UNESCO MAB programme developed the concept of biosphere reserves, and the networks were established and launched in 1976 (Kennea, 1975; UNESCO, 2020). The MAB International Coordinating Council (MAB ICC) designates biosphere reserves (Hedden-dunkhorst and Schmitt, 2020). Under UNESCO's Man and Biosphere (MAB) programme, the first biosphere reserves were designated in eight countries in 1976 (Van Cuong et al., 2017). The biosphere is the part of the Earth occupied by living organisms, where living systems use and transform non-living or abiotic materials, forming a regenerative unit (Danilov-Danil'yan et al., 2009). Several biosphere reserves around the world are currently being studied from different perspectives. Today, the global number of biosphere reserves has doubled to 738 reserves in 134 countries (UNESCO, 2020; Pool-Stanvliet and Coetzer, 2020).

The biosphere reserve protects biodiversity and genetics and supports ecological and environmental research and education (Wehrden, 2020). International guidelines for biosphere reserves have also been established (Raszka and Heldak, 2023). The conservation objectives of biosphere reserves include biodiversity and cultural richness, economic and social development, and logistical support for research and education, all of equal importance (UNESCO, 2020). Ethiopia is a key hub of rich biodiversity hotspots worldwide, with diverse physiographic, attitudinal, climatic and edaphic systems that support a wide variety of habitats and indigenous flora and fauna (Kelbessa, 2005; Sewale and Mammo, 2022); due to its extensive geographical range, Ethiopia stands as a core of biological diversity (Kelbessa, 2005).

Interdisciplinary approaches to understanding and managing change and interactions between social and ecological systems are being tested in different locations. Different strategies for conflict prevention and biodiversity management are being explored. However, many challenges have been encountered in all of Ethiopia's biosphere reserves. These include unclear land use policies related to natural resource management and conservation, deforestation, degradation, logging, agricultural expansion, investments, megaprojects, overgrazing, firewood, charcoal and other factors. It is essential that government and communities prioritise the promotion and development of biosphere reserves and develop specific management plans for each one. The main objectives of this review paper are to assess the current status, threats and strategic solutions in the biosphere reserve area of Ethiopia.

2. Methods

The literature review methods included reading, analysing, evaluating and summarising scientific literature (journals and articles) on the current status, threats and strategic solutions for Ethiopia's biosphere reserves. A systematic approach was adopted for this study to ensure a comprehensive understanding of the key issues surrounding Ethiopia's biosphere reserves. The literature review was conducted using various academic databases and search engines to gather relevant information published in different years. The identified literature was then carefully reviewed to extract valuable insights and perspectives on the topic. This process helped to identify the current status, prominent threats and potential strategic solutions for enhancing the conservation and sustainable management of Ethiopia's biosphere reserves.

3. Results and discussion

3.1 The Status of Biosphere Reserve Area

3.1.1 Global history of biosphere reserves

The United Nations Educational, Scientific and Cultural Organisation (UNESCO) initiated the Man and the Biosphere (MAB) programme in 1971 with the aim of improving the relationship between people and their natural environment. The programme focuses on a human-centred approach to conservation, emphasising the interaction, cooperation and trade-offs between 'conservation' and 'use' of the environment. It also establishes links between people and nature to achieve development goals, implemented in areas designated as biosphere reserves (Pool-Stanvliet and Coetzer, 2020).

The first country to establish and register biosphere reserves was the Democratic Republic of Congo in 1976, and the first biosphere reserve was established at Yangambi, home to 32,000 species of trees and endemic species such as forest elephants (Loxodonta cyclotis) and red river dolphins (Potamochoerus porcus). The Yangambi Biosphere Reserve supports activities such as sustainable agriculture, hunting and mining. One of the newest biosphere reserves is the Yayu Coffee Forest Biosphere Reserve in Ethiopia. The area is mainly used for agriculture, where crops such as honey, timber and fruit are regularly cultivated, and covers 243,755 hectares (Mammadova et al., 2022; Alborzi Manesh et al., 2023). UNESCO designated 11 new biosphere reserves in 9 countries in 2023, including Chad, Georgia and Zambia for the first time. Spain also extended two existing reserves. This action brings the total number of biosphere reserves in the global network to 738 sites in 134 countries (Ishwaran, Persic and Tri, 2008).

There has been an almost linear increase in the establishment of biosphere reserves from 1976 to 2018. Due to the desire to achieve sustainable development, countries understand the benefits of biosphere reserves in the conservation and sustainable management of forest

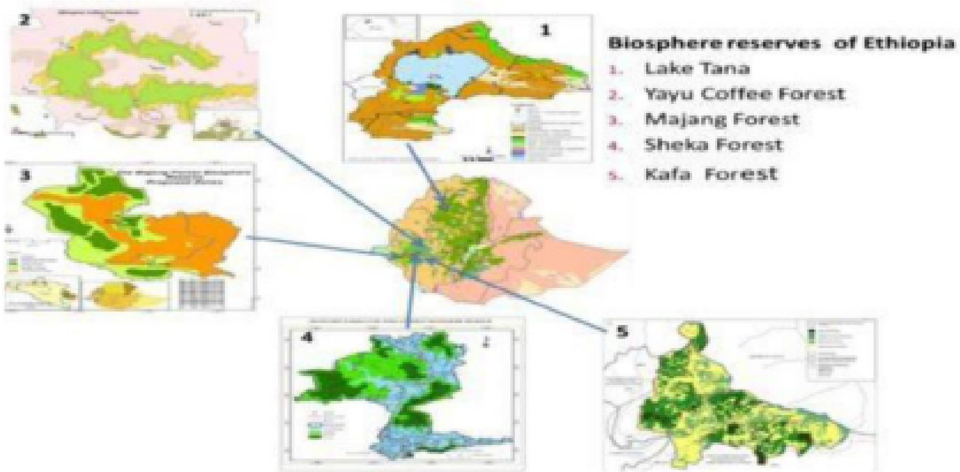

Figure 1: The Global History of Biosphere Reserves. Source: UNESCO, 2021.

resources (Reed, 2016). Different studies around the world have reported different statistical figures for biosphere reserves (Figure 1).

There are currently 738 biosphere reserves in 134 countries, with 22 transboundary sites designated at the global level (Bridgewater and Babin, 2017; Article, 2017; Pool-Stanvliet and Coetzer, 2020). The reported differences between 2002 (411 biospheres and 94 countries) and 2021 indicate an increase of 327 biosphere reserves (79.5%) and 40 countries (42.5%).

3.1.2 Biosphere reserves and other protected areas

Biosphere reserves are large areas that include national parks and wildlife sanctuaries. They create a high proportion of natural habitats with constitutional protection under specific policies and arrangements (Table 2) (Reed, 2016).

3.1.3 History of Ethiopia's Biosphere Reserves

A biosphere reserve is a collection of ecosystems (Bridgewater and Babin, 2017; Article, 2017). It is a place where people live, work and interact with each other (and with nature) in many ways (König et al., 2022). Biosphere reserves are a much broader concept than protected areas; they act as living laboratories for sustainable development (Wehrden, 2020). The biosphere reserve is a special region; not only the wildlife, but also the landscape, culture and people living there make the region deserving of the UNESCO designation (Vaňová et al., 2023). The biosphere reserves balance environmental protection and sustainable development (Bridgewater and Babin, 2017); and are learning places for sustainable development (Ayalew and Alemu, 2021; Clüsener-Godt, 2016).

Ethiopia's biosphere reserves are established and recognised by UNESCO's Man and the Biosphere (MAB) programme to promote and demonstrate balanced relationships between people and nature. Ethiopia has five globally recognised sites, namely Kafa Biosphere Reserve, nominated in 2010, Yayu Biosphere Reserve, nominated in 2010, Sheka Biosphere Reserve, designated in 2015, and Majang Biosphere Reserve, designated in 2017 (Tadese et al, 2021), on plant diversity, challenges and conservation efforts in the Majang, Kafa, Sheka and Yayo Biosphere Reserves in southwestern Ethiopia (Dresen, 2011; Ayalew and Alemu, 2021; Tadese et al., 2021; chuit et al., 2021; Birhanu and Faris, 2022). Ethiopia's biosphere reserves cover approximately 779,381 hectares, representing 5.6% of Africa and 0.7% of the world.

3.1.3.1 Majang forest biosphere reserve

The Majang Forest Biosphere Reserve is located in the Majang Zone of the Gambella National Regional State, which was established in June 2017. The size/area of the biosphere reserve is 225,490 hectares (Ayalew & Alemu, 2021). It comprises four ecological zones: wet afromontane forest, transitional rainforest, cocopreteterminalia forest, wetlands, a lake and numerous rivers (Dresen, 2011). The biosphere reserve is home to a wide variety of plant and animal species. It plays a crucial role in conserving the genetic diversity of many useful plants, especially ensete (Ensete ventricosum) and yam (Dioscoria bulbifera). More than 130 bird species have been recorded in the region. Notable mammal species found here include leopard (Panthera pardus), caracal (Felis caracall), colobus monkey (Colobus guereza) and anubis baboon (Papio anubis). It is home to 39 threatened species on the IUCN Red List, including 5 birds, 3 mammals, 3 amphibians and 28 plant species. The Kafa Coffee Biosphere Reserve (Dresen, 2011) faces challenges such as illegal logging, urbanisation, commercial interests and lack of public awareness.

Table 1: The difference between biosphere reserves and other protected areas

Protected Areas	**Biosphere Reserves**
One type of land • A single category of land, usually relatively small in size and managed for a single purpose (e.g., nature conservation) One type of objective and function conservation One main category of interests • Natural • Landscape • Cultural • Historical One manager Well identified, directly in charge of the management of the territory	A mosaic of different types of land • Several categories of land, generally managed for different purposes (conservation, development, etc.) Overlapping of different types of objectives and functions • conservation, development, logistical support Multitude of interests • Often conflicting: farming, forestry, fisheries, tourism, science, local and national government Several managers Working more or less independently without consultation
Simple zonation Protection through regulation Management plan • Single planning scenario applied to a well-defined land area Single ecosystem approach Populations, ecosystem functioning Manager	Complex zonation • Three zones, transition area without demarcated outer limit Various means of protection • Regulation limited to the core areas, existence of management agreements or contracts Guide to Biosphere Reserve coordination harmonization of different planning scenarios for different areas in line with Biosphere Reserve concept; emphasis on local participation Landscape approach Complex of ecosystems Coordinator

Table 2: *
Source: (Bioret, 2001)

3.1.3.2 Kafa forest biosphere reserve

In 2010, the Kafa Biosphere Reserve was established in the Kafa Zone. The reserve covers an area of 540,631 hectares (Ayalew & Alemu, 2021). It is home to Ethiopia's remaining moist evergreen montane forests and lies within the Eastern Afromontane Biodiversity Hotspot. The wild coffee tree, Coffea arabica, grows naturally in the understorey of Kafa's montane forests and is occasionally harvested without proper management (Leßmeister et al., 2017). It is a biodiversity hotspot in the eastern mountains, with cultural and historical significance, caves and waterfalls, and a genetic pool for coffee arabica (Dresen, 2011; Fashing et al., 2022). The Institute for Biodiversity Conservation claims that the biosphere reserve contains a variety of habitat types. The distribution of these categories in the Kafa Biosphere Reserve is as follows. In 2009, an application for the Kafa Biosphere Reserve was submitted.

3.1.3.3 Yayu coffee biosphere reserve

Yayo (161,021 ha) is the largest area covered by a biosphere reserve in Ethiopia. Located in the Oromia Regional State, Ilu Abba Bora in southwestern Ethiopia was designated a biosphere reserve in 2010 (Birhanu and Faris, 2022). It is a biodiversity hotspot of cultural and historical significance, home to Arabica coffee, caves, waterfalls and an Arabica coffee genetic pool. The Biosphere Reserve nomination form indicates that a total of 450 higher plant species, 50 mammals, 200 birds and 20 amphibian species have been reported. More than 100 species of plants, birds and mammals are endemic to the area (Tadese et al., 2021). Challenges in the area include lack of integration between institutions and sectors, changes in land use such as mining, logging and fertiliser industries, and unsustainable demand and exploitation of natural resources by local communities surrounding the biosphere (Fashing et al., 2022).

3.1.3.4 Sheka forest biosphere reserve

The Sheka Forest Biosphere Reserve, located in the Sheka Zone of the Southwestern Regional State of Ethiopia, was established in 2012 and covers an area of 238,750 hectares. The forest in Sheka, which is also part of the Southwest Highlands Forests of Ethiopia, is important for the conservation of Afromontane forest vegetation types, particularly Afromontane rainforest and alpine bamboo thickets. Afromontane forest vegetation has long been considered one of the most threatened ecoregions in the world. There are two types of ecosystems found there: the wet atofontane forests and environments, alpine bamboo thickets, wetlands, 300 higher plant species,

Table 3: Biosphere Reserves in Ethiopia

Name of BR	Year of Nominated	Region	characterize
Kafa	2010	SWERS	Forest
Yayu	2010	Oromia	Forest
Sheka	2012	SWERS	Forest
Lake Tana	2015	Amhara	Lake
Majang	2017	Gambella	Forest

Table 4: *
Source: (Tadese et al., 2021). NB: SWERS=Southwest Ethiopia Regional State

50 animal species, 200 bird species, 20 amphibian species and 55 endemic plant species (Tadese et al., 2021). It is under significant pressure from increasing changes in plantations, settlements and agriculture (Birhanu & Faris, 2022).

3.1.3.5 Lake tana biosphere reserve

The lake's great biodiversity has led to its inscription on the UNESCO World Heritage List (Anteneh, 2020). Lake Tana, the largest biosphere reserve in Ethiopia, is located in northeastern Ethiopia in the Amhara region (Ayalew and Alemu, 2021a). The presence of 67 different fish species was confirmed in 2015, 70% of which are endemic. It is one of the biodiversity hotspots of the East African Mountains. This area is known for its biodiversity and is globally recognised as an important bird area, as well as being of global importance for agricultural genetic diversity (Fashing et al., 2022; Ayalew and Alemu, 2021). Invasive species such as water hyacinth could pose a threat to the Biosphere Reserve.

Lake Tana and Kafa are the two largest biosphere reserves among Ethiopia's five biosphere reserves in terms of size, covering 695,885ha (37.3%) and 540,631ha (28.9%), respectively (Fig. 3).

3.1.4 The objectives of biosphere reserve

Biosphere reserves aim to increase capacity, conserve biodiversity and promote sustainable development (Wehrden, 2020). These reserves also aim to protect and conserve various unique systems that are essential for biodiversity. They include developing and adapting management strategies for biosphere reserve areas, stabilising and promoting rural areas by ensuring economic, social and demographic stability, promoting sustainable tourism, enhancing inclusive participation of all people, promoting and strengthening cultural identity, and maintaining and enhancing conservation activities of biosphere reserve areas (Hedden-Dunkhorst and Schmitt, 2020).

UNESCO biosphere reserves exemplify sustainable development by protecting biodiversity, promoting regional marketing, encouraging low-impact tourism and promoting environmentally friendly agriculture. They also prioritise education, research and global interaction (Ishwaran, Persic and Tri, 2008). The common goal of conservation and positive development in biosphere reserves serves economic, social, political, environmental and cultural objectives. Through the promotion of ecotourism, ecosystem services, cultural identity, network development, research, statistics and education for sustainable development (Clüsener-Godt, 2016).

3.1.5 Biosphere reserves' functions

Biosphere reserves are essential for the conservation of larger areas surrounding national parks (Society and Cooperation, 2015). They offer hope to local communities and indigenous peoples by providing opportunities to improve their livelihoods (Ishwaran, Persic and Tri, 2008). These reserves aim to address conflicts between different stakeholders in a given environment through stakeholder participation, engagement and cooperation (Hedden-dunkhorst and Schmitt, 2020). The key functions of biosphere reserves include conserving culture and biodiversity, promoting economic and human development, and supporting research, monitoring and information exchange related to conservation and development at local, national and global levels (Tadese et al., 2021). The three basic functions of biosphere reserves are

a. Protective function: The dynamics of natural ecosystems (largely unaffected by human intervention) and habitats close to natural habitats (cultural landscapes with traditional land use) are kept intact by a biosphere reserve (Tian et al., 2016).

b. Development function: Ecological and human development within biosphere reserves is ensured to be socio-culturally and environmentally sustainable through the implementation of exemplary approaches to environmentally sound land use with the local population. Development objectives are adapted to ecological and socio-economic conditions and opportunities for sustainable development are provided that are appropriate to the region (Hedden-dunkhorst and Schmitt, 2020).

c. Logistical support: Logistics functions include support for demonstrations, environmental education, training and research related to local, regional, national and global development (Tian et al., 2016; Hedden-dunkhorst and Schmitt, 2020); Ayalew and Alemu, 2021b; Items et al., 2022). It also supports sustainable development based on local community initiatives and robust research (UNESCO, 2020).

Table 5: Size of Ethiopia's biosphere reserve zones

Name of BRs	Core (ha)	Buffer (ha)	Transition (ha)	Total (ha)
Yayu	27,733	21,552	117,736	167,021
Majang	43,878	73,400	108,212	225,490
Sheka	55,255	76,395	107,100	238,750
Kafa	41,319	161,427	337,885	540,631
L.Tana	22,841	187,567	485,477	695,885
total	96,574	237,822	444,985	779,381

Table 6: *
Source: Ayalew and Alemu, (2021)

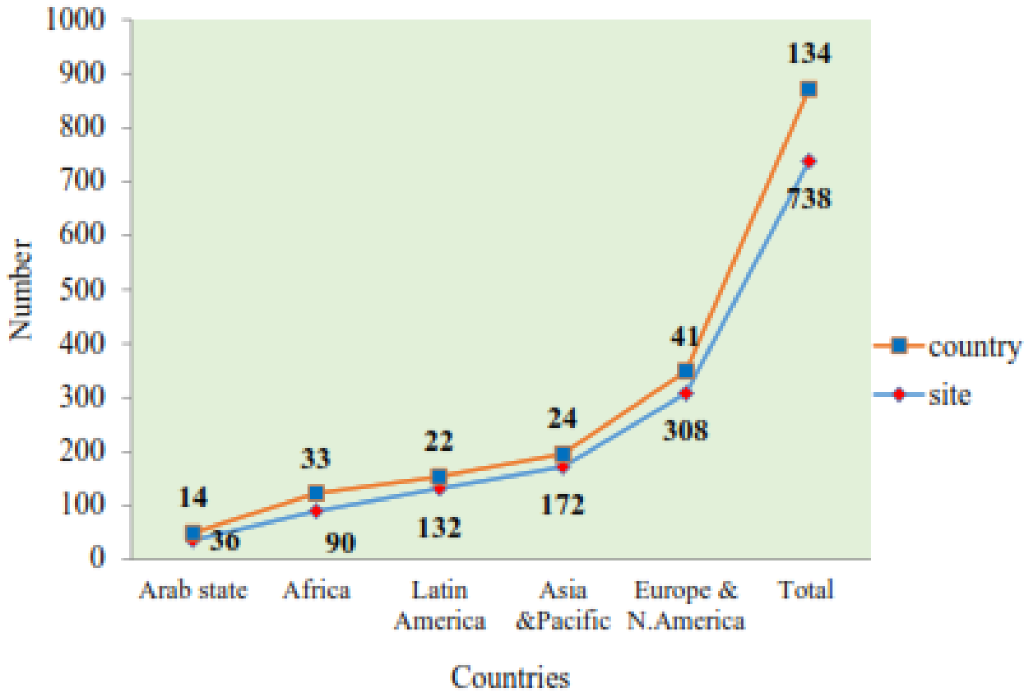

Figure 2: Size of Ethiopia's Biosphere reserves (%). Source: Birhanu and Faris, (2022)

3.1.6 Zones of Biosphere Reserve Area

A biosphere reserve is a legally established core area dedicated to the long-term protection of biodiversity. These reserves protect and serve as a place for environmental experts, decision-makers, scientific societies, management practitioners and stakeholder communities to work together (Tian et al., 2016). Landscape conservation is achieved by preserving ecosystems, endemic species, genetic diversity, biodiversity and cultural diversity in the three biosphere reserves (Deutsches Nationalkomitee MAB. and Unesco., 2005). Each part of the landscape in a biosphere reserve has its own conservation, management and development functions, categorised according to the level of human activity.

a) Core Zone: A core or national zone is an intact and legally protected ecosystem that serves as the most secure area within a biosphere reserve (Ayalew and Alemu, 2021). It is a key component of the biosphere reserve where all forms of human activity are prohibited, except for scientific research and monitoring of natural vegetation changes, typically within a national park where natural processes can unfold without human interference (Tian et al., 2016).

b) Buffer Zone: The area surrounding the core zone is typically affected by human activities, but still serves as a habitat for animal and plant species unique to the region. The core zone itself allows limited human involvement, with land use carefully regulated to prioritise biodiversity conservation (Birhanu and Faris, 2022). Scientific management is used to improve resource use strategies and to conduct research on various aspects of conservation ecology and education in the area (Ayalew and Alemu, 2021).

c) Transition zone: The transition zone is the outermost area of a biosphere reserve where reserve management establishes a positive relationship of activity and cooperation with local communities and tribes. This allows for activities such as settlement, agriculture, grazing, forestry and other economic activities, as well as recreation. It is also a place where traditional forest coffee production systems, garden coffee, agricultural practices and human settlements are allowed. The promotion of environmentally and socially sustainable

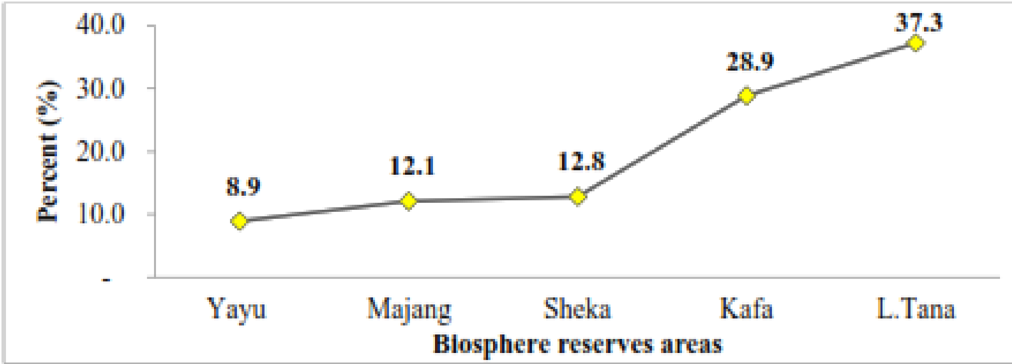

Figure 3: size of Ethiopia's Biosphere reserves (%). Source: Birhanu and Faris, (2022)

Table 7: Biosphere Reserve Designation Objectives

Designation	Objectives
Biosphere Reserve	Fostering the harmonious integration of people and nature for sustainable development through participatory dialogue, knowledge sharing, poverty reduction, human well-being improvements, respect for cultural values, and by improving society's ability to cope with climate change Biosphere reserves represent a unique tool for international cooperation through the exchange of experiences and the promotion of best practices.
World heritage site	International recognition of sites that have outstanding cultural, historical, scientific, or other international significance and universal value
UNESCO Global Geo-park Ramsar site	promotion and conservation of the planet's geological heritage, as well as encouragement of sustainable research and development by the communities concern
	Provision of national action and international cooperation regarding the conservation of wetlands of international importance (especially those providing waterfowl habitats and wise sustainable use of their resources).

Table 8: *
Source: Pool-Stanvliet and Coetzer, (2020)

forms of production and consumption is at the forefront (Tian et al., 2016.; Birhanu and Faris, 2022).

The management policy or plan of biosphere reserves must consider zonation and address all zones equally and appropriately. They play a crucial role in poverty reduction and the implementation of Sustainable Development Goals (SDGs) due to their significant impact on socioeconomic issues (Birhanu and Faris, 2022).

3.2 Ethiopia's Biosphere Reserves in Managing Biodiversity

Biodiversity is essential to the processes that support all life on Earth, including humans. Without a wide variety of animals, plants and micro-organisms, we would not have the healthy ecosystems we rely on to provide the air we breathe and the food we eat. Humans also value nature, and forests contribute to climate change mitigation as important carbon stores (Tadese et al., 2021).

In Ethiopia, tropical biosphere reserves such as Sheka, Majang, Kafa, Yayo and Lake Tana are rich in biodiversity (Tadese et al., 2021). They contain a wide variety of plants, including coffee, spices and medicinal plants. Protecting the entire ecosystems of biosphere reserves is key to ensuring in situ biodiversity conservation (Verlag and Jentzsch-Cuvillier, 2003). Biosphere reserves reconcile nature conservation with economic development, facilitate ecosystem services such as the provision of clean water, and maintain agricultural microclimates (Wehrden, 2020).

Governments around the world are increasingly promoting measures to protect biodiversity. In addition to securing economic prosperity and various facets of human wellbeing such as health, social connectedness and cultural values, it is crucial to protect and maintain natural ecosystems. Conserving biodiversity requires effective human management of the biosphere to maximise benefits for the present generation and enhance its capacity to meet the needs of future generations (Mackinnon et al., 2020). Forests promote an integrated approach and are well placed to contribute to the implementation of biodiversity (Biodiversity, 1996). Forest ecosystems play a role in biodiversity conservation. In other words, they are biodiversity hotspots of global interest (Manley et al., 2006).

The Biosphere Reserve Programme promotes sustainable development, integrated science and conservation of biological and cultural

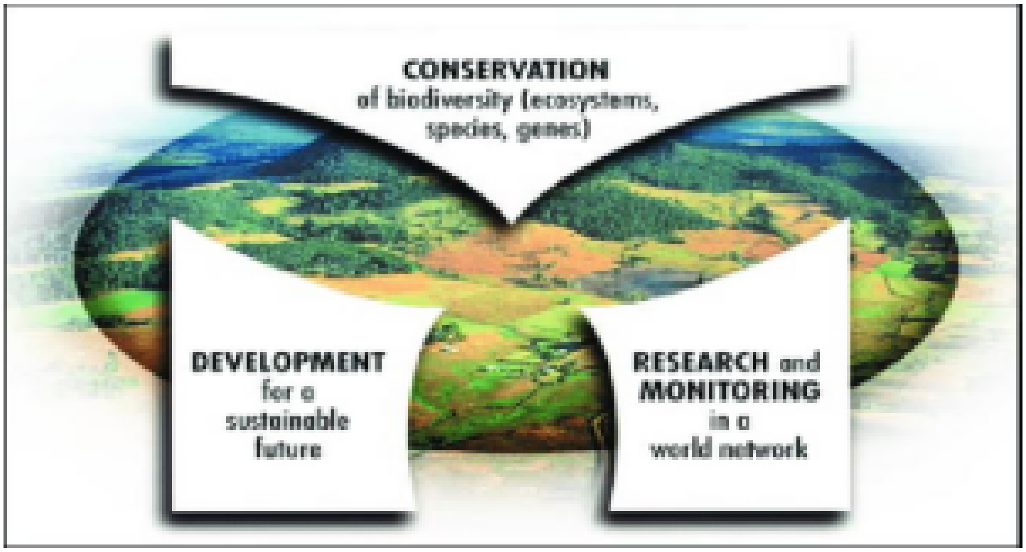

Figure 4:

diversity through partnerships between people and nature (Heddendunkhorst and Schmitt, 2020). Biosphere reserves protect cultural diversity by supporting local and indigenous forms of production and consumption, educating us about how human interventions affect ecosystems and habitats and vice versa, providing opportunities for organic agriculture and ecologically adapted forest management, assisting in peace-building, especially across borders, connecting ecologically significant areas for biodiversity, and acting as educational centres for regional, national and international exchange to promote sustainable development and bridge cultural and biological diversity for the betterment of nature and humanity (Clüsener-Godt, 2016). Majang (550), Yayu (450), Sheka (300), Kafa (224) and Lake Tana (179) were identified as the areas with the highest number of plant species, showing a diversity of plant life based on various research studies (Table 2).

3.3 Threats /challenges towards the sustainable management of Biosphere Reserves

Biosphere reserves are threatened by a variety of human-induced factors. The traditional approach of forest-based or in situ conservation, which depends on zoning, is inappropriate due to limited government resources. The control of local communities' activities has a poor track record (Amogne, 2014). Biosphere reserves work towards a natural harmony between man and nature (Heddendunkhorst and Schmitt, 2020).

Conservation efforts have been significantly hampered by a lack of administrative focus, the absence of integrated natural resource management strategies and programmes, and insufficient commitment by the relevant authority to implement natural resource goals and strategies (Verlag and Jentzschcuvillier, 2009; Bires and Raj, 2019). Changes in land use, influenced by climate change and social factors, pose a significant threat to sustainable land use and ecosystem functionality worldwide (König et al., 2022). Human activities can have negative impacts on ecological diversity if not managed sustainably (Tesfu et al., 2018). The main direct threats to biodiversity in Ethiopia include habitat conversion, unsustainable exploitation of biodiversity resources, invasive species, displacement of local varieties and breeds, climate change and pollution (Tesfu et al., 2018). Unstable security and demographic conditions, expansion of large-scale agricultural plantations, weak governance structures and integration, inadequate control of corruption in management, mining and conflicts between local communities have significant impacts on biosphere reserves (Gesellschaft und Zusammenarbeit, 2015). Land use, deforestation and degradation, agricultural expansion, investment, overgrazing, fuel wood and charcoal production all contribute to the condition of Ethiopia's biosphere reserves (Ayalew and Alemu, 2021; Mammadova et al., 2021).

Most biosphere reserves have indicated that their budgets are insufficient, yet they need to be protected (Ali et al., 2022). Currently, a large number of species are threatened with extinction as a result of unsustainable resource use (Society and Cooperation, 2015). Deforestation and forest degradation in the southwestern biosphere reserves have led to a rapid decline in forest cover, mainly due to various factors. Investors have leased forest land for coffee, tea and spice plantations, resulting in heavy exploitation through logging and agriculture. This has led to a lack of focus on sustainable resource use in the biosphere reserves (Tadese et al., 2021; Ayalew and Alemu, 2021).

Deforestation leads to the loss of wild populations or the isolation of populations (Verlag and Jentzsch-Cuvillier, 2003). Agricultural expansion is ignored in the development of management strategies to mitigate its impact on ecosystems or biosphere reserves (Connelly and Shapiro, 2006); however, the causes of deforestation in all biosphere reserves have been largely subordinated to investment and agricultural expansion (Birhanu and Faris, 2022). Changes in land cover and land use lead to biodiversity loss or ecosystem degradation; production systems often threaten natural biodiversity due to their high land use intensity (Ali et al., 2022). Furthermore, climate

Table 9: Species composition of the Ethiopia Biosphere Reserve

Species	Yayo	Lake Tana	Majang	Kafa	Sheka
Higher Plants	450	179	550	224	300
Mammals	50	16	33	300	50
Birds	30	300	180	474	246
Reptiles	10	35	20	10	8
Amphibians	20	19	20	7	20
Fishes	0	67	0	6	0

Table 10: *
Source Birhanu and Faris, (2022), Tadese et al., (2021; Ayalew and Alemu, 2021, Pool-Stanvliet and Coetzer, (2020))

change is now one of the world's greatest challenges, affecting all aspects of life as well as biosphere reserves; it affects all areas (Mack et al., 2021); and human encroachment is at its doorstep (Tesfu et al., 2018).

3.4 Sustainable Management Measures of Biosphere Reserves

The biosphere reserve can reduce threats by collaborating, coordinating and integrating with different actors in the area through cross-sectoral cooperation. This improves the livelihoods of communities and contributes to the sustainable management of the biosphere reserve (Tadese et al., 2021). Implementation strategies can preserve ecological knowledge, protect local culture, facilitate community-based learning and research, and adopt a scale of social organisation and governance that is appropriate for ecological learning and local adaptation, integrating conservation with the improvement of local livelihoods (Hedden-dunkhorst and Schmitt, 2020).

Sustainable development aims to find solutions for managing the resources of this planet to ensure a decent or clothed life, both globally and for centuries to come (Ishwaran, Persic and Tri, 2008). The biosphere reserve uses conservation as an open system as its primary approach to conservation. Monitoring, awareness raising and training of people in biosphere reserves are necessary to sustain the use of researchers, research and impact assessment of research, which requires both residents and managers (Ayalew and Alemu, 2021). Conserving biosphere reserves, reducing human pressure on ecosystems, and restoring ecological structures and processes are necessary to improve the overall functionality and health of the system (Mack et al., 2021). The establishment of a protected area is one of the conservation mechanisms used by the government to reduce forest conversion and a biosphere reserve is controlled and managed by both the community and the government (Tadese et al., 2021).

An image of the UNESCO World Biosphere Reserve designation will be known or famous to the local community and visitors who value this global award. The strategy of the biosphere reserve has been supported by a change in behaviour due to the strong brand of the area (German National Committee MAB. and Unesco., 2005). Monitoring, awareness raising and training of people in biosphere reserves can be beneficial for both the population and the administrators (Birhanu and Faris, 2022). UNSECO's Man and Biosphere Reserve is considered a good conservation strategy for the sustainable use and conservation of plant genetic resources. This approach allows for the classification of the forest landscape where the target genetic resources are found in different management zones.

To achieve conservation goals, people should allow non-damaging uses in certain areas while protecting core areas of the reserve (Verlag and Jentzsch-Cuvillier, 2003). The government and communities should establish conservation mechanisms to maintain a protected area and biosphere reserve while reducing forest conversion (Tadese et al., 2021). Sustainable landscape governance and management of biosphere reserves should be achieved through the use of governance, adaptive management, information, communication and capacity building elements, together with multi-stakeholder participation and engagement components (Hedden-dunkhorst and Schmitt, 2020).

4 Conclusion and Recommendations

Biosphere reserves are areas where life forms and biotic environments interact, with the aim of protecting biodiversity and sustainable use of land and natural resources. Established in 1976 by UNESCO's Man and the Biosphere Programme, they promote human involvement and enhance conservation efforts. Challenges include lack of government focus, inadequate natural resource management policies, security issues and conflicts between local communities. Conservation strategies include sustainable conservation, research and impact assessment, with effective coordination between stakeholders. Efforts to address these challenges include capacity building for local communities, education programmes on sustainable practices, and partnerships with non-governmental organisations. By engaging with stakeholders and implementing innovative solutions, biosphere reserves can continue to play a vital role in safeguarding our planet's biodiversity for future generations.

Government and communities must prioritise the promotion and development of biosphere reserves. A strong management plan should be developed for each group to promote stakeholder ownership. It is essential to involve local communities and stakeholders in planning and management. Sites should implement strategies that balance conservation and sustainable use. Providing incentives for conservation and sustainable practices can help reduce pressure on protected areas. Supporting communities through employment opportunities, agriculture and increased productivity is essential. The management of biosphere reserves involves dealing with multiple institutional mandates. Inadequate management often results from a lack of ownership. Institutional restructuring will be needed in the future.

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Research Article

Wood production potential of different agroforestry practices and underlying production constraints in Tula woreda of Sidama regional State, southern Ethiopia

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Article Info

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Abstract

On-farm trees have an essential role in supporting the livelihoods of the community in the study area thouth providing various wood products. The objective of the study was to characterize the attributes, constraints, and opportunities of on-farm wood production, with the view to increase farm wood production in the study area. Tula district was purposively chosen because it is among areas with a high concentration of smallholder tree growers. Both qualitative and quantitative methods were employed investigate farmers' tree-growing conditions, constraints and to undertake tree inventory using selected potential wood production sites. The results of the study showed that home gardens, boundary planting, and woodlots were the three major agroforestry practices (AFPs) contributing to the production of 1,750 ± 292 m³ (Mean ± SE, ha) wood volume per annum in the area. Indigenous trees were investigated from natural regeneration while exotic ones were established through planting from seedlings. There were 20 tree species recorded in the three AFPs. As a constraint, the lack of access to planting material in terms of quality and quantity tree species was the major problem faced by farmers in the study area. Therefore, it is recommended that multidimensional intervention mechanisms with regard to improve tree management practices, facilitate determinant factors of production desired tree species, and improve extension services towards purpose-driven tree growing practices should be put in place to change the state of wood production in the study area.

Keywords: Agroforestry practices, crown volume, mixed species woodlot, tree management, wood products

1 Introduction

The then Ethiopian Ministry of Environment, Forest and Climate Change (MEFCC, 2017) reported that there is high demand of fuelwood and forest/ tree product consumption have exerted pressure on existing forest resources and contributed to forest and land degradation, soil erosion and loss, water pollution, landslides, and flooding. Damte et al. (2012) have also reported that wood is becoming scarce in many parts of Ethiopia. According to MEFCC (2017), the projected fuelwood gap will be around 80 million m^3 in 2033, and hence to close this gap, plantation areas of about 4 million ha are required. Therefore, trees on farms for fuelwood supply and construction material have received due attention in Ethiopia (Duguma, 2013, Eshetu, 2014 and MEFCC, 2017). Wood production is the quantity of wood produced (Mangnussen and Reed (2004), whereas volume is the most widely used measure of wood quantity (Mangussen and Reed, 2004; Henning and Mercker, 2009). McCabe (2013) reported on-farm trees are sources of farm wood production and are spatially arranged in different agroforestry practices. These trees could be naturally regenerated and also deliberately planted through direct sowing tree seeds and planting tree seedlings (Rao et al. 1997). There are factors that determine the growth of trees on farms and enhance better wood production. For instance, Bekele (2011) stated the provision of financial and technical support to the local farmers; (Perdomo 2017) reported also the availability of technical assistance for the sustainability of farms and the adoption of new technologies; Kiptot and Franzel, 2011; Glover et al., 2013 and Eshetu et al.,2018) claimed the availability of land and labor as the decisive factors for the households to choose farming practices. Land size and tenure are important factors in changing the decision of households to plant trees on their farmlands (Tsegaye, 2008, Mekonnen, 2009, Bekele, 2011).

In many parts of Ethiopia and specifically in the study area, the amount of wood that contributes to household consumption and marketing was not well documented and the overall yields and quality of the trees are lower. Tree management has a significant role in farm wood production, but little has been reported about its practices in the study area. Also to meet the wood demand gap in the study area, investment consideration and the provisioning status of necessary production material and facilitations made were not reported. Therefore, the objective of the study was to characterize the attributes, constraints, and opportunities of on-farm wood production, with the view to increase farm wood production in the study area.

2. Materials and Methods

2.1 Study Area Selection

Tula is one of the districts of the Sidama Region and was purposely selected to carry out the study. Out of 12 kebelles in Tula district, Chefasine kebelle was selected due to its high concentration of smallholder tree growers planting trees in different agroforestry practices known for their Sidama Agroforestry practices (CSA, 2007). Existing value chain studies, marketing, and its proximity to the main road made its selection appropriate.

The Chefasine kebelle is located between 6°55’0” to 8°57’35” N latitude and 38°29’0” to 38°30’48” E longitude (Fig. 1). According to the Kebelle Administration Office, Chefasine kebelle has an area of 1,040 hectares (Perdomo, 2017). The most common agroforestry practices identified in Chefasine during the reconnaissance survey of the area were boundary planting, home gardens, and farm woodlots. Different woody tree species are spatially distributed in these practices at most. Based on the data from the Chefasine Kebele Administration Office (2018); Butelo, Belamo, and Argeta ‘development groups’ or sub-kebeles were selected purposively as potential wood production sites in the kebelle. They have been using the name ‘development group’ to express the hierarchy below kebele which is almost similar to the term village. According to the report of Eshetu et al. (2018), Chefasine kebele has an estimated population size of 12,366. There are 1,110 households and among these, 97% are male-headed. Since the area is in the Sidama Region, the language spoken in the area is Sidama and the Sidama culture is also well practiced by the local people regardless of where they come from originally.

2.2 Methods of Data Collection

Household Survey and Sampling Intensity

The number of households in the three villages according to the Chefasine Kebele Administration Office (2018) was: Belamo (503), Butelo (231), and Argeta (253) households in the selected villages were randomly selected using a lottery method encompassing 62 households from Belamo, 28 households from Butelo, and 31 households from Argeta totaling 121 sample households were selected for interview based on Cochran (1977) in Equation (1). Both structured and semi-structured questions were computed to obtain responses.

$$n_0 = \frac{Z^2 pq}{e^2} \tag{1}$$

This is valid where n_0 is the sample size, $Z^2 =$ the value of the desired confidence level (95%/ 1.96), e is the desired level of precision (0.05), p is the estimated proportion of an attribute that is present in the population (10%/ 0.1), and q is $1 - p$ (0.9).

The sample size was corrected using a finite population correction factor for proportions as follows:

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \tag{2}$$

Where n is the sample size and N is the population size.

The number of households in each Kebeles was calculated as follows:

$$n_1 = n \times \frac{N_1}{N} \tag{3}$$

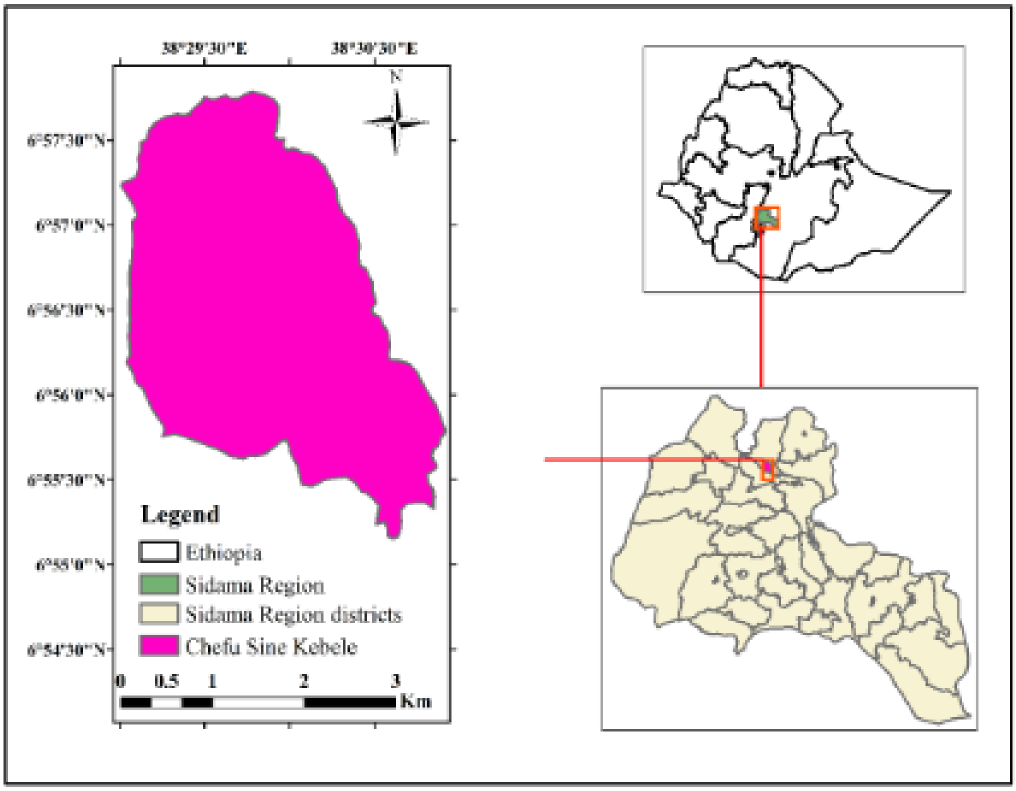

Figure 1: Location map of the Study area (Source: Ethio-GIS, Admin boundaries shape files)

Where n_1 = sample size in the first Kebele, n number of households in the first kebele, N_1 = total number of households -121- in the study, N = total number of households in three sub kebelles.

Several direct field observations mostly using transect walks were conducted during field visits to acquire a deeper understanding and to validate the information gathered through interviews.

Focus Group Discussions and Field Observation

Three focused group discussions, thirty (30), ten (10) participants from each village composed of groups of men and women interviewed together. The focus group discussions and field observation were administered and used to triangulate household survey findings and to create a common understanding of some relevant issues based on the method used by Angelsen ed. (2011).

Key Informants Interview

Key informants are knowledgeable individuals who have lived in the study area for a long time as well as possess expertise and experience about the identified problems of the study (Angelsen ed., 2011). Thus, the interview with the selected Key informants helped to develop variables that were important during the study and minimized misunderstandings. An exponential non-discriminative of snowball sampling method was adopted for the selection of key informants to increase the quality of key study variables before conducting the household survey. A total of fifteen (15) key informants farmers from the three villages were asked to provide their responses on the selected topics.

Inventory

Overall 24 farms representing 20% of sample households were selected for tree dimension measurements in the three selected villages. Then, based on the selected household sample sizes, sample farms were proportionally distributed over the study sites (selected villages) to conduct the required measurements. Accordingly, the measurements were conducted on 12 farms from Belamo, and 6 farms each from Butelo and Argeta. Caliper and Hypso meter were used to measure the diameter at breast height (dbh) and height of the trees, respectively. All trees that have a breast height diameter of more than 10 cm were measured to obtain necessary data. As measured by Asfaw and Hulten (2003), crown diameter above 2m was measured for trees in the homegarden and boundary planting. It was assumed that the trees in farm field have enough volume of wood production for utilization.

Measuring Trees in Boundary Planting. The method used by Asfaw and Hulten (2003) was adapted also to measure trees in boundary planting practices. Accordingly, the total length of the boundary tree was determined and sectioned into every 50m. Again the 50m long boundary section was sectioned at every 10 m and became five sections. For measurement purposes, one section was selected randomly out of five and a complete count and record of trees was made.

Actual length of some sections was considered for boundaries with less than 10 m. For boundary planting having more than one line of trees, the area was calculated from boundary length and width. The area of boundary planting with a single line of trees was defined based on the existing length of the boundary and the spacing between the section border. A total of sixteen (16) boundary planting sections/fields were obtained and sampled for measurements from all sites.

Measuring Trees in Homegarden Practice. The actual size of a section was sampled since trees were planted far from each other. Then the results were extrapolated to hectare. A total of twenty-four (24) sample sections within the homegarden were measured in all sample sites.

Woodlot tree measurement. A total of six (6) woodlots from all sampled sites and trees measurements were undertaken. Measurements were conducted in a plot that represents different height classes that included dominant, co-dominant, and intermediate trees. A plot size (10 x 10 m) accounting for 10% of the size of the woodlot was used for sampling. Proportionality sampling method was selected because it is appropriate for any small woodlot field. Then, the results were extrapolated to a hectare basis.

2.3 Data Analysis

Qualitative data collected from KIIs and FGDs were summarized, transcribed, and narrated for use in the report. Data collected from the household survey were coded and entered into IBM SPSS statistical package (Version 20). The data were analyzed using frequency and descriptive and summarized using tables and graphs. Data from field measurements were analyzed using MINITAB (V.17). Descriptive statistics was used to calculate the averages.

Wood Volume Quantification

The results obtained from the sampled tree measurements were extrapolated to describe the amount of wood under production, according to the equation proposed by Magnussen and Reed (2004) as follows:

$$V = 0.42 \times B \times H \tag{4}$$

Where B is tree basal area at breast height and H is tree merchantable tree height. The basal area will be calculated as:

$$BA = \pi \times \frac{DBH^2}{40000} \tag{5}$$

Where the basal area is in m^2 DBH is in cm and 40,000 is the converted DBH in square centimeters to square meters. In one square meter, there are 10,000 square centimeters.

The volume calculated from merchantable height does not consider the wood products that might be obtained from branches. According to Johnson et al. (2005), the wood volume obtained from merchantable height is mostly for saw logs and pulp woods. Thus, the calculation of crown volume is important. Crown volume was measured for Eucalyptuses trees of boundary plantings and mixed species woodlots since they have relatively medium to large branch sizes. So, Laar Van and Akca (1997) calculated crown volume as follows:

For conifer tree species

$$V_{cr} = \frac{1}{3} \times \frac{\pi}{4} \times d_{cr}^2 \times l_{cr} \tag{6}$$

For deciduous tree species

$$V_{cr} = \frac{1}{2} \times \frac{\pi}{4} \times d_{cr}^2 \times l_{cr} \tag{7}$$

Where V_{cr} is crown volume, d_{cr} is crown diameter and l_{cr} is crown length.

Finally, total tree volume was used to report the amount of wood produced per hectare basis as follows:

$$\text{Total Volume} = \text{Merchantable tree volume} + \text{Tree crown volume} \tag{8}$$

3. Results and Discussion

3.1 Socio-demographic Characteristics of Household Respondents

The majority (54%) of the respondents have attended elementary education (Grade 1-8) (Table 1). This showed the literacy level of the respondents was not an obstacle to comprehend lessons in extension services. The average household size was 7 persons per household which is similar to what Eshetu et al. (2018) reported. This also shows that household size has implications for the possibility of farm wood production. The average land size of the household was 1.1 ha (Table 2). It is described as total land size because any available open space helps farmers of the area to grow trees and also any crop and tree growing are interlinked.

Table 1: Socio-demographics (categorical variables) of the study site (n = 121)

List of Attributes	Percentage (%)
Sex	
Male	85
Female	15
Marital status	
Single	2
Married	96
Widowed	2
Education	
Illiterate	30
Read and Write	5
Elementary (1-8)	54
High school (9-12)	6
College and Secondary Education	5
Occupation	
Working on farm	100
Casual farm labor	2
Salaried or Wage labor	6
Student	2
Merchant	12

3.2 Agroforestry Practices Contributing to Wood Production in Chefasine

The Agroforestry practices contributing to wood production in the study area including their field of planting are presented in Table 3. This is in agreement with different authors that Small-scale forest plantations provide a range of benefits to rural communities tangible material products and other non-tangible environmental services (Bekele, 2011); Live fences and windbreaks or boundary planting are also some of the practices that have been practiced by farmers for wood production and other ecosystem services (Perdomo, 2017); and Woodlot practice also exists for fuel wood, construction purpose, and fencing pole and as source of income (Alemayehu, 2019; Eshetu et al., 2018).

Boundary tree planting was arranged both as irregular planting (no standard spacing) with densely planted trees (a single or mixture of trees) and also was arranged (with spacing) 2-3 rows of trees planted up to the compound limit (mostly single species). Boundary planting practice (80%) was the second largest agroforestry practice next to homegarden (100%) contributing to wood production in the study area. Alemayehu (2019) reported 50% boundary planting in the same area which is 30% lower than present study. Also, the high percentage of boundary planting practice is in agreement with a report made by Duguma and Hager (2010) and Abiyu et al. (2016) that boundary plantings are the most common tree planting practices.

Homegarden practice in the area is extended farm fields around the home as categorized also by Rgalema et al. (1994). Within the practice, different woody spp. were grown together (Table 3) with other crops that provide households with different wood products for different purposes.

Woodlots were spatially arranged around homes and away from home based on the availability of the land. Farmers have been planting woodlots around homes and away from their homes. Some woodlots have a bigger land size (above 0.125 ha, which is the minimum land size of the study area), and were located far from the homestead (field observation). Eshetu et al. (2018) reported that woodlots were planted near the homestead which were easy to manage and use. In terms of species, single species woodlots mostly constitute Eucalyptus species have been planted on sloppy and erosion (water erosion) affected areas which are not appropriate for cropping perennial cash and annual crops. This practice was also in agreement with what Alemayehu (2019) has reported. Mixed species woodlots were mostly planted on available spaces around homesteads. These are large stemmed trees (with larger dbh) having characteristics of natural woodlot. Some scholars like Asfaw and Agren (2007) including Negash et al. (2005) characterized these trees as "front yard trees" under some situations. Such kind of practice has a prominent role in household income diversification, risk diversion, and environmental benefits. In this case, it was observed that all trees do not have the same maturity age for utilization as well as do not have the same wood quality and demand for consumption and marketing purposes. Moghaddam (2014) also discussed, "under subsistence and commercial level timing of production there might be more predictable advantages of mixture plantings". Mixtures are important for economic improvement and ecological restoration.

Eucalyptus spp was planted abundantly on the border of the Khat field, house front side, and along the roadside while other diverse indigenous tree spp were planted at the border of other crop fields (Table 4). Cordia africana (98%), Croton macrostachylus (32%), and Millettia ferrugenia (30%) were among the highly grown tree species in Enset-coffee shade tree, Khat with shade tree, Enset-Khat shade tree and Khat alone. The availability of C. africana and M. ferrugenia as the most widely used species in this practice is in line with what Asfaw and Agren (2007) reported in their study results.

The study made in the same area by Perdomo (2017) also confirmed C. africana is the most widely used shade tree in enset-coffee-based homegarden practices. Eucalyptus camaldulensis (90%) is grown as a single species woodlot and a Mix of indigenous and exotic tree species in mixed type woodlot.

1.1 Agroforestry Land Size and Number of Stem

The average size of sampled woodlots was 0.33 hectares with a maximum of 0.5 hectares and a minimum of 0.125 hectares (Table 5). The average land size of the study area is 0.36 ha which is similar to study result obtained by Alemayehu (2019) in the same study area. The mean number of stems was 18 in homegarden which is much lower than reported by Yakob et al. (2014) which is 34 in the southwest part of Ethiopia. This shows that there is still a chance to increase the number of woody species in homegarden in the study area besides farmers' diverse perspectives of interaction among components and uses obtained from them. In boundary planting, Eucalyptuses camaldulensis was planted with high density resulted in less vigorous stems because of competition (Field observation). This is in agreement with the reports of Orwa et al. (2009) and Mendham et al. (2011), Forrester et al. (2013) stated that "Productivity declines because of poor forestry tree management practices".

1.2 Tree Establishment and Management

1.2.1 Tree Establishment Aspects

Narrow intra-row spacing of 20 cm (n=121, 72%) and inter-row spacing of 30 cm (n=121, 19%) were used for field tree planting in the study area. Thus, it decreases mean wood volume per tree as well as low tree production per year and unit area because of high density. Alcorn et al. (2007) and Forrester et al. (2012) reported, narrow spacing negatively resulted in a smaller average tree size because of resource competition. Figure (2) below shows the planting pit size of the study area resulting in huge misplacement of trees could lead to different physiological disorders like poor growth of the seedlings.

The Indigenous trees were mostly from natural regeneration in the study area (Table 6). This is almost following the finding of Liyama et al. (2016) who reported that farmers in the Rift Valley use farmer-managed natural regeneration as the principal strategy of tree establishment. Eduardo Somarriba et al. (2012) also reported trees on farms are the result of selection (and protection) of valuable trees obtained from natural regeneration. Farmers in the study area transplant newly regenerated seedlings (70%) to appropriate areas in the farm when needed. Farmers also protect trees (85%) from damage at seedling or early growth. This shows every important management that has been given to the trees at early stages determines the quality of the tree at the later stage.

Farmers responded that the source of planting material for most tree species is from own sources (Table 7). G. robusta as a highly planted tree in the area obtained from traders as the highest source of planting material (n=121, 44%). This shows G. robusta has a better source of planting material than other species.

Tree Management Aspects

Watering. Planted trees in the area like Eucalyptus spp. (mostly) and G. robusta; and the new naturally regenerated trees require watering during dry months in some cases. January (n=121, 9%), February (n=121, 9%) and March (n=121, 7%) were the major dry months trees require watering. Overall, there was limitation of water is available during those months in the study area. According to Abebe et al. (2010), the rainy season also could extend from March to September. This shows the period of the dry season could be extended over the rainy season if the month March is added. The frequency of watering of those species at the time of need was two times per day (n=121, 9%). Tending Operations (Thinning and Pruning). January, February, and March were the three most common months in which the tending operations are applied in the study area. The frequency of thinning and pruning was not more than twice a year (Table 7). Most of the indigenous trees being under use at the study area were deliberately retained with crops and passed through important management practices at different times. In a similar study area, Zeleke et.al (2015) reported that the majority of the farmers apply pruning and pollarding to the trees on their farms. The frequency of pruning was around once every year or every year followed by twice a year rarely. This was done to reduce shade effect on underlying crops and at the same time to obtain firewood to meet household energy needs. This is in line with what Abebe (2005) reported that farmers apply pruning of branches for different reasons and at the same time use wood energy. Zeleke et al. (2015) and Abebe (2005) also reported farmers apply different tree management practices to obtain multiple products. Thinning is not applied fully and regularly on a timely basis, especially in woodlot practices in study the area. The woodlots were densely planted and branches from pruning are less demanded than thinning supposed to reduce stocking and generate some income in the area. Forrester et al. (2013) revealed that pruning effects can be smaller in un-thinned stands of Eucalyptus plantations i.e. lower crowns of fast-growing eucalypt trees shed rapidly whether they are pruned or not.

Harvesting and Coppice management. The harvesting age of E. camaldulensis and G. robusta was short which reflects the two spp. are frequently utilized (Table 7). Grevillea has been planted recently along boundaries of farms and woodlot which may play the same role as that of Eucalyptus species in the future. The harvesting and utilization age of indigenous trees such as C. africana, F. sur, and J. procera was the longest while C. macrostachyus and M. ferrugenia showed medium harvesting age. The coppice rotation age of Eucalyptus species was 4 years (Table 8) and lies between what Asfaw and Agren (2007) have found who stated 3-7 years rotation age used by poor and rich households, and de Rezende et al. (2005) reported two cycle rotations are more profitable. The number of coppiced stems (3-4) allowed to grow in the area is a good practice to be considered. Ferraz Filho et al. (2014) reported the abundant regeneration of sprouts per stump can either be managed by thinning to

Table 5: Mean (± std, ha) of Agroforestry land size and number of stems in Chefasine

Practices	Land size	Min	Max	Stem number	Min	Max
Boundary planting	0.013 ± 0.002	0.001	0.025	16812 ± 4907	7200	23000
Homegarden	0.8 ± 0.4	0.3	2.0	18 ± 5	7	32
Woodlot/ Mixed Spp.	0.5 ± 0.07	0.4	0.5	3075 ± 869	2000	4000
Woodlot/Single Spp.	0.4 ± 0.2	0.13	0.5	7500 ± 5000	2082	10000
Woodlot(Both)	0.33 ± 0.15	0.13	0.5			

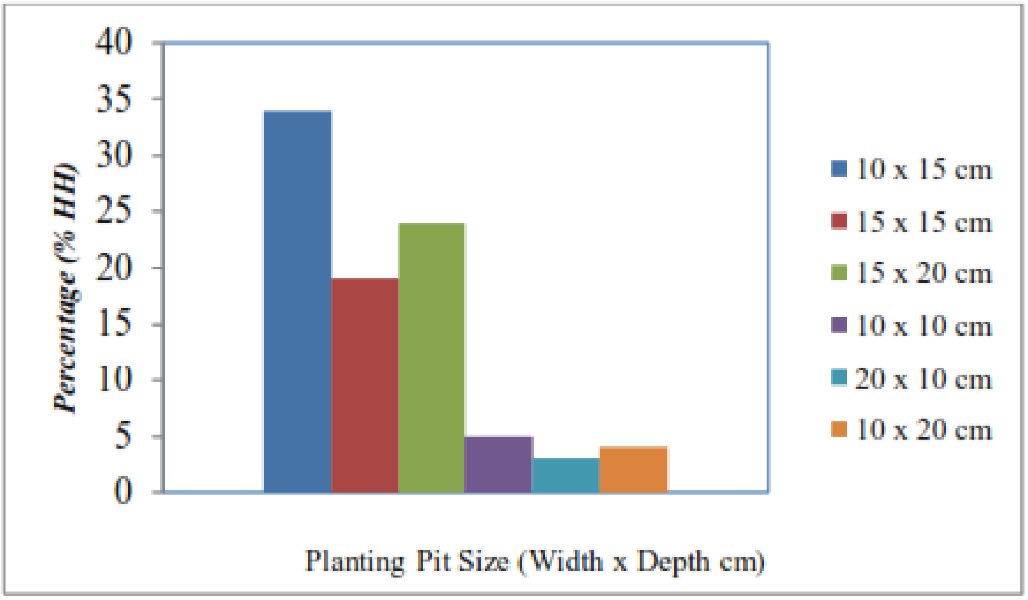

Figure 2: Planting pit sizes used by households (%) at the study site (= 121)

one, two, or three coppice stems per stump for harvesting in the later years or with no thinning but can be harvested during earlier years for biomass. A coppice stump thinning operation reduces growth competition between coppiced stems, which can result in more vigorous growth for the remaining coppice stems.

3.5 Wood Production and Utilization

The overall mean wood volume, 1750 m^3 was recorded for all measured trees in all practices in Table (9) below. Highest wood volume and high standard deviation were obtained for trees in boundary planting because trees planted in this practice were mostly overstocked and big-sized trees were also common (mostly E. camaldulensis). A low amount of wood volume was recorded for homegarden due to the density of trees per hectare basis was too low as compared to others.

The mean wood volume is less than the production objective of households energy consumption and market selling as a source of income (Table 10).

Based on the ratio of wood produced for different uses, 53.5% (945 m^3) was desired for household consumption purposes out of the total volume while 42.5% (752.5 m^3) for market selling. The left 3% (52.5 m^3) is considered as the trees that do not face cutting for a long time for cultural and different ecological benefits.

Note: In this paper, firewood refers to the wood used for household energy consumption while fuel wood refers to the wood used to sell to the market.

3.6 Major Constraints of Tree Growing

Major constraints of tree growing in the study area are lack of seeds, seedlings and proper extension services of some species among others in the order of importance (Table 11). Some of the these constraints found are similar to those reported by Alemayehu (2019). Negash et.al (2005) also stated farmers have been expanding Eucalyptus planting with little support from extension agents as poor access to extension service is one of the constraints raised by the farmers.

Table 6: Tree planting material of some selected tree species at the study site (n = 121)

Species name	Sowing seeds (%)	Seedling planting (%)	Natural regenerated seedlings (%)
C. africana	21	6	72
F. sur	6	2	14
C. macrostachyus	2	3	29
e M. ferrugenia	3		22
G. robusta	9	44	
J. procera	1	10	
E. camaldulensis	15	54	

Table 8: Tending operations of some selected species in the study site (n = 121)

Tree Species	Thinning month (%)		Thinning frequency yr^{-1}, %		Pruning month, %		Pruning frequency yr^{-1}, %		
	Jan	Feb.	Mar.	Once	Jan.	Feb.	Mar.	Once	twice
C. africana	8	8	68	22	64	10			
F. sur	2	1	3	6					
C. macrostachyus	7	2	19	12	17.8				
M. ferrugenia	2	3	4	6.5	10.8	10.8			
G. robusta	35	33	32	10	51				
J. procera	4	1	4	5	3	62			
E. camaldulensis	20	29	4	25	15	26	7	24	

4. Conclusion

Homegarden, boundary planting, and woodlot practices are the three agroforestry practices important for wood production in the study area. The purpose of growing trees in these different agroforestry practices in the area was principally to meet household domestic wood consumption and to sell to the market. Broad-leaved species are commonly used species for consumption and marketing purposes due to their branching habit that helped farmers to obtain enough firewood and the remaining stem or large size stem parts mostly used for saw logs. Eucalyptus spp. (mostly E. camaldulensis) is the most widely used species that provides farmers with enough firewood, fuelwood, and construction material through splitting and cutting into pieces or direct use in the household. Despite some environmental consequences, the sound role of Eucalyptus species for different uses in the area helps conserve other indigenous tree species that have even better wood quality. Other conifer species are also the sources of different wood product as well as mostly small wood leftovers used as firewood and fuel wood after harvesting.

There were no universal tree establishment and management practices in the study area. Indigenous trees known for their wood quality are rarely available in the open wood market. This was due to the farmers having been implementing a ban on cutting these trees. Lack of appropriate planting material and no focus made on conservation of these species from further extinction. Tree production is in the state of traditional subsistence level that was not supported by different tree development technologies. The availability of different Agroforestry practices for tree growing is a high opportunity for future improvements. Especially, practices like mixed species woodlot encompassing a mixture of trees have multiple ecosystem services. In order to obtain enough amount of production, it is recommended that to have standard tree planting and management sytem, put inplace mixed species wood lots, avail sustaibale planting materials

Table 12: Farm wood Production Constraints (%) at the study site (n = 121, multiple answers possible)

No.	Wood Production Constraints	Percent (%)	Rank
1	Lack of access to seed	100	1
2	Lack of access to seedling	93	2
3	Poor access to extension service	47	5
4	Lack of water for watering during the dry season	59	3
5	Competition between trees and crops	35	8
6	Farm size	95	2
7	Land tenure problem	38	7
8	High costs for transporting wood products to market	42	6
9	Inaccessible road	50	4

or seed sources other tha Eucalyptus species and improve access to credits facility associated with interest free banking service for farmers.

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Research Article

Arbuscular mycorrhizal status of *Cordia africana* and *Millettia ferruginea* trees in traditional agroforestry land use systems of Sidama Regional State, southern Ethiopia

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Abstract

Arbuscular mycorrhizal fungi (AMF) enhance plant growth and productivity through nutrient acquisition, organic matter decomposition, improved soil health, increased resilience and stress tolerance. A higher percentage of root colonisation by AMF indicates a stronger symbiotic relationship and potentially greater benefits to the plant. A high abundance of AMF spores reflects their overall potential to colonise plant roots. The aim of this study was to determine the number of spores and root colonisation potential of AMF in the soil beneath *Cordia* and *Millettia* trees grown in enset and maize fields, and to estimate the extent of AMF colonisation of *Millettia* and maize seedling roots grown on these field soils. Six tree-crop combinations, making 36 plots, and two open maize plots in the traditional agroforestry systems of Sidama. At the field level, the study was conducted under the canopy of *Cordia africana* and *Millettia ferruginea* trees in different plots. To assess the relationship, root colonisation and spore counts of field soils sampled from different *Cordia* and *Millettia* trees in enset and maize plots, maize and *Millettia* plants were grown in the nursery. The tree-crop combinations induced higher spore counts and higher colonisation levels than in the open maize field. Significantly, lower numbers of spores were observed in soils under *Cordia* and *Millettia* trees grown in maize plots than under trees grown in enset coffee and enset plots. The order of colonised roots was: tree enset coffee ¿ tree enset ¿ tree maize for *Cordia* trees and tree enset ¿ tree enset coffee ¿ tree maize for *Millettia* trees. At the nursery level, a significantly higher level of root colonisation was observed for maize plants grown on soil from under tree-enset-coffee and enset plots than for those grown on soil from tree-maize and open maize plots. The percentage of AM colonised maize roots was significantly positively correlated with spore counts for field soils. Both maize and *Millettia* plants with high root colonisation achieved higher fresh weight. The presence of spore counts and root colonisation in the plants studied suggests a contribution of native AMF in improving plant growth and productivity.

Keywords: Number of spores, Open-maize plot, Root colonizations, Tree-enset,Tree-maize

1 Introduction

Mycorrhizal association can contribute to agricultural sustainability through improved mineral uptake, especially of low mobile ions (e.g. Sieverding, 1991), and biological N fixation (Ibijbijen et al., 1996). Mycorrhizal association can also improve nutrient cycling and soil structure quality (Hamel, 1996), plant community diversity and plant tolerance to biotic and abiotic stresses (Hamel 1996; Smith and Read, 1997). Studies of some agroecosystems (Sieverding, 1991) and natural forests in the tropics (Janos, 1996) suggest that the presence of mycorrhizal associations can maintain plant diversity. Mycorrhizal association is also helpful in explaining the relative abundance of plant species in a given habitat (Reader, 1998). In tropical agroecosystems, AMF is the most common mycorrhizal symbiosis (Sieverding, 1991). In managed ecosystems, however, these contributions may be influenced by management practices. The most important management practices influencing AM associations are the intensity of agricultural, high and low input practices.

High-input farming practices in this context refer to the use of artificial fertilisers, intensive tillage, weed control with herbicides, chemical control of insects and diseases, and monoculture with high-yielding crop varieties, while low-input farming practices refer to mixed cropping, low fertiliser application, mainly of organic origin, hand weeding and no pesticide application (Sieverding, 1991). The effects of high-input farming practices include (i) reduction in the diversity and effectiveness of native mycorrhizal populations (Sieverding, 1991; Schreiner and Bethlenfalvay, 1995); (ii) high rates of P and N fertiliser application, which both reduce the effectiveness and alter the population structure of mycorrhizal fungi (Sieverding, 1991; Scullion et al, 1998); (iii) the use of pesticides, which can adversely affect mycorrhizal associations and communities (Perrin and Plenchette, 1993); (iv) intensive tillage, which reduces the amount of mycelium and adversely affects AM spore density in agricultural soils (Schreiner and Bethlenfalvay, 1995; Kabir et al, 1997; Miller et al., 1995; Gavito and Miller, 1998, Menendez and Scervino, 2001); (v) continuous monocropping, even in the case of perennial crops, which can lead to significant changes in the composition of native mycorrhizal fungal species (Sieverding, 1991). The effects of high-input agricultural practices include: (i) reduction in the diversity and efficacy of native mycorrhizal populations (Schreiner and Bethlenfalvay, 1995); (ii) high rates of P and N fertilization, which both reduce the efficacy and alter the population structure of mycorrhizal fungi (Scullion et al, 1998); (iii) the use of pesticides, which can adversely affect mycorrhizal associations and communities (Perrin and Plenchette, 1993); (v) continuous monocropping, even in the case of perennial crops, which can lead to significant changes in the composition of native mycorrhizal fungal species (Sieverding, 1991). The effects of high-input agricultural practices include: (i) reduction in the diversity and efficacy of native mycorrhizal populations (Schreiner and Bethlenfalvay, 1995); (ii) high rates of P and N fertilization, which both reduce the efficacy and alter the population structure of mycorrhizal fungi (Scullion et al, 1998); (iii) the use of pesticides, which can adversely affect mycorrhizal associations and communities (Perrin and Plenchette, 1993); (iv) intensive tillage, which reduces the amount of mycelium and adversely affects AM spore density in agricultural soils (Schreiner and Bethlenfalvay, 1995; Kabir et al, 1997; Miller et al., 1995; Gavito and Miller, 1998, Menendez and Scervino, 2001); (v) continuous monocropping, even in the case of perennial crops, which can lead to significant changes in the composition of native mycorrhizal fungal species (Sieverding, 1991). As certain crops have a preferential selection for certain AM fungal species and strains, cropping sequence may also influence species composition (Sieverding, 1991).

Low-input systems often involve reduced tillage, increased crop diversity, maintenance of vegetation cover, reduced chemical inputs, and also tend to establish more undisturbed ecosystems in which the mycorrhizal symbiosis can provide some of the ecological functions mentioned above (Sieverding, 1991; Kabir et al., 1997; Hamel, 1996). Such systems also influence the composition of AM fungal communities by increasing diversity and altering the relative abundance of fungal species (Douds et al., 1993) and increasing sporulation (Kurle and Pfleger, 1994) by having a higher infectivity of AMF spores than the high input systems (Sieverding, 1991; Hamel, 1996: Scullion et al., 1998). However, the selection and management of non-host plants can delay or inhibit the infective potential of propagules (Thompson, 1987; Sieverding, 1991). If at least one of the plant components in an intercropping or agroforestry system is mycorrhizal or potentially mycorrhizal, adequate inoculum levels are likely to be maintained (Sieverding, 1991; Michel-Rosales and Valdes, 1996).

The use of AM for the above benefits is not well advanced because inoculum cannot be readily produced in artificial (axenic) culture. The need for large quantities of inoculum may limit artificial inoculation of agricultural crops with AMF in the field (Sieverding, 1991). Therefore, production on roots and their environment in the field is of great importance for AMF. In the case of agroforestry, standing farm trees or tree inoculation at nursery level could help to overcome the need for large amounts of inoculum. However, in order to properly manage the mycorrhizal symbiosis on the farm, it is necessary to know the current status of the agroecosystem at farm, field and plot level.

In the traditional agroforestry land use systems of the Sidama, it is not known how farmers' practices in selecting and managing crop and/or tree components affect native mycorrhizal associations. In these systems, 87 tree species are reported (Zebene Asfaw 2003), of which *Cordia africana* and *Millettia ferruginea* are the second and fourth most abundant tree species, respectively. However, studies on the AM fungal hosting capacity of these two tree species in these traditional agroforestry systems are lacking. Research aimed at understanding the status of mycorrhizal fungi in a Sidama traditional agroforestry system in general and around these two tree species is valuable in determining appropriate management strategies as a background against which inoculation techniques will be developed. For this, it is necessary to understand the host capacity of these agricultural trees and the compatibility of the symbionts.

Some AMF have a wide host range. Therefore, the roots of standing crop trees may harbor inocula that are also of value to crops intercropped with them. Therefore, it was hypothesised that *Cordia africana* and *Millettia ferruginea* trees in the traditional agroforestry land use system of Sidama could promote greater reservoirs of AM inoculum for agricultural crops, with particular reference to maize and *Millettia* /Ensete plants grown on the underlying soils. This study was designed to (i) determine the number of spores of AM fungi in the soil under *Cordia* and *Millettia* trees grown on enset and maize fields, including without trees in maize monoculture; and estimate the extent of colonisation of *Cordia* and *Millettia* trees and maize roots by AMF(ii) assess the potential of field soils from the differently managed plots, under *Cordia* and *Millettia* trees, to cause AMF colonisation of maize and *Millettia*.

2 Materials and Methods

2.1 Description of the study area

This study was carried out in the Awassa Zuria District of the Sidama Zone in southern Ethiopia. The present report is a part of other work carried out at three sites namely Entaye (Enta), Haranfama (Hara) and Murancho Kutela (Figure 1). For this particular study, two sites, namely Entaye and Murancho Kutela, were randomly selected to collect soil and root samples for both nursery experiments and routine laboratory activities at the Wondo Genet College of Forestry.

2.2 Sampling plots within the fields

Sidama farms have about 10 different types of fields (Zebene Asfaw, 2003). For this study, we selected two predominant field types, namely enset and maize fields. A plot was defined as a relatively homogeneous area within a field, characterised by a single species or species mix and common management (Huxley, 1983). Soil samples for AMF spore counts (n=36) and root extractions (n=72) Table 2. For nursery level growth media, soil was collected from these plots. In the sample plots, the main weeds were first identified by the farmers themselves, then the botanical name was given based on the corresponding local names (Kelecha, 1980) or in the description by Edward et al. (1995).

Tree and enset-coffee:- These plots were characterised by multi-storey structure in which *Cordia* or *Millettia* are the upper storey. The age of the sample trees ranges from 24-32 and 17-25 year for *Cordia* and *Millettia*, respectively. Under both tree species at mid storey, a mixture of enset and coffee crop has been grown for the last five years. The ground cover, lower storey, includes Ethiopian kale, local cabbage ”Tunaye”, and pepper. The major weeds were *Snowdenia polystachya* ”merge”, *Galinsoga parviflora* ”Butissa”, *Commelina benghalensis* ”Laluntie” *Digitaria abyssinica* ”Hiele”, *Cyperus spp.* ”Gicha”, *Agrostis semiverticillata* ”serdo”. No external input was used. Hand hoeing was carried out twice a year. The topsoil properties are indicated in Table 1.

Tree and enset:- These plots are also located in enset fields but without coffee. The main under growth was Ethiopian Kale, ”Tuneye” and pepper. At these plots enset has been grown for 5 and 7 years beneath *Cordia* and *Millettia* plots, respectively. No external input is applied. Hand hoeing is carried out twice a year. The recorded weeds were *Amaranthus spp.*, *Snowdenia polystachya*, *Cyperus spp.*, and *Galinsoga parviflora*. Soil properties are indicated in Table 1.

2.3 Spore and root sampling

Topsoil samples (0-20 cm) for spore counts and estimation of mycorrhizal colonisation and soil for the nursery experiment were collected at the beginning of the main rainy season. The physicochemical properties of all soil samples are shown in Table 1. To identify the specific plant roots in a composite soil sample is very difficult, but efforts were made to directly collect fine roots of standing plants to learn about specific characteristics, mainly their colour. Based on this fine root colour, we learnt that the maize root colour is white, while that of *Millettia* is cream and that of *Cordia* is very light brown. Using this common approach, we therefore made educated guesses based on these known root characteristics of these plants. For *Cordia* and *Millettia* grown in the top layer of enset mixed with coffee, soil samples were taken under the canopy at three distances in four different directions. Soils from each direction were pooled to obtain a composite sample. Finally, 400 g of the sample was taken separately for estimation of arbuscular mycorrhizal spores and root colonisation. Similarly, soil under *Cordia* and *Millettia* grown on enset coffee and scattered on enset and maize plots was also sampled.

For the nursery experiment, four lines, E-W and S-N, were established in both the enset and maize plots from the trunk to the canopy edge or open field. On each line from the trunk, three sample points were marked at 0.75 m, mid-canopy and canopy edge, and a fourth sample point was marked along the line in the open field. Soil samples of approximately 3 kg were then taken from a randomly selected line. During sampling, every effort was made to avoid disturbing the soil, such as repeatedly mixing by hand, as was done with the spore count samples. This precaution was taken because the process of repeated mixing can lead to loss of the hyphal network. Three replicates of soil samples from each plot were used to start the growth of maize and millet seedlings.

2.4 AMF spore estimation

As one of the objectives of the present study was to estimate the number of AMF spores in the soil on different plot types, it was decided to keep the samples separate (Table 2). Spores were isolated from 50 g subsamples of soil. The methods described by Brundrett et al. (1996) were used for spore extraction. The spore suspension was stored in a refrigerator at -4 °C for preservation, as suggested by Dalpe (1993), until counting. Spores were counted by placing them in an 8 cm diameter nematode counting dish. Some spores were densely grouped in sporocarps and it was difficult to count the number of spores per sporocarp, so in these cases the sporocarp was referred to as one spore. A dissecting microscope was used to count the spores.

2.5 Root colonization by AM fungi

2.5.1 Root sub-sampling and cleaning

Each 400 g soil sample was immersed in a bucket of water and gently swirled to mix and remove most of the soil. To obtain a cleaner sample of root fragments, the soil with roots was washed vigorously and poured off, the liquid passed through 350-500 µm sieves and the roots washed free of soil. The suspended root fragments were

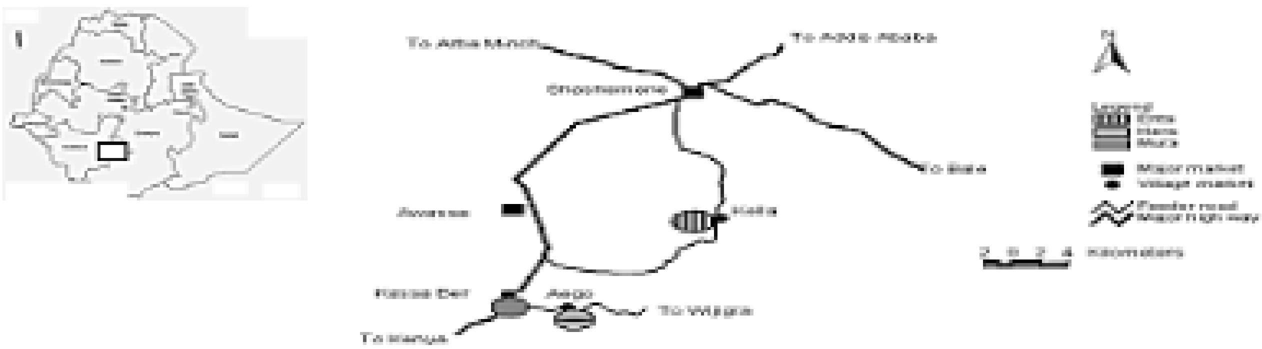

Figure 1: Map of the study sites showing the nearest markets and road network in Sidama, south Ethiopia.

Table 1: Top soil characteristics from which spore density, tree root colonisation and on which seedling of maize and *Millettia* was raised

Plot Type	Sand %	Silt %	Clay %	pH[1]	Na	K	Ca	Mg	CEC	T:N[2]	O:C[3]	P[4]
Tree -enset-coffee												
Cordia	36	34	30	6.7	0.7	2.7	15.4	3.1	28.5	0.4	3.1	12.6
Millettia	36	34	30	6.3	0.9	1.7	16.7	3.0	29.9	0.4	3.1	9.5
Tree and enset												
Cordia	36	36	28	7.0	0.6	2.0	17.7	3.0	27.7	0.3	3.4	15.4
Millettia	36	35	29	6.6	0.8	1.4	14.0	2.1	27.3	0.4	2.7	9.0
Cordia-maize[5]												
CT	33	35	32	6.5	0.5	2.2	18.1	3.2	29.0	0.3	3.5	9.4
MC	35	34	31	6.5	0.5	1.9	17.1	3.2	27.4	0.3	3.4	8.4
CE	35	33	32	6.4	0.4	1.9	16.7	2.9	26.4	0.3	3.1	7.4
OF	36	33	31	6.2	0.4	1.6	16.0	2.8	25.9	0.3	2.8	5.7
Millettia- maize												
CT	39	31	30	6.2	0.7	1.0	12.4	2.1	29.1	0.3	2.7	6.6
MC	39	35	26	6.1	0.8	1.2	12.6	2.2	29.0	0.3	2.9	6.4
CE	40	34	26	6.0	0.8	1.0	12.0	2.0	28.8	0.3	2.5	4.9
OF	38	34	28	6.0	0.7	1.3	10.7	1.92	26.5	0.2	1.3	4.6

[1] pH in H20 1:2.5; [2] T:N total nitrogen in %; [3] O:C organic carbon; [4] Available phosphorus ppm; [5] For maize-tree plots at laterally increasing distance from the tree trunks: CT= 0.75 m, MC= mid canopy, CE= canopy edge OF= open-maize field

rapidly decanted onto the 50-100 µm sieve and the decanting was repeated until all the root fragments were on the 50 µm sieve. The fine 50 µm sieve was placed in a pan of shallow water so that the floating roots and any debris could be picked up. Roots were sorted into two categories, living ¡1 and 1-2 mm, representing fine roots. Depending on the type of sample, up to 0.5-1.5 g of the ¡1 mm categories were taken and samples were stored in 50% ethanol until clarified and stained (Brundrett et al., 1996).

2.5.2 Root clearing and staining

The duration of autoclave sterilisation can vary depending on the type and density of the plant root. Autoclave sterilisation at 121°C is usually the same temperature for most materials. To standardise sterilisation we used a range of times and replicated three times. Based on this, the better time was found to be 20 minutes for *Millettia* and 25 minutes for *Cordia*. Young roots of maize and *Millettia* plants grown in the nursery were autoclaved for 5 minutes.

From the fresh field soil samples, the roots were gently washed with tap water to remove adhering soil particles. The roots were then cut into short segments (typically 1-2 cm) using a sharp scalpel. The roots were boiled in 10% KOH solution for 15-20 min at 90-0°C in a boiling water bath, rinsed several times with water and acidified with 1% HCl solution. Root samples were stained by adapting the techniques developed by Phillips and Hayman (1970) as modified by Koske and Gemma (1989). Roots were stained by boiling in 0.05% trypan blue at 90 0°C for 10 min, followed by distaining in acidic glycerol at room temperature. The stained root segments were mounted on slides in acidic glycerol, the coverslips placed over them and gently tapped with the blunt end of a pen. The stained roots were poured onto 50 cm sieves and destaining solution. The stained root segments were evenly distributed in a petri dish marked with grid lines (the method of intersecting grid lines on the bottom to form approximately 1.3 cm squares and root colonisation of individual species was estimated as described by Brundrett et al. (1996)). Cross-checks were made at a higher magnification of x200 (McGonigle et al., 1990). In most cases, *Cordia* roots were crushed when examined to confirm the presence of arbuscules, vesicles and/or In

Table 2: Number of soil samples collected from different plots for estimation of number of AM spores (n=36) and root colonisation n=72).

Tree	No. of samples			
Plot type	species	Spore	growth	substrate
			maize	*Millettia*
Tree and enset-	*Cordia*	3	3	3
coffee	*Millettia*	3	3	3
Tree and enset	*Cordia*	3	3	3
	Millettia	3	3	3
Tree and maize	*Cordia*	12	12	12
	Millettia	12	12	12

general, the intersections of the grid with the root were examined for the presence of AMF structures. The presence of colonisation in a root segment was recorded if hyphae (only), vesicles or arbuscules were found. Approximately 100-150 sections were examined for each sample. Total root colonisation was calculated as % colonisation = total number of positive segments/total number of segments examined x 100.

2.6 Nursery experiment

The aim was to assess the potential of field-collected soil to induce root colonisation of the two important plants in the study area. Thirty-six soil samples were used as growth medium in the nursery (Table 2). Maize and millet were used as host plants. Both species started germination after 5-8 days. A local variety of maize was purchased from the local market and sown. For *Millettia*, a locally collected seed source was used after four months of storage. Four seeds of each species were sown on 7 July 2000 in soil contained in a perforated plastic pot of approximately 3000 ml, with three replicates of each soil type and host seedling species. Plants were thinned to one per pot 15 days after sowing. All plants were harvested 45 days after sowing. Feeder roots were cut from the main root system, chopped into 1 cm lengths and mixed to represent fine roots ¡ 2 mm. Then, 1.5 g of fine roots ¡ 1 mm were collected for clearing and staining as described above. The percentage of root colonisation was calculated and the total fresh weight of the plant was determined.

2.7 Data analysis

To assess the relationships between spore counts in field soils and AM colonisation percentage n of maize and *Millettia* plants grown on these soils from the same sample plots, spore counts per sample were log-transformed. Data from colonised roots were also arcsine transformed to conform to the normal distribution (Sokal and Rohlf, 1981). Pearson's correlation was used to assess the relationships between the number of spores in field soils and the degree of root colonisation in the nursery experiment. The transformed values were also used for the ANOVA calculation. One-way ANOVA with STATISTICA (1999) was used to test for differences between the number of spores and the degree of root colonisation in each sampling plot and the data at the nursery level. Where significant F values were obtained (P ¡ 0.05), the plot means were separated by the Duncan test. Results for spore counts and percent root colonisation are presented as back-transformed data.

3 Results

3.1 Number of AM spores and root colonization in the field

3.1.1 Spore number

Spore counts varied from 3 to 31 and 1 to 24 g -1 dry soil under *Cordia* and *Millettia* canopy, respectively, at enset-coffee, enset and open maize fields (Tables 3) at the different and grown at increasing distances from tree trunks of seated trees (Table 4). Soil samples beneath *Cordia* and *Millettia* had about the same number of spores. There were significantant differences (n = 24, F = 3.807, p ¡ 0.004) in number of spores between soil samples from varying tree-crop combination plots. Significantly, (p ¡ 0.05) lower numbers of spore were observed in soils under *Cordia* and *Millettia* trees grown on maize plots than under tree grown in enset-coffee and enset plots (Table 3). Numbers of spores were variable among soil samples collected at increasing distances from tree trunks (Table 4). However, the number of spores under the canopy did not significantly (p ¡ 0.05) vary with increasing distances from tree trunks (Table 4). In the maize field outside the canopy the number of spores was about half the number under the canopy.

3.1.2 Percentage of AMF root colonization

Tables 3 shows mean spore count g -1 dry soil from under *Cordia* and *Millettia* canopy, enset-coffee, enset and open maize fields at the different sites. Spore counts varied from 3 to 31 and 1 to 24 g -1 dry soil under *Cordia* and *Millettia* canopy, respectively. Soil samples beneath *Cordia* and *Millettia* had about the same number of spores. There were significance differences (n = 36, F = 3.807, p ¡ 0.004) in number of spores between soil samples from varying tree-crop combination plots. Significantly, (P ¡ 0.05) lower numbers of spore were observed in soils under *Cordia* and *Millettia* trees grown on maize plots than under tree grow in enset-coffee and enset plots (Table 3).

Numbers of spores were variable among soil samples collected at increasing distances from tree trunks (Table 4). However, the number of spores under the canopy did not significantly (p ¡ 0.05) vary with increasing distances from tree trunks. In the maize field outside the canopy the number of spores was about half the number under the canopy (Table 4).

For *Cordia* and *Millettia* trees scattered on maize fields, there was a non-significant tendency for lower proportion of colonized roots with increasing distances from the tree trunks (Table 4). At all distances from tree trunk, higher root colonization was also noticed for *Millettia* than for *Cordia* trees.

3.2 Nursery grown plants

3.2.1 Levels of AM colonization

Table 5 shows the mean level of root colonization while the overall value ranged from 4 to 66% for maize and 3 to 37% for Millettia. Colonization of roots by AMF was relatively more intensive in maize than in Millettia seedlings. There were significant differences (n = 24, F = 2.671, P ¡ 0.030) in levels of root colonization between maize plants grown on soil samples from different tree crop combinations, with the lowest colonization in soil from maize fields. Although not significant, root colonization of nursery-grown Millettia plants tended to be higher than values on soils from under Cordia trees at enset-coffee plots, followed by soil from under Millettia trees at enset plots. The lowest root colonization was noted in soils from maize fields. The percentages of AMF colonized roots of maize plants grown on soil from under Cordia trees at enset-coffee plots were 25% greater than those grown on soil from under Cordia tree canopy at maize plot. For both maize and Millettia plants grown on soils collected at laterally increasing distances from tree trunks, no consistent pattern of colonization was observed (Table 6). The relationships between estimates of AMF colonization of maize roots and Millettia seedlings grown in the nursery and the number of spores in the soil samples used as growth media was determined. The percentage of AM colonized roots of maize was significantly positively correlated with the number of spore counts from field soils (Table 7).

The same letter(s) following mean values indicate no significant (P ¡ 0.05) difference between tree species.

3.2.2 Fresh weight of plant

Soils used as growth media in the nursery, from different plots beneath Cordia and Millettia trees, had no significant effects on the fresh weight of either maize or Millettia plants 45 days after sowing. In all cases, maize plants attained higher fresh weight than Millettia (Fig. 2a, 2b, 3a, and 3b). Fresh weights of plants grown in the soil collected from under Cordia and Millettia trees grown in enset fields (Fig. 2a and 3a) were greater than from maize fields. Although not statistically significant (P ¡ 0.05), a decrease in fresh weight was noticed for both maize (Fig. 2b) and Millettia (Fig. 3b) plants grown on soils from plots at laterally increasing distances from Cordia and Millettia tree trunks.

4 Discussion

Studies on the effect of Cordia and Millettia trees on the number of AM fungi spores in field soils are lacking. It is therefore difficult to compare the results of this study with those of others, as most of the studies on spore numbers and colonization levels have been carried out on other trees, crops, and/or land-use systems under different ecological conditions. Spore counts and/or root colonization levels are commonly used to study mycorrhizal associations (Dalpe, 1993; Brundrett et al., 1996). However, the number of spores and the percentage of mycorrhizal colonization of root systems are not always good measures of the potential effectiveness of mycorrhization (Reich and Barnard, 1984; Merryweather and Fitter, 1998). Despite these limitations, both the number of spores and the percentage of infection in roots in the soil are used as a means of assessing mycorrhizal association.

4.0.1 Number of spores

Depending upon the seasons, AM fungi spore formation could be different at a given site (Allen et al., 1998). Since the sampling period of this work was 6 weeks after the onset of the main rainy season, the high number of spores could be related to seasonality effect, as suggested by other workers for other species (Brundrett et al., 1996; Janos, 1996).

The number of AM fungi spores ranged 1-31 per gram of dry soil, which is comparable with some of the previous findings from various land use types (Table 8). The number of spores was approximately the same under Cordia and Millettia canopies (maximum 31 and 25 g-1 soil, respectively). The occurrences of spores reflect many factors: such as the ability of native AM fungi to produce spores, the successful development of AM fungi and host tree/plants, or suitability of the environmental conditions. Soil physical, chemical, and biological conditions are well-known to affect spore germination and mycelial dispersion of AM fungal species (Sieverding, 1991). Soil beneath Cordia and Millettia at maize fields had a significantly lower number of spores than in enset fields. Similarly, soils beneath trees at enset-coffee and at enset plots in enset fields contained four to five as many spores as in open-maize plots on maize fields.

The increased number of spores beneath Cordia and Millettia trees at enset-coffee and enset plots could probably be explained by four major factors or by their combined effects: (1) less soil disturbance/tillage (Gavito and Miller, 1998; Menendez and Scervino, 2001), (2) higher number of plant species (Schreiner and Bethlenfalvay, 1995), (3) more active biological conditions (Sieverding, 1991), and (4) higher cover/vegetation as compared with plots in

Table 3: Number of spores g [-1] soil dry weight and percent length of colonised roots of *Cordia africana* and *Millettia ferruginea* grown at different sites. Mean ± std of three replications.

Plot type	species	Spore g [-1] soil	Colonised root length in%
Tree-enset- coffee	*Cordia*	20a ± 11.0	44.49 ±11.0
	Millettia	15a ± 6.7	41.47±17.0
Tree-enset	*Cordia*	14a± 8.8	38.01±8.4
	Millettia	17a± 6.5	48.38±11.4
Tree-maize	*Cordia*	8bc± 4.8	30.31±12.2
	Millettia	6bc± 4.1	39.76±14.0

The same letter(s) following mean values indicate no significant (P ¡ 0.05) difference between tree species

Table 4: Mean number of spore g[-1] dry weight soil and percent length of colonised roots of *Cordia africana* and *Millettia ferruginea* grown at increasing distances from tree trunks of scatted trees in maize fields. Mean ± std of three replications

Distances from	Spore g[-1]soil	Colonised root length %		
	Cordia	*Milletia*	*Cordia*	*Milletia*
CT at 0.75 m	9±3.4	7±5.2	31.54±17.1	44.06±14.3
Mid Canopy	6±6.6	6±4.2	30.30±10.3	39.58±17.4
Canopy edge	8±5.5	7±4.8	29.09±9.5	35.65±10.9
open-maize field	4±3.9	5±2.6	-	-

open-maize fields (Sieverding, 1991; Janos, 1996). Although those factors have not been critically investigated in this study, based on farmers' knowledge on frequency of tillage, one could speculate that tillage could influence mycorrhizal inoculum/spore. Farmers practice relatively higher frequency of tillage for maize than enset plots. Available reports for different species and land use types indicated a lower AM fungi spore density in disturbed soils than in less disturbed (Miller et al., 1995; Gavito and Miller, 1998; Menendez and Scervino, 2001) or undisturbed soils (Lovera and Cuenca, 1996). There are also several reports of low AM fungi spore number in disturbed maize fields (Jasper et al., 1991; Douds et al., 1993; McGonigle and Miller, 1996; Kabir et al., 1998; Boddington and Dodd, 2000). Variation in spore number could also be related to the differences between soil properties of studied plots.

Regarding biological conditions, the host genotype, vegetation cover, and microbial activities could influence AM symbiosis (Janos, 1996; Smith and Read, 1997). The difference in number of spores between the Cordia and Millettia trees could be explained by the hosting ability for AM fungi of individual tree species. As having dominantly perennial plant species and high vegetation cover, the enset-coffee and enset plots have some characters of forest-dominated ecosystems. The numbers of spores recovered from tree-enset combination plots are higher than those reported from some tropical natural forests (Table 8). However, in the tropical moist forests, the number of spores tends to be lower (Janos, 1980; Sieverding, 1991; Fischer et al., 1994) than in polyculture agricultural systems. In these systems, like the Sidama traditional agroforestry land use, the spore numbers are much greater than in intensive or high input systems (Sieverding, 1991). In general, the effect of vegetation and microorganisms on the amount of spore/inoculum is site-specific (Sieverding, 1991; Fischer et al., 1994).

The number of spores did not significantly vary with increasing distances from tree trunks (Table 4), which was observed only on maize fields with a generally low number of spores. At the closest distances from tree trunks, the number of spores was only slightly higher than further away from the crown cover. This is in agreement with Musoko et al. (1994) who reported that distance from Terminalia superba trees trunk has no influence on the number of spores, although more spores were observed close to the trunks. The open field samples were taken well outside the area less influenced by tree roots and the farmers are growing maize under the tree canopy with almost the same intensity of weeding and tillage practice as outside the canopy. The lower spore number outside the crown canopy in the maize field sample may thus indicate that the high spore number under the canopy is influenced by the root system of trees.

4.0.2 Root colonization in the field

The degree of AM fungi colonization of Cordia and Millettia trees was variable, with fairly high standard deviation. This could be explained by differences in rapid root growth between trees and field plots during the wet period when the sampling was carried out. The seasonal influence on colonization of grass roots and common forbs and graminoids was reported by Allen (2001) and Michelsen et al. (1993), respectively. In this investigation, levels of root colonization were relatively high for both Cordia (25 to 57%) and Millettia (33 to 62%) reflecting their mycotropic nature. This is comparable with 27 to 57% root colonization for lime grown in three agroecosystems reported by Michel-Rosales and Valdes (1996). Difference in AM colonization in the soil beneath Cordia and Millettia trees grown at enset-coffee and enset, and at maize plots examined in this study, probably resulted from interactions between tillage practices and species composition/cover. The relatively higher plant cover and richness at enset plots may explain differences in mycorrhizal infection between soil samples collected from various plots. At tree enset-coffee and tree enset plots, the infection of new roots probably occurred directly from the roots in a manner more rapid and efficient way than from germinating spores. Moreover, as being a perennially dominated and more diverse system, the tree enset-coffee and

Table 5: Mean proportion of colonised roots of maize and Millettia seedlings grown in nursery soils taken from under the canopy of Cordia and Millettia trees grown in different fields. Mean ± std of three replications.

Plot type	Colonised root of maize seedling (%)	Colonised root of Millettia seedling (%)		
Tree-enset-coffee	51.9a ± 13.6	32.4a ± 8.4	27.4 ± 10.2	19.5 ± 10.6
Tree-enset	42.9ab ± 11.4	48.2ab ± 14.3	21.7 ± 8.1	26.0 ± 8.4
Tree-maize	24.9b ± 13.2	26.4b ± 9.8	15.2 ± 8.2	12.4 ± 7.1

Table 6: Mean proportion of colonised roots of maize and Millettia seedlings grown in nursery soils taken at increasing distances from the trunk under Cordia and Millettia trees grown on maize fields. Mean ± std of three replications.

Distances from trunk	Colonised roots of maize seedling (%)	Colonised roots of Millettia seedling (%)		
CT (0.75 m)	31.1 ± 16.9	25.2 ± 12.9	12.5 ± 9.5	15.4 ± 9.5
Mid Canopy	25.6 ± 6.72	26.8 ± 10.5	11.1 ± 3.1	11.2 ± 8.8
Canopy edge	18.1 ± 15.45	27.1 ± 10.3	15.9 ± 10.7	10.5 ± 3.8
Open-maize field	24.0 ± 13.42	23.1 ± 14.9	19.8 ± 13.0	11.4 ± 6.1

tree enset combination plots are probably suitable to host various AM fungi species. It is possible that due to low frequency of tillage practices for these tree-enset coffee and tree enset plots, plant roots suffer less damage and the hyphae network is less disturbed. This is in agreement with Michel-Rosales and Valdes (1996) who reported a higher percentage (57%) of root colonization for lime trees grown in gardens than those grown (27%) in plantations. Boddington and Dodd (2000) reported a greater length of extra-radical mycelium of AM fungi in soil under agroforestry systems than in a monoculture. McGonigle et al. (1999) also reported that reduced tillage increased the mycorrhizal association. However, different species of AM fungi that colonize host roots can respond to soil disturbance in different ways (Merryweather and Fitter, 1998). Although not quantitatively and qualitatively assessed in this study, it is possible that tree species or maize might selectively favor only certain AM fungal species, which may initiate relatively low root infection or are less compatible at this stage of development.

Slight spatial differences were detected in levels of mycorrhizal colonization. The lack of significant differences among plots at increasing lateral distances from tree trunks could be attributed to the fact that roots might be extended at least up to the edge of the crown with uniform distributions of AM fungal infection.

4.0.3 Root colonization in nursery

At nursery level, relatively more intensive root colonization was observed for maize plants than for Millettia plants. The literature does not appear to contain details of mycorrhizal dependency of Millettia. The high colonization of maize could be due to its high mycorrhizal dependency, as it is well known to be a facultative host for AM fungi (Sieverding, 1991). However, soil under Cordia and Millettia trees at enset-coffee and at enset plots resulted in significantly higher levels of maize root colonization than in soil from beneath tree-maize and open-maize plots.

The difference in number of spores that occurred as a result of differences in tree-crop plots and open-maize were reflected in the levels of root colonization of maize and Millettia grown in the nursery. Significantly positive correlation of spore numbers in field soil with the level of colonization on maize roots (Table 7) indicates that the original set of AM fungi might play a role in the functional relationship between the roots and the fungi, as well as to support hyphae for nutrient uptake. These results agree with the conclusion that level of colonization was positively correlated with the number of AM fungi spores (Simpson and Daft, 1990; Frank and Morton, 1994; Frioni et al., 1999; Oliveira and Sanders, 1999). On the other hand, it is in disagreement with the lack of relationships between spore number and root colonization as suggested by Merryweather and Fitter (1998).

The relatively poor correlation of the spore number in the soil samples before planting and level of root colonization in Millettia plants could partially be explained by the low number of suitable spore of AM fungi species, lack of compatibility of AM fungi or most probably a too small Millettia plant not capable of acting as an effective host at this stage of development. The low proportion in the extent of AM colonization of maize and Millettia roots with increasing distances from the tree trunk was not significantly related to the number of spores in field soil.

4.0.4 Plant size

Both maize and Millettia plants with a high level of root colonization attained higher fresh weight when grown in soil under Cordia at enset-coffee, and Millettia at enset plots. The differences in fresh weight might also be related to the differences in the level of soil fertility, since soil fertility indicators under tree-enset combinations were relatively higher than in all other soil samples (Table 1). Apart from these, there was no readily apparent explanation of the difference in fresh weight between plants grown on soils from different plots.

Regarding AM association, we believe that this is the first report to deal with Cordia and Millettia trees in the Sidama traditional agroforestry land use systems. It could contribute the base line data necessary for future in-depth studies, on the relationship to environmental components of this complex system. For better understanding, of

Table 7: Pearson correlation between log-transformed spore density and arcsin-transformed proportion of AM colonization of maize and Millettia seedlings grown in soils from under Cordia and Millettia canopy of different fields and in soils from open maize fields.

Species	r	p	n
Maize	0.340	0.043	36
Millettia	0.131	0.447	36

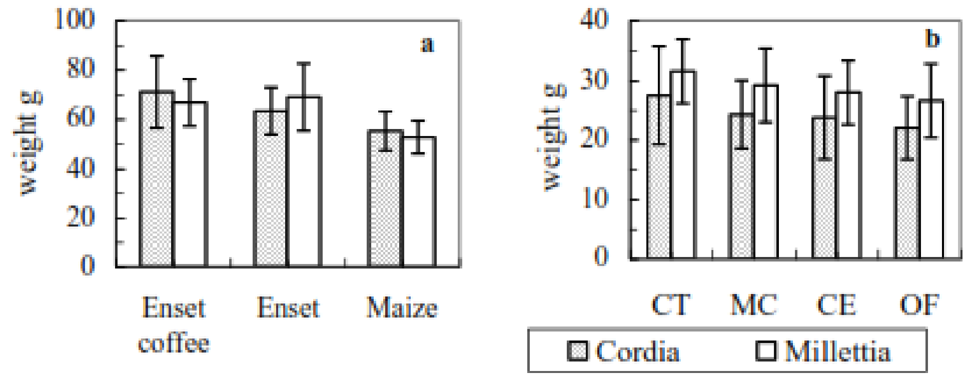

Figure 2: Mean and standard error fresh weight of maize plants grown on soils from beneath Cordia and Millettia trees (a) grown at enset and maize fields and (b) at laterally increasing distances from tree trunks at maize fields. CT = distance at 0.75 m, MC = at mid-canopy, CE = at canopy edge, and OF = at open maize field.

the factors that influence AM colonization, continuous sampling is needed, during both dry season and rainy seasons. Furthermore, detailed investigations are needed to understand the reasons for occurrences and species diversity of AM fungi as well as the predominant species.

5 Conclusions

In conclusion, tree-enset-coffee and tree-enset combinations can induce a higher number of spores and level of colonization than tree-maize plots or the open maize field. Soil under Cordia and Millettia in maize fields had a significantly lower number of spores than in enset fields. The number of spores did not vary significantly with increasing distance from the tree trunk. Although not statistically significant, differences were observed in the degree of root colonization for both Cordia and Millettia trees grown in different plots. In general, the proportions of colonized roots were in the following order: tree enset coffee ¿ tree enset ¿ tree enset maize for Cordia trees and tree enset ¿ tree enset coffee ¿ tree enset maize for Millettia trees.

Soil under Cordia and Millettia trees in enset coffee and enset plots resulted in significantly higher levels of maize root colonization than soil under tree maize and open maize plots. The high number of spores in the field soil had a positive, statistically significant effect on the colonization of maize and Millettia plants in the nursery. Both maize and Millettia plants with high root colonization achieved higher fresh weight when grown in soil under Cordia in enset coffee and Millettia in enset plots.

Table 8: Spore density g-1 soil of AMF recorded at different places under three major land uses.

Land use	Country	Site/species/forest type	Spore no. g-1 dry soil	References
Tropical natural forest	Argentina	Semi-humid deciduous	5-23	Fontenla et al., 1998
Tropical natural forest	Mexico	Deciduous moist forest	2-28	Allen et al., 1998
Tropical natural forest	Costa Rica	Moist forest	120	Johnson and Wedin, 1997
Tropical natural forest	Cameroon	Deciduous moist forest	2-5	Musoko et al., 1994
Tropical natural forest	China	Deciduous moist forest	6-19	Zhao et al., 2001
Woodland	UK	Oak	1-5	Merryweather and Fitter, 1998
Woodland	UK	Sycamores	1-50	Merryweather and Fitter, 1998
Agriculture	Colombia	Cassava	7-28	Sieverding, 1991
Agriculture	USA	Orchard	5-36	Reich and Barnard, 1984
Agroforestry	Senegal	Plantation	1-8	Ingleby et al., 1997
Agroforestry	Indonesia	Tree-maize	4-28	Boddington and Dodd, 2000
Agroforestry	Mexico	Citrus/dry tropics	1-4	Michel-Rosales and Valdes, 1996

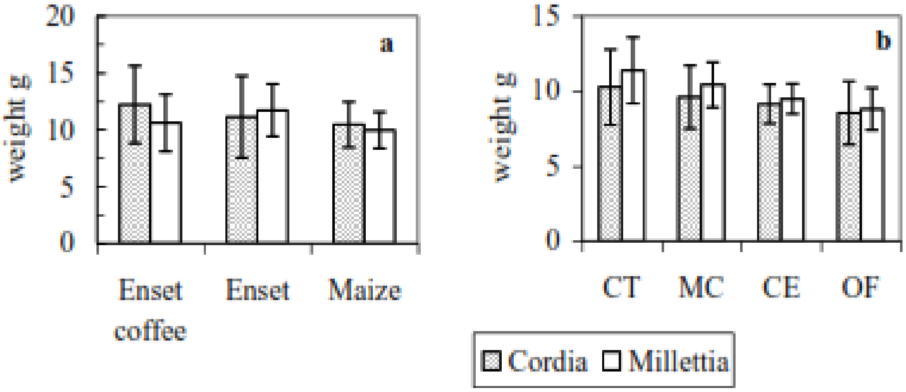

Figure 3: Mean and standard error fresh weight of Millettia plants grown on soils from beneath Cordia and Millettia trees (a) grown at enset and maize fields and (b) at laterally increasing distances from tree trunks at maize fields. CT = distance at 0.75 m, MC = at mid-canopy, CE = at canopy edge, and OF = at open maize field.

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Journal of Forestry and Natural Resources (JFNR)

Authors Guideline

Abbreviation J. for. nat. resour.

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1. Editorial policy and Author's Guidelines

1.1. Background

The Journal of Forestry and Natural Resources (J. for. nat. resour., or JFNR) (JFNR) is a peer- reviewed online open-access published annually by the Wondo Genet College of Forestry and Natural Resources, Hawassa University. JFNR publishes original research findings in all subject-matter areas of forestry and natural resources. It seeks disciplinary and interdisciplinary research articles, review articles, featured articles, and short communication.

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1.2. Aims and Scope

Aims:

- serve as a communication medium among scientific communities in forestry, natural resources research, and other related fields
- publish original and innovative scientific works relevant to forestry and natural resources situation of Ethiopian as well as global problems
- encourage Ethiopian researchers, graduates, and postgraduate students to align their disciplinary and interdisciplinary researches in the direction of solving major problems in the areas of forestry and natural resources and conservation needs of the country, and
- serve as a platform to foster scientific knowledge sharing among researchers, scientists, policymakers, and practitioners working on sustainable forestry, green economy transition, issues of sustainable development goals, desertification, and dryland agriculture and forestry, combating desertification and drought, natural resource management, and conservation and other related topics.

Scope of the journal

The JFNR publishes scientific articles related to social, economic, policy, and environmental aspects: forestry, agroforestry, wildlife, soil, water and land resources, renewable energy, tourism, urban forestry, and greening, environmental science, GIS, and remote sensing.

2. Submission Guidelines

Submission system: Online

General contents of the journal JFNR uses the following format:

2.1. Research articles

These papers treat both disciplinary and interdisciplinary (thematic) types of researches encompassing basic and applied researches, graduate and postgraduate studies researches related to forestry and natural resources. JFNR will consider for publication articles from the regional and international forest and natural sources covering tropical and subtropical regions.

2.2. Review articles

Encompass critically reviewed scientific papers covering the state of the art knowledge in various aspects of forestry and natural resources. Review articles will be submitted by experts in the fields of forestry and natural resources with their expertise and experiences or invited by the editor-in-chief, associate editors, or editorial board.

2.3. Featured articles

These include topics in forestry and natural resources management, conservation, utilization, education, and non-conventional research articles.

Technical papers in the areas of forestry and natural resources development encompassing different aspects of socio-economics, policy issues, wildlife, environment, rehabilitation efforts and forestry and natural resources inventory and surveys, biodiversity conservation, processing and value addition of forest products, agroforestry, non-timber forest products, medicinal plants and their domestication and commercialization, integrated watershed management, green economy transition, green initiative related studies, climate change and development, land degradation and drought, aquatic ecosystem management, fisheries, etc.

2.4. Short communications

This includes articles of brief scientific notes on preliminary results, scientific observations, experimental techniques, and recent technological advances in forestry and natural resources. It also included information on specific cases and limited applications. Manuscripts for this column should not be more than six typed pages. They should have a brief abstract and not contain more than two figures and/or two tables.

2.5. Book Reviews

A critical evaluation of recently published books in any discipline of forestry and natural resource sciences will be published under this column.

3. Manuscript evaluation process

The manuscript must be written and prepared in English. Grammar and language quality are the responsibilities of the authors to submit the manuscripts in clear and communicable language quality. Once manuscripts are submitted the editor-in-chief or associate editors will check the manuscript for possible plagiarism results, originality of the work and contents of editorial policy and scope, and authors' guidelines of JFNR. Submission of a manuscript to the Journal must be accompanied by a cover letter stating that no similar paper, other than an abstract or an oral presentation, has been or will be submitted for publication elsewhere. The manuscript should be submitted online or by email to the editorial manager, who gives the manuscript number and notifies the author of receipt of the manuscript. The manuscript number will be used in all correspondence regarding the manuscript. The editor-in-chief will consult associate editors to decide whether the manuscript is within the scope of JFNR and whether the contents are worthy of further review. Manuscripts that do not meet the minimum criteria will be returned back to the author within two weeks' time. Those that meet the minimum criteria will be passed to associate editors for quick check-ups and suggestions of potential reviewers. The associate editor is an expert selected in certain disciplinary areas and who has a wide network among professionals in their field of specialization.

3.1. Peer review process

The peer-review process will follow double-blind where the manuscript will first be evaluated by the editor-in-chief or associate editors, followed by at least two reviewers. The names of the authors will be kept anonymous while sending them to the reviewers. At least one of the reviewers will be out of the staff of the publisher institute. If the reviewers recommend publication without any change(s) and the associate editors agree(s), the manuscript and the reviewer's comments are sent to the editor-in-chief who will notify the author accordingly. If the reviewer and the associate editor recommend that the manuscript could be published after revision, the editor-in-chief will return the manuscript to the author for minor or major revision. If the reviewer and the associate editor recommend that the manuscript be rejected, the associate editor sends the manuscript and the reviewers' comments to the editor-in-chief, and the editor-in- chief will check the comments forwarded by reviewers and associate editor to make a decision and return to the authors. If very different comments and decisions are observed between or among reviewers, a third or fourth reviewer will be invited to resolve the issue. The author whose manuscript is released has the option of appealing to the editorial board. The first review process will take 6-8 weeks.

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Authors whose manuscript has been accepted for publication will receive a letter of acceptance. The authors will also receive the proofreading to send their opinion in five days. The pdf version of the published manuscript will be sent to the author and co-authors via their email addresses and also will be available online on the website of the college and university. The hard copy of published articles will be dispatched to various institutions upon request free of charge.

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Reviewers are requested to evaluate the manuscript on originality of the work, state of the art and nobility of the study topic, relevant objectives, soundness, latest and appropriate methodology, results in quality to address the objectives, adequate discussion, and relevant conclusion made.

And also, the way references are presented both in the text and reference lists. Reviewers are expected to give their comments and suggestions clearly (referring to the line numbers in the paper) to the authors to assist the author (s) to address all comments and suggestions given. Language correction is not part of the review process but suggestions can be made by reviewers.

3.3. Submission checklist

You can use this list to carry out a final check of your submission before you send it to the journal for review.

One author has been designated as the corresponding author with contact details:

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All necessary files have been uploaded:

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- Ensure all figure and table citations in the text match the files provided Further considerations
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Where the family name may be ambiguous (e.g., a double name), please indicate this clearly. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name, and, if available, the e-mail address of each author.

Corresponding author: Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. Ensure that telephone and fax numbers (with country and area code) are provided in addition to the the e-mail address and the complete postal address.

3.5. Changes in Authorship

Change in authorship requests is only made by the corresponding author to editor-in-chief.

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The manuscript should be prepared in Times New Roman with 11 font sizes, double space, and 2.5 cm marginal indentions on all sides. The maximum number of words should be 8000. The first page should contain the full title of the manuscript, the name(s) of the author(s) including address (es), and the institution(s) in which the research was carried out. For ease of communication, authors are requested to include their email addresses. For manuscripts with multiple authors, an asterisk should indicate the author to whom all correspondence is to be addressed.

Second and consecutive paragraphs after a heading should be indented while the first paragraph after a heading should start flush left. No space should be left between two consecutive paragraphs. Scientific names should be written in full when mentioned for the first time in the text. They should be italicized. Subsequent citations should abbreviate the genus name.

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The title of the manuscript should be concise, descriptive, in good order, and carefully chosen. It should clearly reflect the contents of the article.

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This appears on the second page after the title. The abstract should reflect the concise contents of the paper. It should not exceed 250 words and must include a brief background on the study topic, the rationale for the study, objectives, methods used, results, and a conclusion. References and uncommon abbreviations should be avoided. Keywords should be up to five words, separated by a comma and in alphabetical order.

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This section of the manuscript should include state of the art of background on the topic being studied, an in-depth description rationale of the study, objectives of the study, hypothesis, and significance of the study. It should provide a brief review of literature, limited to information essential to orient the reader.

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sub-headings under this section include specific study site description and selection, sample layout (experimental design) or survey methods, methods of data collection, and data analysis.

4.5. Results:

The major findings in response to objectives set in the study. Be selective and focus on reporting your results.

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This can be written in a separate section or can be part of the discussion. It should also be concise, clear, and align to stated objectives and major findings.

4.8. Funding

Information that explains whether and by whom the research was supported

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Include appropriate disclosures

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Collate acknowledgments in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof-reading the article, providing finance, logistics, etc.).

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- In the case of Ethiopian names, the author's given (first) name precedes that of the
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Paper in proceedings

Tesfaye Awas, Sebsebe Demissew (2009) Ethnobotanical study of medicinal plants in Kafficho people, Southwestern Ethiopia. In: Svein Ege, Harald Aspen, Birhanu Teferra and Shiferaw Bekele, Trondheim (Eds.), Proceedings of the 16th International Conference of Ethiopian Studies. Addis Ababa, Ethiopia.

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Follow internationally accepted rules and conventions: use the international system of units (SI). If other quantities are mentioned, give their equivalent in SI.

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