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Estimating the Amount of Litterfall and Rate of Decomposition for Cordia Africana and Croton Macrostachyus From Agroforestry Systems in the Aba Gerima Watershed, Amhara Region, Northwestern Ethiopia

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COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

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POSTGRADUATE PROGRAM

M.Sc. IN AGROFORESTRY

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M.Sc. Thesis

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M.Sc. Thesis

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (M.Sc.) in Agroforestry

Department: Natural Resource Management

Advisor: Habtamu Assaye (PhD)

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Bahir Dar, Ethiopia

DECLARATION

I declare that this thesis titled "**Estimating the Amount of Litterfall and Rate of Decomposition for *Cordia africana* and *Croton macrostachyus* from Agroforestry Systems in the Aba Gerima Watershed, Amhara Region, Northwestern Ethiopia**" submitted in partial fulfillment of the requirement for the award of the degree of master of science in "**Agroforestry**" to the graduate program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Kerebih Aragaw Fentie** (ID. No. BDU1401227) is an authentic work carried out by himself under the guidance of his supervisor. The content embodied in this project work has not been submitted earlier for an award of any degree or diploma to the best of our knowledge and belief.

Kerebih Aragaw Fentie		01/11/2016 E.C
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ADVISOR APPROVAL FORM

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Natural Resource Management

Approval of thesis for defense

I hereby certify that I have supervised, read, and evaluated this thesis/dissertation titled "**Estimating the Amount of Litterfall and Rate of Decomposition for *Cordia africana* and *Croton macrostachyus* from Agroforestry Systems in the Aba Gerima Watershed, Amhara Region, Northwestern Ethiopia**" by **Mr. Kerebih Aragaw Fentie** prepared under my guidance. I recommend the thesis/dissertation be submitted for oral defense.

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Approval of thesis for defense result

As members of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr. Kerebih Aragaw Fentie** entitled **"Estimating the Amount of Litterfall and Rate of Decomposition for *Cordia africana* and *Croton macrostachyus* from Agroforestry Systems in the Aba Gerima Watershed, Amhara Region, Northwestern Ethiopia".** We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in **Agroforestry.**

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LIST of ABBREVIATION

AF	Agroforestry
ANOVA	A One-Way Analysis of Variance
BDUSL	Bahir Dar University Soil Laboratory
BDZW	Bahir Dar Zuria Woreda
CAES	College of Agriculture and Environmental Sciences
CO_2	Carbon dioxide
CBD	Complete Block Design
DSRD	Dry Season Rate of Decomposition
Ha	Hectare
HFA	home field advantage,
HGA	Homegarden Agroforestry
ICRAF	International Centre for Research in Agroforestry
TN	Total Nitrogen
OM	Organic Matter
Av. P	Available Phosphorus
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
THSD	Tukey Honest Significant Difference
WSRD	Wet Season Rate of Decomposition

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ABSTRACT

The selection and use of appropriate agroforestry tree species that maintain soil nutrients thereby improving productivity remains to challenge in low-input agricultural systems. Therefore, this research focuses on two agroforestry tree species, C.macrostachyus and C.africana. The objective of this study was to estimate the amount of litterfall and rate of decomposition in the Aba Gerima watershed. The decomposition rate was analyzed using the litter-bag technique, while soil and litter samples were used to analyze the soil's physicochemical properties. The litterfall was collected every 15 days using litter bags from February to May 2023. Besides, the rate of decomposition was determined using RCBD design; considering species types as the main factor and incubation period (30, 60, 90, and 120 days) in the dry and wet seasons of the sub-plot factors. Soil samples were collected from four directions (north, south, east, and west) beneath and outside the canopy of each tree species. Composite soil samples were then prepared from these collections, and selected soil physicochemical parameters were analyzed. Results showed that the total amount of litterfall in four months was greater for C.africana than for C.macrostachyus at 5.89 t/ha and 5.19 t/ha, respectively. Regarding the rate of decomposition, C.macrostachyus decomposed significantly faster than C.africana for the incubation period (30-120 days) with a rate constant (k) of 0.012 to 0.04 g/days and 0.13 to 0.04 g/days for C.macrostachyus and 0.01 to 0.02 g/days and 0.09 to 0.04 g/days for C.africana for the dry and wet seasons, respectively. The mass loss is 94% and 47%; C.macrostachyus recorded a greater mass loss than C.africana during the 120 days of the dry season. However, the wet season from 120 days had no significant difference in mass loss between the two tree species. The effect of tree species in the soil nutrient input as observed from C.macrostachyus was significantly higher than that of C.africana. Hence, Utilize litterfall and organic matter from the two indigenous tree species as mulch or compost to enhance soil fertility. Therefore, Raise awareness and encourage the community to conserve these agroforestry trees in cropland to improve soil fertility and crop productivity.

Keywords: litterfall, decomposition rate, soil nutrient content, *C. macrostachyus*, *C. africana*.

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Chapter One: INTRODUCTION

1.1 Background and Justification

Agroforestry (AF) is a dynamic, ecologically oriented plan for managing natural resources that diversifies and sustains smallholder production on farm and range land for greater social, economic, and environmental advantages (Leakey, 2017). In land use systems known as agroforestry, woody perennials (trees, shrubs, etc.) are grown alongside herbaceous plants (crops, pastures) or livestock in a spatial arrangement, a rotation, or both (Dawson et al., 2016). Generally, there are interactions between trees and other components of the system on both an ecological and economic level (Munroe & Isaac, 2014). In addition to lumber, the tree species also provide firewood, farm tools, leaves for fodder, compost fertilizer, *etc*. (Shial & Mohanty, 2018).

Litterfall is considered to be one of the most critical ecological processes in agroforestry systems and is a key component of the system's biogeochemical cycle of matter (Liu et al., 2004). Leaf litter either as natural litterfall or through pruning activities is the two types of litter released by trees, shrubs, and/or herbs. Such litterfall production allows nutrients to be returned to the soil (Pandey et al., 2007). The generation of litterfall, the most decomposed material, is one of the most important components of the nutrient cycle in an ecosystem and is also critical to the maintenance of ecosystems (Andivia et al., 2013). The quantity and quality of litter generation and the process of decomposition are significant factors influencing soil fertility through nutrient cycling, carbon allocation, and the genesis of soil organic material in plantation settings, where a portion or the entirety of the biomass accrued during the growth phase is removed from the area post-harvest (Ambachew Demessie et al., 2012).

Decomposition is a process that breaks down dead organic matter into its parts: carbon dioxide, nutrient-rich minerals, and water (Petit-aldana et al., 2019). It is a series of physical and chemical processes that reduce litter and foliage to their basic chemical components, and is the main mechanism in nutrient recycling within ecosystems (Aerts, 1997). This is one of the most significant ecological events as it adds nutrients to the soil (Aber et al., 1991). Wide ranges of decomposing organisms, including bacteria, fungi, and decomposing agents, are responsible for this process Austin et al., 2014). Bacteria play a significant role in the decomposition of dead animal matter, while fungi are the main decomposers of dead plant matter. The main process, known as lighting decomposition, is highly complex and can be further divided into many sub-processes (Petit-aldana et al., 2019). The critical link between autotrophs and heterotrophs is the dead organic matter on the forest floor (Bhalawe et al., 2012). The management of regions under natural, agricultural, or forestry systems benefits greatly from the knowledge of organic matter degradation (Cardona-Calle & Sadeghian-khalajabadi, 2005). Although abiotic factors have an impact on soil fauna, most degradation is biological. The most important elements influencing litter decomposition are climate, soil properties, quality of the decomposing organic waste, and soil organisms (Swift et al., 1979). The environment in which decomposition occurs, the chemical composition of leaf litter, and the type and number of decomposing organisms present are the main factors affecting decomposition (Polyakova & Billor, 2007).

In agroforestry systems, nutrients come from a variety of sources, including rain, fertilizers, and organic residues. These nutrients can then accumulate in the soil, cropland, shade trees, or litter. In addition, nutrients can be translocated by crop yields, leaching, runoff, and denitrification processes. Interactions between plant layers include residue deposition, infiltration, absorption, and mineralization (Petit-aldana et al., 2019). As senescent plant debris is broken down and then incorporated into soil organic matter along with microbial products, muddle decomposition is an essential first step in the carbon and nutrient cycle in terrestrial ecosystems. The relevance of plant-soil interactions influencing the biogeochemical cycle is illustrated by the discovery of scattering affinity effects that result in decomposition being accelerated in the environment in which it originally ascended home field advantage (HFA)(Austin et al., 2014).

The rate at which forest litter decomposes and consequently litterfall affects soil fertility and primary productivity in forest ecosystems, as well as the regulation of nutrient cycling. Forest litter also serves as an input-output system for nutrients (Björn, 2000). Energy flow, primary production, and nutrient cycling are regulated by the rates at which forest litter accumulates and decomposes in forest ecosystems (Olson, 1963). Many researchers have shown that there are differences in the decomposition rate of leaf litter from species to species (Swift et al., 1979; Koukoura et al., 2003; Pandey et al., 2007; Nivethadevi et al., 2022). Regulation of ecosystem carbon storage and nutrient cycling is heavily dependent on waste removal (Ettema & Wardle, 2002; Santiago, 2007). The nutritional status of an ecosystem is strongly influenced by the nutrient dynamics of the litter and its decomposition rate, which in turn has a significant impact on plant productivity (Knorr et al., 2005; Van Der Heijden et al., 2008). In agricultural environments, a more diversified soil fauna community causes faster decomposition but has minimal effect on the overall rate of decomposition (Nivethadevi et al., 2022).

Organic matter is provided by adding the leaf litter which improves the water-holding capacity, microbial activity, and organic carbon content (Bhalawe et al., 2012). Organic matter, produced by the decomposition of litterfall, plays a crucial role in the processes of soil formation and the nitrogen cycle (Pandey et al., 2007). After being broken down by microbes, the organic matter eventually converts into organic carbon compounds that help improve soil structure and provide nutrients to plants (Austin et al., 2014). The transfer of nutrients and energy from living biological components to the soil is a key mechanism of nutrient recycling, as most of the organic matter (OM) produced by plants is returned to the soil as waste. Catabolism mechanisms play an important role in the cycling of these nutrients, converting complex organic molecules into basic forms that plants can use for healthy growth and development (Fayiga & Saha, 2016).

In the study area, farmers maintain or plant valuable tree species such as *Croton macrostachyus, Cordia africana, Milletia ferruginea, Albizia gummifera, Mangifera indica, and Persea American* in their homegarden. The relative abundance of trees in residential areas compared to croplands indicates improvement of soil organisms, soil enhancement, maintaining soil fertility, and sustainable productivity.

1.2 Statement of the Problem

In Ethiopia's traditional agroforestry system integrating trees such as *Cordia africana, Croton macrostachyus, Milletia ferruginea, Albizia gumifera, Mangifera indica, Acacia abyssinica*, etc. are cultivated in the cropland as well as homegarden agroforestry practice. These practices significantly contribute to enhancing the physical and chemical characteristics of the soil and crop yield. When moisture is available, these tree species grow comparably to eucalypts and are less susceptible to drought than eucalypts, which are known to be drought tolerant (Dechasa Jiru, 1999; Gindaba et al., 2004). However, the role of tree/shrub species in multiple agroforestry practices can increase soil nutrient supply through nitrogen fixation, improve soil structure, and reduce soil erosion, and nutrient losses (Hailie Shiferaw et al., 2021). Some studies have additionally proposed that during the early phases of litter decomposition, nitrogen can serve as a reliable indicator of the rates of decomposition, whereas during the later stages, chemical compounds such as lignin may play a more significant role (Liu et al., 2007). Research carried out by (Abraham Mahari, 2014) in the area of Lalibela, located in the northern region of Ethiopia, an exploration was conducted to examine the rate at which decomposition occurs and the pattern of nutrient release for *Croton macrostachyus* and *Cordia africana*. Similarly, Kasu Hailu, (2022) in Jima, situated in the southwestern part of Ethiopia, investigated the rate of litter decomposition and the pattern of nutrient release among specific indigenous agroforestry tree species. These findings offer substantial evidence to support the development of agroforestry practices.

One of the most important things in agroforestry is selection of the right tree species based on nutrient cycling. However, the plants in the highlands of north-western Ethiopia have not been sufficient for the amount of litterfall and subsequent decomposition rates. Litterfall is often used for firewood. Farmers would have benefited more by incorporating tree litter into the soil, which can enhance the overall productivity and sustainability of their agricultural land. Hence, due to the misuse of litterfall, soil fertility, and soil organic matter are decreasing (Hailie Shiferaw et al., 2021). In general, there is a lack of awareness of the role of trees in maintaining soil fertility and hence sustaining agricultural productivity. Therefore, the goal of this study is to determine the amount of litter released and the rate of decomposition and incorporation into the soil nutrient content of input for *Croton macrostachyus* and *Cordia africana* species. It is also to find out which species of tree decomposes faster.

1.3 Objective of the Research

1.3.1 The general objective of the study was

To investigate the amount of litterfall and rate of decomposition for two indigenous trees *Croton macrostachyus and Cordia africana* from the agroforestry system in the Aba Gerima watershed.

1.3.2 The specific objectives of the study were

- ✓ To Quantify and compare the amount of leaf litterfall from *Croton macrostachyus* and *Cordia africana* from the watershed of the study area.
- ✓ To Measure and compare the rate of decomposition of litterfall for *Croton macrostachyus* and *Cordia africana* in the watershed.
- ✓ To determine the effect of the litterfall from *Croton macrostachyus* and *Cordia africana* on the soil nutrient content.

1.4 Research Question

1) How much is the amount of leaf litterfall of *Croton macrostachyus* and *Cordia africana* from the Aba Gerima watershed?
2) What is the rate of decomposition of Croton *macrostachyus* and *Cordia africana* litterfall?
3) How significant is the contribution of the litterfall from *Croton macrostachyus* and *Cordia africana* to the soil nutrient content?

1.5 Significance of the Study

The amount of litter, the pattern of litter decomposition rate, and the effect of tree species on soil nutrient input have important implications for the use of *Croton macrostachyus* and *Cordia africana* as agroforestry tree species in the study area. Comparing the amount of litterfall, decomposition rates and soil nutrient content between different tree species can help us understand the role of species diversity in ecosystem functioning (Abraham Mahari, 2014). It can provide insights into how different tree species contribute to the overall nutrient cycling processes. The decomposition of litterfall contributes to the formation of organic matter in the soil, which is crucial for maintaining soil fertility. By studying the decomposition rates of different tree species, we can assess their contributions to soil fertility and nutrient availability. Furthermore, in agroforestry land-use systems, species characterized by slow decomposition rates are beneficial for the long-term build-up of soil organic matter, whereas those species that rapidly decompose are vital for boosting the soil nutrient condition. Overall, studying litterfall and decomposition rates from two tree species can provide valuable information on ecosystem dynamics, nutrient cycling, and the role of tree species in maintaining ecosystem health and function.

1.6 Scope of the study

The scope of this study involves quantifying the amount of litterfall and determining the decomposition rates of two indigenous tree species, *Cordia africana* and *Croton macrostachyus*, within agroforestry systems in the Aba Gerima watershed, located in the Amhara Region of Northwestern Ethiopia. It encompasses the collection and analysis of litterfall data, monitoring decomposition processes, and examining the associated soil physicochemical properties. By comparing these parameters beneath and outside the tree canopies, the study aims to provide insights into the ecological roles of these species in nutrient cycling and soil health within the agroforestry systems of the watershed.

1.7 Limitations of the study

The findings may be specific to *Cordia africana* and *Croton macrostachyus* in the Aba Gerima watershed and may not be easily applicable to other regions or tree species due to variations in environmental conditions, soil types, and vegetation composition. In this study, some factors such as expensive of nylon mesh, extreme rainfall, human activities (e.g., land use changes), animal trample, and financial scarcity could affect litterfall and decomposition rates but may not be fully accounted for in the study. Addressing these limitations with transparency in this study methodology and careful interpretation of results can enhance the validity and reliability of the findings regarding litterfall and decomposition rates of *Cordia africana* and *Croton macrostachyus* in the Aba Gerima watershed.

Chapter Two: LITERATURE REVIEW

2.1 Definition of Agroforestry

Agroforestry is the artwork and technology of developing woody and non-woody plants collectively on the same unit of land for agreed benefits (Dawson et al., 2016). It is the use of land for the combination of agriculture and forestry. In other words, it is the practice of growing tree crops or other fast-growing trees along with the main crop. It is also one of the important techniques of sustainable land management, which involves a combination of different practices in agriculture, horticulture, forestry, and animal husbandry (Munroe & Isaac, 2014).

Agroforestry is the collective period for land use structures and technology where perennials (e.g. trees, shrubs, palms, or bamboo) and crops or animals are deliberately used on the same plot in a spatial and temporal arrangement as a dynamic, ecologically based management system for natural resources that diversifies and sustains production through the incorporation of trees on farms and in agricultural landscapes or through the production of agricultural products in forests to provide greater economic, social and environmental benefits to land users (ICRAF's, 1998).

Today, almost a billion hectares of agricultural landscapes already have more than 10% tree cover, and an estimated 1.6 billion hectares of land worldwide have the potential to be agroforestry in the foreseeable future (Kumar et al., 2014). Globally, about 560 million people live in agricultural ecosystems with more than 10% tree cover, accounting for 31% of all people in inhabited arm lands. According to the ICRAF definition, around 22.2 million square kilometers of arable land and at least 10% of trees are used for agroforestry purposes worldwide (Scherr et al., 2009; Kumar et al., 2014). A high percentage of tree cover is found on almost every continent in the world, with the highest in Central America and Southeast Asia and although Africa has a lower percentage of tree cover at a continental scale, the most prevalent agricultural system in Africa is what is known as agroforestry parkland (scattered trees in farmland), making Africa a typically forested continent in agricultural areas (Zomer et al., 2009).

2.1.1 Homegarden Agroforestry Practice in Ethiopia

One of the tropical nations with widespread homegarden agroforestry in the highlands is Ethiopia (Habtamu & Zemede, 2011). The main element of the Ethiopian farming system is agroforestry. Homegarden agroforestry is classified as the agro-silvopasture type based on its constituent parts (Nair, 1993) where the system includes trees, crops, and animals. Homegardens, parklands, and woodlots are the three main forms of agroforestry activities (Aklilu Nigussie et al., 2015).

In the cereal crop-based agricultural method, vegetables and fruits are cultivated in the homegarden together with staple food crops including *barley*, *teff* (*Eragrostis Tef*), *Wheat*, and *Maize*. Parkland agroforestry is the name for this particular type of agroforestry system. In Ethiopia's traditional agroforestry systems known as "parklands" valuable, naturally growing trees are safeguarded and nurtured on crop and grazing lands. Perennial-crop-based homegardens are a kind of agroforestry system, wherein perennial crops, fruits, spices, vegetables, trees, etc. are produced inside the homegarden (Aklilu Nigussie et al., 2015). Woodlot agroforestry is the third kind of agroforestry system used in Ethiopia. The bamboo-based agroforestry in the lowlands is an illustration of woodlot agroforestry (Madalcho & Tefera, 2016).

Agroforestry(AF) in homegarden varies greatly in composition, structure, and function and is key for on-farm conservation, ensuring environmental well-being, and supporting livelihood systems (Habtamu & Zemede, 2011). The upper level is primarily made up of homegarden agroforestry tree species such as *Ficus spp., Cordia africana, Croton macrostachyus, Albizia gumifera, and Millettia ferruginea* as well as fruit trees like *Mango (Mangifera indica)* and *Avocado (Persea americana)*. The middle section is composed of dominant species like *coffee (Coffea arabica L.)*, an evergreen shrub, and a sizable non-woody perennial plant. Vegetables, spices, and herbs frequently occupy the lower section (Boz & Maryo, 2020).

2.1.2 Scatter Tree Agroforestry Practice in Ethiopia

In parklands, one or a few dominant species may prevail on a local scale or across large land areas with substantial variations in relative abundance, frequency, and overall species composition. Thus, scatter trees are often described by their dominant species (Jama & Zeila, 2005). The process of scatter tree establishment relies on traditional agricultural practices which include selective clearing of natural vegetation leaving only desired woody species on the land when establishing crop fields (Nikiema, 2005). Scatter trees can restore a significant proportion of tree cover over the long term, provide valuable shelter for livestock, and add to the character of the landscape (Race, 1993). As the width of the spacing among trees decreases, their effect on soil and water conservation increases (Nikiema, 2005). Moreover, these parkland trees have the advantage of increasing soil fertility by naturally fixing atmospheric nitrogen and/or by adding green manure to the soil through their leaves, roots, and other vegetative parts which can decompose easily (Race, 1993). For example, growing multipurpose woody species integrated with cereal crops in higher altitude basin areas was common in western Turkey (Tolunay et al., 2007)

2.1.3 Improved Fallow

Improved fallow is an agrisilvicultural practice and the components are arranged sequentially (Torquebiau & Akyeampong, 1994). It is a rotational fallow system where trees, usually fast-growing leguminous trees or shrubs are introduced into fallow systems for the restoration of soil fertility (Nair, 1993; Young, 1997). The purpose is to shorten the fallow period and increase the fertility of the soil by introducing high biomass-yielding species in rotation with annual crops (Nair, 1993; Young, 1997). Species that can be used include *Sesbania sesban, Cajanus cajan, Gliricidia sepium, Senna siamea, Leucaena leucocephala* and any other fast-growing species, and such species should be deep-rooted to ensure pumping up of leached nutrients from the sub horizon to the soil surface and have good coppicing ability(Nair, 1993).

2.1.4. Socioeconomic benefits of homegarden agroforestry

Due to its constituent high-value income crops and essential crops, homegarden agroforestry is more economically viable than other land use systems (Tesfaye Abebe, 2005). It also has the best performance among Ethiopia’s agroforestry systems. According to the study of Yeshimebet Ayele et al., (2014), homegarden agroforestry practices centered on coffee, enset, and cereal crops do extremely well economically when compared to parkland agroforestry. It provides a variety of goods, such as building supplies, food for people and animals, fuels, fibers, and shade. In Ethiopia, women tend homegardens more actively than other farms. In their homesteads, they selectively domesticate valuable species. Women use homegarden agroforestry products extensively (Galfato Gabiso and Tesfaye Abebe, 2015).

2.1.5. Contribution of homegarden and scatter trees to food security and nutrition

Agroforestry techniques used in tropical homegardens are known for their structural complexity and variety of cereal and other plant species (Megabit Beyene and Mukhtar Mohammed, 2018). Traditional food production methods like homegardens have been modified through many generations to suit certain ecological and cultural contexts. In many tropical and subtropical areas, they offer smallholder agricultural communities a year-round variety of healthful meals (Whitney et al., 2017). When there is a food shortage and the main crops fail, homegardens are highly helpful. They serve as a tool for the development of crop diversity, which can result in the production of a variety of resources, including wholesome foods, commercial goods, firewood, herbs, spices, and medicinal plants. Household gardens are another effective way for low-income groups to employ scarce resources like time, energy, money, and land. They provide a crucial means of generating revenue for women, who typically prepare meals for the family, without obviously challenging social and cultural restraints on their choices. Additionally, other family members can work, including the young and old (Akter et al., 2021).

The rural women plant vegetables and spices in these gardens as varied agricultural spaces to meet a variety of family requirements and earn some money (Garí, 2003). The variety of nutrient-rich crops grown in homegardens enhances local foods by supplementing main crops with high levels of vitamins and minerals, ensuring year-round access to nutritious vegetables even in times of resource scarcity, and promoting environmental stewardship. Plant genetic resources, agricultural experimentation, and the dissemination of traditional agricultural knowledge; to provide money if properly connected to markets; additionally, being close to the homestead aids women in balancing their lives. Furthermore, contributes to gender equality in agricultural productivity by combining farming and domestic tasks (Abiyot Berhanu & Zemede Asfaw, 2014).

2.2. Overview of Selected Indigenous Agroforestry Tree Species

2.2.1. *Croton macrostachyus* Hochst (Ex Del.)

One of Ethiopia’s indigenous tree species is *Croton macrostachyus*. *Croton macrostachyus* grows in Ethiopia at elevations between 500 to 3500 m a.s.l, though it is more common between 1100 and 2700 m.a.s.l. The species can be found on the borders of roads and in woodland margins. mostly in Ethiopia's moist lowlands, dry and moist midlands, and highlands of the area (Azene Bekele, 2007). By holding the water for a while and then releasing it gradually, the canopy of the *Croton macrostachyus* minimizes soil erosion and environmental degradation. Reduce soil Water infiltration which then surface runoff is increase when the canopy proportion is doing, resulting in more water in the soil. higher water availability, higher volume and discharge to springs, and shorter effective dry seasons are the results, which are comparable to those seen in other native tree species such as *Podocarpus falcatus* and *Ficus spp* (Negash Legesse, 1995). *Croton macrostachyus* is also a suitable choice for planting on hillsides where erosion is an issue which produces vast lateral roots to hold the soil. It is believed that *Croton macrostachyus* is vital for the reforestation of eroding dunes, degraded wastelands, and hill slopes due to its drought resistance and rapid growth. The species is suggested for planting on steep slopes to conserve soil and water (Azene Bekele, 2007). It is also one of the most important traditional treatments for a variety of illnesses affecting people and domestic animals. It is used medicinally to treat a variety of skin conditions, treat helminths and venereal infections, and cause abortions (Amare Getahun, 1976; Kasu Hailu, 2022).

2.2.2 *Cordia africana* (Lam.)

In Ethiopia, the rapidly expanding and highly prized *Cordia africana* tree is used to make fine furniture, doors, windows, cabinets, drums, beehives, joinery, paneling, and veneering (ICRAF, 1998). The *Cordia africana* can be found in open forest, riverine forest, borders and clearings in montane forest, and woodland grassland between 500 and 2200 m. a. s. l. Along with that, it can be found in woodlands, main or secondary forests, or both, at elevations between 1200 and 2200 m. a. s. l (Negash Legesse, 1995). It generates litter, which improves soil organic matter, and nutrient cycling, decreases soil bulk density, and increases soil biological activity are the effects of tree plantations on soils that are most effective (Paul et al., 2002). There has been a significant improvement in soil conditions as a result of planting trees, according to several studies that evaluated the ability of planted trees to restore soil fertility in degraded fields. Many studies have been conducted on the effects of trees like *Faidherbia albida, Cordia africana,* and *Croton macrostachyus* on soil characteristics and yields (Lugo, 1992; Mulugeta Lemenih, 2004; Abraham Mahari, 2014; Abey et al., 2023). The species sheds a lot of leaves during the dry season, which acts as mulch while helping in the cycling of nutrients through decomposition.

2.3. Leaf Litter and Rate of Decomposition

According to (Wood, 1974) decomposition of litter is defined as weight losses brought on by a variety of processes, such as leaching, biochemical degradation by microbes during passage through invertebrate intestines, and the removal and/or consumption of tissues by leaf-feeding invertebrates. Moreover, Berg & McClaugherty, (2008) defined it as any changes in biochemistry, appearance, and weight are referred to as decomposition. Furthermore, (Coûteaux et al., 2002) defined it to include both the simultaneous leaching of soluble chemicals and the mineralization and humification of lignin and cellulose by microorganisms. The procedure is necessary for the regrowth of nutrients that are attached to organic matter because it enables carbon and other minerals to be gradually immobilized or mineralized into the soil (Berg & McClaugherty, 2008).

Plant materials decompose by first being broken up by soil macrofauna (such as earthworms, millipedes, and termites) and then by microbial activity through the synthesis of enzymes for additional transformations (Coûteaux et al., 2002). Each phase includes the creation of microbial tissue and the partial conversion of carbon to carbon dioxide (Stevenson, 1986). Additionally, it is known that the components of organic residues degrade at various rates. For instance, bacteria are mostly responsible for the quick decomposition of simple sugars, amino acids, most proteins, and cellulose, whereas actinomycetes and fungi are primarily responsible for the delayed decomposition of lignin and certain microbial melanin (Berg & McClaugherty, 2008).

Decomposition, which involves interactions between vegetation, soil nutrient availability, micro-and macro-fauna, and microbial populations, is a crucial measure of ecosystem stability (Knoepp et al., 2000). More importantly, the decomposition of forest litter is a significant avenue for supplying both organic and inorganic components to the processes involved in the nitrogen cycle (Mudrick et al., 1994). Productivity and decomposition are two examples of functional activities that are commonly recognized as significant indicators of ecosystem stability or homeostasis (Rapport et al., 1985). The quantity, type, and rate of decomposition of forest litter all have a major role in the growth and productivity of forest ecosystems. Additionally, the decomposition of litter is crucial for the cycling of carbon in terrestrial ecosystems (Aerts et al., 2006). It also occurs largely on the forest floor, where bacteria and fungi are among the earliest colonizers of fresh litter (Berg & McClaugherty, 2008).

2.3.1 Amounts of litterfall in different forests

Different forests across the world experience different levels of litterfall. Researchers studying litterfall in secondary lowland forests in Nigeria found that from November 2001 to October 2002, yearly litterfall total 9.3 t ha^{-1}(Oziegbe et al., 2011). They determined that the amount is well within the stated range of 7.0-14.1 t ha^{-1} for other tropical lowland rainforests in West Africa (Odiwe & Muoghalu, 2003). According to this reporter (Chave *et al*., 2010) found that 8.61 t ha^{-1} of litter is dropped annually on average in old-growth tropical rainforests. Secondary woods exhibit less litterfall than old-growth tropical forests, with an annual average of 8.01 t ha^{-1}. At the Mata de Piedade location in Brazil's Atlantic rainforest, 14.74 t ha^{-1} of rubbish was produced annually. In low woods and mountain forests, however, the mean annual litterfall was lower (7.06 t ha^{-1} per year and 3.01 t ha^{-1} per year, respectively). This research, (González, 2012)identified a wide range of total litterfall in a large Mediterranean river's floodplain woodlands, ranging from 1.99 to 9.16 t ha^{-1} annually (Liu et al., 2005). It was shown that in the subtropical region of China, evergreen broadleaf forests saw litterfall ranging from 7.1 to 11.0 t/ha/years, but pine forests experienced an average annual litterfall of only 2.67 t ha^{-1}. In the southern Amazon Basin, a tropical semi-deciduous forest produced litter at varied rates every year, ranging from 8 to 10.5 t ha^{-1} (Sanches et al., 2008). Litterfall in some evergreen and deciduous forests in Chile ranged from 3.5 to 5.8 t/ha/yr., and was temporarily lower in the managed than in the unmanaged deciduous stand (Staelens et al., 2011). The amount of litterfall estimated in some of the tropical forests is given in Table 2.1.

Table 2.1: Amounts of Litterfall (t/ha) in Tropical Forests

Forest	Location	Litterfall	Reference
Natural tropical forest	Ghana	10.7	(Vitoussek & Sanford, 1986)
Variable species diversity	Zaire	12.4	
Natural forest	Indonesia	13.67	(Tjitrosemito et al., 2011)
Broad-leaved forest	China	3.56	(Zhou et al., 2007)
Mixed pine and Broad-leaved forest	China	8.61	(Zhou et al., 2007)
Evergreen broad-leaved forest	China	8.16	(Zhou et al., 2007)
Broad-leaved plantation species and Natural forest	Ethiopia	9.7 -12.6	(Ambachew Demessie et al., 2012).
Coniferous species	Ethiopia	4.9-6.6	(Ambachew Demessie et al., 2012)

2.3.2 The rate of litter decomposition

Leaf litter decomposition, which is a complicated and multi-step process of litter breakdown, involves the combination of leaching, chemical and invertebrate fragmentation, and transformation through the action of microbes. One of the most important ecological processes is plant litter decomposition (Swift *et al.*, 1979; Rothenbuecher, 2016). In terms of nutrient cycling and the creation of soil organic matter, it is crucial for soil fertility, the forest's nutrient budget, ecosystem management, and agro-ecosystems, where vegetation mainly depends on the recycling of nutrients found in plant debris (Bargali *et al.*, 2015). Different organic components sequentially predominate breakdown processes (Bargali *et al.*, 2015). The quality of the chemical variable in different types of litter affects the mass loss rate and chemical changes during the early and late phases of leaf litter decomposition (Cornelissen *et al.*, 1999). As a result, the two-phase model predicts that litter mass loss in the early phase will be faster in litter types with higher initial content of soluble compounds and lower lignin content as well as higher N content, which enhances microbial hydrolysis of carbohydrates; in contrast, litter mass loss in the late phase is suppressed more in litter types with higher lignin content as well as higher N content, which suppresses the microbial lignin lytic enzymes (Berg *et al.,* 2007). Most researchers have consistently shown that soluble carbohydrates have good impacts on litter mass loss rate while lignin has negative effects (Murphy et al., 1998).

Three main roles are served by litter in the forest ecosystem. These are the energy input for the microbial life in the soil, the nutrient input for plant nutrition, and the material input for the synthesis of organic matter in the soil. The first two tasks are finished by decomposition and mineralization, and the third task is finished by decomposition and humification. These roles are associated with fundamental soil processes like biological activity, nutrient cycling, and soil structure (Bernhard-Reversat & Loumento, 2002).

Chemical composition, abiotic variables, and biotic factors influence the rate of litter decomposition (Singh &Gupta, 2016). It is essential to consider the relationships between decomposition processes, soil biota, physicochemical environment, and plant quality (Swift et al., 1979). The decline of old-growth forests is frequently correlated with decreases in the rate of litter decomposition, P release from litter, biomass, and activity of the decomposer community (Wardle et al., 2004). In enhancing predictions of nutrient dynamics, carbon cycling, and ecosystem function, precisely monitoring litter decomposition and its sensitivity (biotic and abiotic) to environmental conditions is extremely significant (Sitch et al., 2003; Cornwell et al., 2008). Dry tropical forests have been given high in-situ and ex-situ conservation priority despite being the most changed and vulnerable ecosystem due to their rich ecology and species (Miles et al., 2006; Wang *et al*., 2010).

The quality of the litter, the activity of the decomposing organisms, the macro- and microclimate, and the soil nutrient status all have an impact on the decomposition processes (Vesterdal, 1999). Integrating leaves from species with different resource qualities and leaf structures modifies both the physical and chemical environment where decomposition is taking place (Purvis & Hector, 2000). Decomposition rates can be influenced both directly and indirectly by physical and chemical changes in leaf mixtures, driven by the decomposer community and their activities. To determine whether decay rates in mixtures of species can be predicted from the known decay rates of the individual decaying solitary litter. In general, decomposition is understood to mean both the loss of mass (rate of decay) and the release of nutrients (including nutrient transfers between leaves of different species).

2.4 The Effect of Tree Species on Soil Physicochemical Properties in Agroforestry Systems

Nutrient availability and supply in the soil can both be impacted by trees. Both places for nutrient deposits and channels with which nutrients circulate are represented by trees. As measured by improved soil OM, soil texture, available P, total N, soil pH, soil moisture content, exchangeable K, Na, Ca, and Mg, available water capacity, decreased sand particles, and increased clay particles. Trees improve the chemical, physical, and biological aspects of soil (Daniel Hagos & Nigussie, 2015). The most important physicochemical properties that are the mainstay of this thesis, include soil texture, moisture contents, soil pH, OM, TN, and Av. P, and are discussed below.

2.4.1. Soil texture

Soil texture refers to the quantification of the relative proportions of particles such as sand, silt, and clay within a given soil. The presence of different soil textures has a significant impact on various soil characteristics, including its capacity to retain water, its degree of aeration, its ability to allow infiltration, and its overall porosity (Brady & Weil, 2002). The existence of trees on agricultural land can contribute to improvements in soil temperature, the soil's capacity to retain water, the aggregation of soil particles, the permeability of the soil due to root effects, and the addition of organic matter to the soil (Shibu et al., 1976; Rhoades, 1996). While soil texture is generally less affected by management practices and the influence of trees, it has been observed that the sand fraction of the soil is reduced in areas under the tree canopy compared to open field areas (Abebe Yadessa et al., 2009).

It is one of the most reliable soil characteristics and a helpful indicator of several other characteristics that affect a soil’s ability to support farming (White, 2006). Belay Manjur *et al.*, (2014) observed that the soil under tree canopies contained more clay than open, farmed ground. It is more likely that the trees on the soil textural differences between the soils are responsible for the observed differences between the soil in open areas and under-tree canopies (Belay Manjur *et al.*, 2014).

2.4.2. Soil moisture content (MC)

One of the elements that reduce agricultural success in semi-arid areas is soil moisture. Mulch or litter layer beneath shade trees may act as a one-way barrier to moisture flow since it enhances rainwater infiltration while also lowering soil evaporation (Agena et al., 2014). Kessler, (1992) and Agena et al., (2014), reported that enhanced water infiltration and less actual evapotranspiration were both responsible for the increased availability of water under tree canopies. This change in soil moisture content under the canopy compared to the external environment can be explained by an improvement in soil structure due to increased porosity and increased organic matter content, which is reflected in the improved soil moisture retention under the canopy (Abey et al., 2023). This organic matter helps retain moisture in the soil, increases its surface area, improves the soil structure, and increases its porosity (Desalegn Mamo & Zebene Asfaw, 2017).

2.4.3. Soil pH

The pH of the soil is susceptible to changes in the environment and soil management techniques brought about by human activities. Different anthropogenic and natural processes, such as the leaching of exchangeable bases, acid rains, the breakdown of organic materials, the application of commercial fertilizers, and other agricultural practices, have an impact on the degree and type of soil reactivity (Brady & Weil, 2002). By adding bases to the soil surface, trees typically reduce the impacts of leaching. Kahi et al., (2009) discovered a substantial variation in soil pH between *Prosopis juliflora* and *Acacia tortilis* canopies and open, farmed ground, with the latter having a higher pH than the former. More acidic soils are found under canopies than in open areas. The leaches and flows from roots and litterfall could be to blame for the mild acidity of the soil within the canopy zone (Kahi et al., 2009).

Soils exhibiting a pH range of 6.0 - 7.0 commonly possess elevated concentrations of accessible nutrients. The average pH value of soil beneath the canopy of trees was observed to be higher compared to that of the surrounding open area (Desalegn Mamo & Zebene Asfaw, 2017). The average pH value of soil beneath specific shade tree canopies was found to be higher in comparison to soil located in the open field (Alemayehu Diribaet al., 2017). The pH of the soil is significantly impacted by the type of tree species present; a decrease in pH levels is acknowledged in agroforestry due to the augmented accumulation of above-ground biomass, associated uptake of cation, and the generation of organic acids by the tree component within agroforestry systems (Sarvade et al., 2019).

2.4.4. Soil organic matter (SOM)

The physical, chemical, and biological features of the soil, as well as its fertility status, plant nutrition, and biological activity, are all significantly influenced by organic matter (Brady & Weil, 2002). Kahi et al., (2009) reported substantially higher levels of organic carbon and total soil nitrogen in the *Prosopis juliflora* and *Acacia Tortilis* canopy than in the surrounding soil. Likewise, (Zebene Asfaw & Ågren, 2007; Kindu Mekonnen et al., 2009), have also reported an important decline in OC and OM away from tree trunks and into open, farmed terrain. Basic soil component organic matter controls the soil's physical, chemical, and biological characteristics (Błońska *et al.*, 2021).

Soil structure, moisture holding capacity, diversity and activity of soil organisms, and nutrient availability are among the characteristics influenced by organic matter. There are various advantages to preserving and increasing soil organic matter (SOM), including reducing the effects of climate change (Bossio *et al*., 2020). Trees contribute organic matter to the soil in a variety of ways, such as through their roots, litterfall, or root exudates in the soil biota (Bertin *et al.*, 2003). The presence of organic substances holds a significant way over both the physical and chemical attributes of the soil, as well as its fertility status, plant nutrition, and the biological processes occurring within it (Abey et al., 2023). Among the various layers, the shade tree species exhibited the highest average concentration of organic carbon at the second layer, whereas the lowest average concentration was found in the open soil (Alemayehu Diriba *et al.*, 2017).

2.4.5. Total Nitrogen

One of the most important components that inhibit plant growth in soil is nitrogen. In semi-arid regions of northern Senegal, total nitrogen and mineral nitrogen flux gradually decreased under the canopy of *Acacia Senegal, Balanites aegyptiaca, and Adansonia digitata* trees (Young, 1989). Additionally determined a trend of accessible nitrogen becoming less abundant the further away it is from the tree trunk (Daniel Hagos *et al*., 2013).

The difference in total nitrogen was found to be statistically significant across different distances from the tree trunk. Notably, the nitrogen content was higher beneath the tree canopy compared to the open area (Desalegn Mamo & Zebene Asfaw, 2017). Consequently, soil nitrogen levels exhibited a decrease with increasing distance from the tree trunk (Musa Abdella et al., 2020). Nitrogen, a crucial plant nutrient, exists in various forms within the soil. The distribution of total nitrogen content demonstrates a similar pattern to that of organic matter distribution (Belay Manjur et al., 2014). Soils with greater organic matter content tend to have higher nitrogen levels, while those with lower organic matter content exhibit lower nitrogen levels (Simret Mekonnen, 2014). The shade effect plays a vital role in increasing the mean value of total nitrogen in the soil, as compared to the outside the shaded. This observation highlights the significance of total nitrogen in the soil, as it influences various parameters under the shaded effect (Alemayehu Diriba et al.,2017).

2.4.6. Available Phosphorus

Available phosphorus is present in soils in both organic and inorganic forms. The presence of phosphorus in soil parent materials, however, is typically of limited availability for plants (Abey et al., 2023). The availability of phosphorus and its adsorption reactions in the soil is influenced by the physical and chemical properties of soils. These properties encompass the composition and quantity of soil minerals, soil pH, the effects of cation and anions, reaction time and temperature, flooding, and fertilizer management practices (Tisdale, 2002). The levels of available phosphorus were found to be significantly higher beneath tree canopies compared to the open field at their respective soil depths (Aschalew Emire, 2018). Moreover, there was a noticeable decrease in available phosphorus with increasing distance from the tree base towards the open cultivated land (Musa Abdella et al., 2020). Changes in land use, which often entail alterations in vegetation cover, biomass production, and nutrient cycling in the ecosystem, can impact the dynamics of soil phosphorus (Wakene Negassa & Heluf Geberekidan, 2003).

Phosphorus uptake by plants is restricted in the majority of natural ecosystems, including forests and grasslands, by the element's low total concentration in the soil as well as by its extremely low solubility (Abebe Nigusie, 2006). In the Harerghe Highlands, it was discovered that there was more readily available phosphorous inside than outside of the canopy of *Cordia africana, Acacia albida (Faidberbia albida), and Croton macrostachyus*). In the Umbulo Wacho watershed (Hawassa Zurya district), Southern Ethiopia, it was also noted that accessible phosphorus was higher under the canopy of *F. albida and Croton macrostachyus* tree species than on the open, cultivated ground (Belay Manjur et al, 2014).

Chapter Three: MATERIAL AND METHOD

3.1. Study Site Description

3.1.1. Location

Aba Gerima watershed is found in the Amhara region, North Gojam zone, Bahir Dar Zuria Woreda specifically in Aba Gerima Gonibat Kebele. It is situated about 15km east of Bahir Dar city. The head of the watershed, at its southern part, can be accessed through a road that goes from Zenzelima to Abune Hara Monastery, where the boundary touches the road to the north off-ramp at a small village called Aba Dama. Aba Gerima watershed is bounded by two Kebeles namely, Gonibat Aba Gerima to the north and North West and Laguna Abune Hana to the south and South West, but the majority of the watershed is found in Gonibat Aba Gerima Kebele. Aba Gerima watershed covers an area of 900 ha. The watershed is part of Tana Sub-basin located nearby Lake Tana. It is a representative landscape of the northern part of the Abay basin, particularly Lake Tana surroundings. Heterogeneity in the landscape is highly observed in the watershed as a result of diverse landforms, land use systems, and land cover types. Most of the watershed is severely degraded by erosion. The watershed was developed in 2012 by the Water and Land Resource Center (WLRC) to involve participatory, integrated watershed development that is supported by research to combat land degradation and achieve sustainable land management. The study watershed is located between 11^{o}38'30" and 11^{o}41'30"N latitude and 37^{o}29'0" and 37^{o}31'0"E longitude (Figure 3.1). The location of the watershed is between 1600 and 2200 m.a.s.l. The elevation in the study watersheds ranges from 1880 m to 2078m, which is typical for a tropical highland environment.

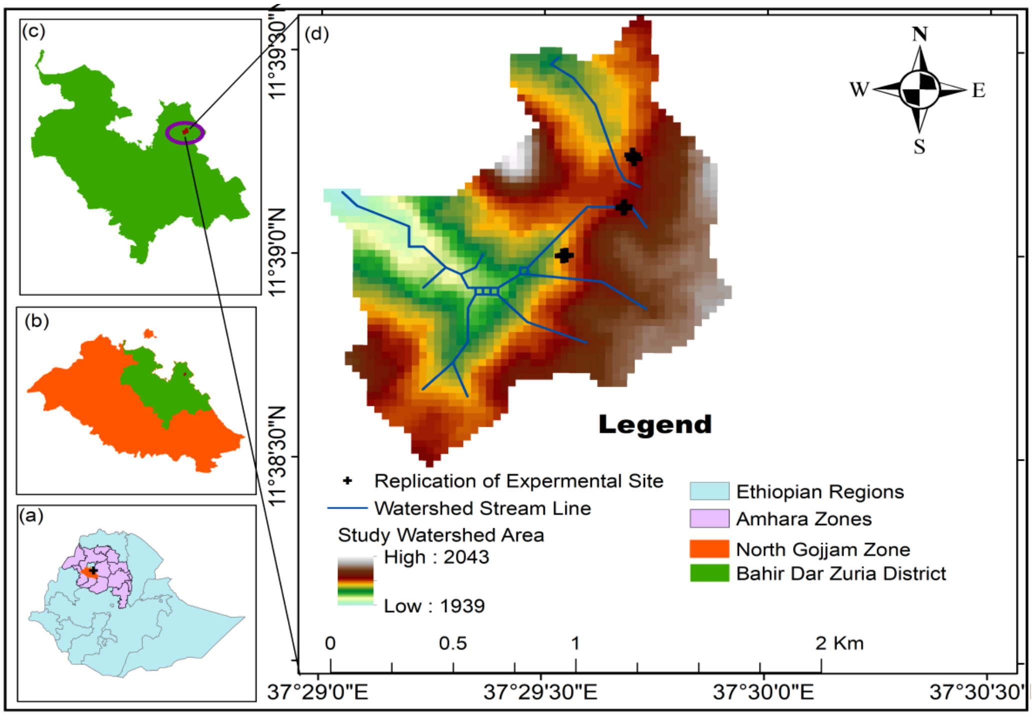


Figure 3.1: Study area location

Figure 3.1 indicates (a) a Map of Ethiopia and Amhara region, (b) the North Gojjam Zone, (c) Indicates Bahir Dar Zuria District, and (d) Indicate Aba Gerima watershed area, watershed streams feature, and experimental site.

3.1.2. Climate

The seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) from the south to the north, and back is the main factor controlling the climate in the upper Blue Nile basin. The study watershed experiences a lot of rain. The study watershed receives 1300 mm of rainfall on average yearly. In the study watershed, there is substantial soil erosion as a result of the majority of precipitation events occurring during brief, intense thunderstorms with high erosive levels. The typical average temperature is 20^{o} C (http://www.wlrc-eth.org).

3.1.3. Socioeconomics and land use practices

A total of around 1,340 people live in the water catchment area. With an average area of one hectare, rainfed agriculture is the dominant land use in a mixed farming system with scattered native trees. Three major crops with yields of 1.2 t/ha, 3.2 t/h, and 2.0 t/ha respectively are *Eragrostis, Zea mays (maize),* and *Eleusine coracana (Finger millet*) grown in the watershed.

Cropland (66%) is the most common type of land use, followed by grazing (17%), planted forests and riverside wild edible trees (3–4%), homesteads (9%), and degraded land (4%). It is a typical scene from the northern region of the Nile Basin. Due to the high heterogeneity of the landscape, different land use systems and land cover types are often observed in the watershed, and leaf erosion has severely affected most of the watershed (http://www.wlrc-eth.org)

3.1.4. Land use

Grain/livestock farming is the dominant farming system in this subzone. Most of the studied watershed (66%) consists of cultivated land. *Teff, wheat, sorghum, legumes*, etc., which have very low production volumes, dominate seasonal cultivation. According to http://www.wlrc-eth.org, the productivity of teff is only 1.2 t ha^{-1}. The reliable development time is about 3 to 5.5 months. Cultivation in this subzone is extensive. Farm animals living in this subzone include cattle, sheep, goats, and donkeys. On the plains and in the mountains, this subzone offers the potential for rain-fed agriculture. Erosion and deforestation are the sublimation zones (MoA, 2000). According to Temesgen Tadesse, (2011), farming in these agroecology contributes significantly to more effective agricultural production and therefore has both positive and negative effects on soil health and newly produced soil.

3.1.5. Watershed of agroforestry tree species resources

A watershed is an area on the properties of the household and its surroundings, where various annual agriculture, livestock, and trees are integrated and produced. The Homegarden agroforestry system provides household families with various goods including food/fruit, firewood, fodder, timber, and other tree products. In the study of the Aba Gerima watershed the most common tree and shrub species resources such as *Mangifera indica*, *Rhamnus prinoides*, *Coffea arabica, Rhus natalensis, Cordia africana, Arundo donax, Albizia gummifera, Croton macrostachyus, Acacia albida (Faidherbia albida)Citrus sinensis, Persea americana, Millettia ferruginea, Catha edulis, Grevillea robusta, Eucalyptus camaldulensis, Citrus aurantifolia, etc.* Therefore, in the study area of tree species for the most dominant of agroforestry practices include *Croton macrostachyus, Cordia africana, Eucalyptus camaldulensis, Coffea arabica, Rhamnus prinoides*, and *Catha edulis* for the aba Gerima watershed.

3.2 Sampling Technique

3.2.1. Selection of the specific *Croton macrostachyus* and *Cordia africana* trees from the Aba Gerima watershed

The dominant tree species in the Aba Gerima watershed were *Croton macrostachyus* and *Cordia africana*. Therefore, these two agroforestry species were found to be appropriate for this study. The selected watershed with these tree species is characterized by approximately similar slopes where under the shade of these tree species *Rhamnus prinoides* and *Coffea arabica* were grown as the main socioeconomic cash crop of the area. The sampled trees taken also have a more or less similar management history. On the selected field, individual trees of *Croton macrostachyus* and *Cordia africana* having approximately similar height, diameter at breast height (DBH), crown diameter, and uniform site conditions were taken to factors nearly constant. The potential candidate trees identified, three individual *Croton macrostachyus* and *Cordia africana* trees were selected purposively for this study. Finally, their DBH, height, and crown diameter were measured by using a caliper, hypsometer, and measuring tape, respectively.

Table 3.1: The DBH, height, canopy/crown radius, X-Y coordinate, and elevation of individual trees considered in this study

Tree species	Replication	DBH(cm)	Height(m)	Crown Radius(m)	X	Y	Elevation
Croton macrostachyus	1	25	11.5	4.5	335672	1288283	1999
	2	31	14	5.7	335911	1288499	2013
	3	28.5	12	5.4	335951	1288720	2003
	average	28.16	12.5	5.2	-	-	-
Cordia africana	1	23.5	13	4.3	335660	1288280	1995
	2	27	14.5	4.7	335907	1288497	2011
	3	24.5	12.5	3.8	335944	1288738	2008
	average	25	13.33	4.26	-	-	-

Each tree species was replicated three times. The dimension of each replication was almost uniform with the average DBH, height, and crown radius of 28.16 cm, 12.5 m, and 5.2 m for *Croton macrostachyus*, respectively. Similarly, for *Cordia africana* the average DBH, height, and crown radius were 25 cm, 13.5 m, and 4.26 m respectively (Table 3.1).

3.2.2 The amount of leaf litter collection

For this study, litterfall samples were collected from isolated trees of the species *Croton macrostachyus* and *Cordia africana* growing in the same soil type, landscape location, and roughly comparable age of the tree species. From February 2023 to May 2023, leaf litterfall of these tree species was collected every 15 days using a litter bag. In the four sides of the tree canopy 1.5×1.5-meter plots were laid for each tree species beneath the canopy. The three replicate plots each containing four composite litter bags contain the 24 bag samples of each species. After the bags had been used for approximately four months, one sample bag of each species was taken from each plot every two weeks. A total of 24 sample bags were installed, i.e. 2×3×4 each (tree species, replication, and sample bags). The sample bags in the four directions were mixed and six composite samples were taken for analysis from each sample tree. Litterfall was collected using litter traps established beneath the canopy of the trees as shown in Figure 3.2 below.

Figure 3.2: Litter trap installation and measuring the amount of litter bags. (Photo: Field data by Kerebih Aragaw in February 2023 – May 2023)

Calculate the crown area; (assuming an elliptical crown shape) using the formula (Kuyah et al., 2012). $ca = \pi(d/2) \times (w/2)$……………Eq.1

Where d is the crown diameter at its widest point and w is the perpendicular crown extent at the same height.

The amount of litterfall: The litter trap samples were estimated from the litterfall plot established beneath the tree and litterfall samples were collected every two weeks the amount of litter was determined using the plot area (m^2), the canopy or crown area (m^2), and the amount of litterfall (g) collected (Eq. 2,):

$$Amount\ of litterfall\ (g) = \frac{Tree\ crown\ area\ (m^2) \times litterfall\ \ collected\ (g)}{\text{Plot area}\ (m^2)} \text{……Eq. 2}$$

3.2.3 Rate of decomposition

Leaf litter decomposition was studied using the standard litter bag method defined by (Swift & Anderson, 1989). The 10 × 10 cm nylon mesh bags with a mesh size of 2 mm are used to hold batches of 5g of leaf litter oven-dried at 65^{o}and 24 hours. Litter bags were placed and buried into the soil layer about 2cm deep in the ground where they were exposed to weathering and soil-borne decomposers.

The data collection continued from February 2023 to September 2023, covering both the dry and wet seasons. Nylon meshes were installed in the dry and wet seasons, from February 2023 to September 2023. For each dry and wet season, species there were 24 bag samples; the three replication plots, each with four assembled litter bags. After using the litter bag technique in nylon mesh bags for approximately eight consecutive months, one sample bag of each species was removed from each plot every month (Bekele et al., 2021). During the dry season, 24 samples were collected using the nylon mesh bag technique, i.e. 2×3×4 (tree species, replication, and sample bag). Similarly, 24 sample bags were used for the wet season. A total of 48 sample bags were installed, i.e. 2×3×4×2 (tree species, replication, sample bag, and seasonal variation).

Figure 3.3 The rate of decomposition in the installation of nylon meshes and leaf litter bag techniques: (field data by Kerebih Aragaw in February 2023 - September 2023)

Decomposition rate (k): The litter decomposition rate was calculated using the formula (Olson, 1963; Makkonen et al., 2012; Darmawan et al., 2021) procedures.

$$K_t = -\ln (X_t/X_o) \text{ and } (k) = {-\ln(W_t/\ W_o)}/{t} \ \text{ Or } \ldots\ldots\ldots\ldots\text{Eq. 3}$$

$$(R) = \frac{W_o - W_t}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eq. 4 or}$$

Where: (R/k) is the decomposition rate (g/months), t is the time of observation (months), W_o, X_o is the initial dry weight of litter (gr), and W_t, X_t is the final dry weight of litter (g) time, and Half-life periods t(0.5) of decomposing litter samples were estimated from k values using

Mass loss (%): The estimated oven-dry weight of the litter samples that are collected each month was used to calculate the decrease in weight [mass loss (%) and remaining mass (g)] of all the leaf litter collected for four months of each season (Nivethadevi et al., 2022, Darmawan et al., 2021).

$$\text{Mass loss}(\%) = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\text{Eq. 5}$$

Mass remaining in the litter bag = 100 - % Mass Loss …………Eq. 6

3.2.4. Soil laboratory analysis of soil physical and chemical properties

For the measurement of soil physicochemical parameters, the composite soil samples were air-dried and processed to pass through a 2mm sieve, except for total nitrogen and organic carbon, which passed through a 0.5 mm sieve. For analysis of soil organic carbon/soil organic matter (SOC/SOM), N, P, pH, soil texture, and soil moisture, the oven-dried litter samples are crushed and sieved through a 0.5 mm sieve. On the four sides (North to South and East to West) of the tree canopy soil sample plots were laid for each tree species beneath and outside the canopy. A total of soil 12 sample bags were taken, i.e. 2×2×3 each (tree species, treatment, and replication). From each tree species, the composite soil samples per tree were taken under and out of the tree canopy cover in each plot. The plot was established by clear layer and unrecompensed organic matter and the soil samples were collected through a depth of 0-20 cm and analyzed at the Soil and Plant Analysis Laboratory of the Department of Natural Resources Management, Bahir Dar University.

3.2.4.1 Soil moisture content

The soil moisture content at the time of sampling was determined gravimetrically through oven drying at 105^{o} C to a constant weight from the known mass and volume of soil sample collected using soil moisture cans (Hao et al., 2006). The soil moisture content was then calculated by using the given formula:

$$Soil\ Moisture\ Content\ (\%) = \frac{Weight\ of\ moist\ soil - Weight\ of\ oven\ dried\ soil}{Weight\ of\ oven\ dried\ soil} \times 100$$

3.2.4.2 Soil texture

The textural class of soil is determined through a mechanical analysis by plotting a line at the designated percentage for each separate component on a triangular graph, parallel to the corresponding base. The soil texture class was determined by placing on the top of the sieve arrangement taken by hand for approximately 10 min. The mass of soil particles from each sieve was measured. To conduct the texture test, a small amount of soil sample was placed in the hand along with a few water droplets, and the soil type was determined using the decided techniques. Soil texture was analyzed by the percentages of each type of soil obtained from each sieve using the equation (Rowell, 1994):

$$Soil\ texture\ (\%) = \frac{\text{soil obtained from each sieve (g)}}{\text{Total weight of soil (g)}} \times 100$$

3.2.4.3 Soil pH reaction

Soil water suspension was prepared using a soil-to-water ratio of 1:2.5. The contents allowed equilibrating for 30 minutes and then the pH was recorded by using a pH meter with a combined glass electrode (Lean, 1982).

3.2.4.4 Soil organic matter

The organic carbon content of all samples was determined by the Walkley and Black method in which the organic matter was oxidized by potassium dichromate in the presence of concentrated H_2SO_4 (Walkley & Black, 1934). The excess potassium dichromate was back-titrated with ferrous ammonium sulphate using a diphenylamine indicator (Walkley & Black, 1934). Organic matter (OM) content was calculated from organic carbon by multiplying each SOC value by 1.724.

3.2.4.5 The total nitrogen content

The total nitrogen content was determined using the Kjeldahl digestion method by oxidizing the organic matter with sulfuric acid and converting the nitrogen into NH_{4+} as ammonium sulfate (Black et al., 1965).

3.2.4.6 The available phosphorus

Available phosphorus (P) was determined using a spectrophotometer after extraction of the soil samples with 0.5M sodium bicarbonate ($NaHCO_3$) solution at pH 8.5 following the Olsen extraction method (Olsen, 1954).

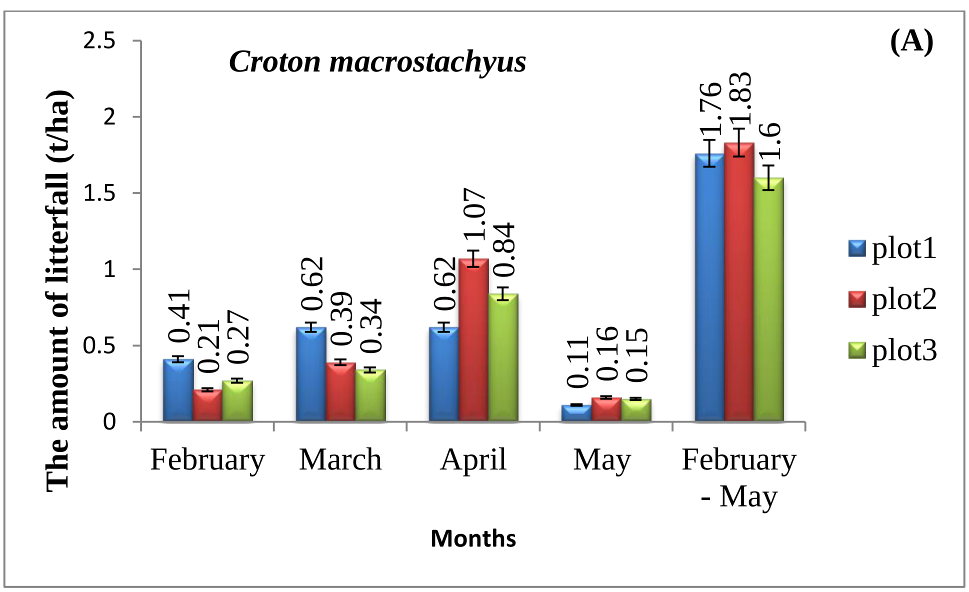
3.3. Data Analysis

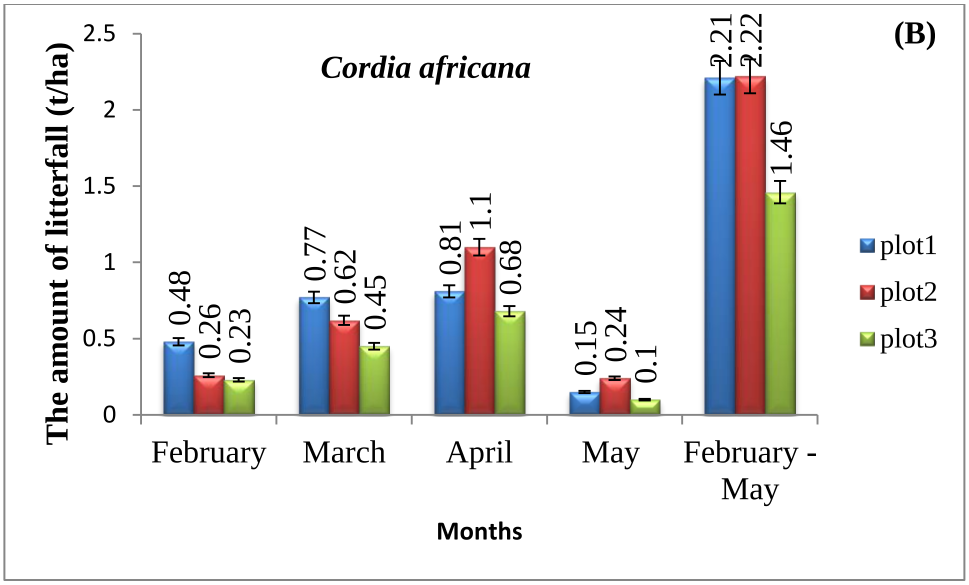
Descriptive statistics was used to determine leaf litter, decomposition rate, and soil nutrient status under *Croton macrostachyus* and *Cordia africana* tree species. A one-way analysis of variance (ANOVA) was used to compare the amount of litterfall and rate of the decomposition between, and *Croton macrostachyus* and *Cordia africana* tree species. Similarly, the soil fertility characteristics and nutrient content of each litter species were compared using one-way ANOVA. The LSD (Least Significant Difference) test was used to compare means at significance levels of 0.05. All statistical analysis was performed using Microsoft Office Excel and SAS 9.4 software.

Chapter Four: RESULTS AND DISCUSSION

4.1 The Amount of Litterfall for *Croton macrostachyus* and *Cordia africana*

The litterfall collected from *Croton macrostachyus* and *Cordia africana*, in four months the two tree species of the crown litterfall were 1.76 t/ha, 1.83 t/ha, and 1.6 t/ha at plot1, plot2, and plot3 sites, respectively. At plot1, plot2, and plot3 sites, it was 2.21 t/ha, 2.2 t/ha, and 1.46 t/ha of the equivalent per the canopy of litterfall. From the amount of litter collected, it is evident that the mean difference between the *Croton macrostachyus* and *Cordia africana* species was significant (Figure 4.1A, B, C). The variation in litterfall between the two species suggests that the disturbance has a substantial impact on the soil physicochemical properties, as can be illustrated later. *Croton macrostachyus* and *Cordia africana* species have a total amount of form four-month litterfall of 5.19 t/ha and 5.89 t/ha respectively, (which is equivalent to the crown area of both tree species), respectively, in four months. The amount of litterfall for the *Cordia africana* is greater than *Croton macrostachyus*. The trend of amount of monthly litterfall in February, March, April, and May were 0.89 t/ha, 1.35 t/ha, 2.53 t/ha, and 0.42 t/ha for *Croton macrostachyus* and 0.97 t/ha, 1.84 t/ha, 2.54 t/ha, and 0.49 t/ha for *Cordia africana* respectively; indicating that litterfall peaks in April and radically decline in May for both species (Figure 4.1a, b, c). In the agroforestry system of the Aba Gerima watershed, the fractions and the total litterfall between *Croton macrostachyus* and *Cordia africana* revealed substantial differences in the total amount of litterfall.





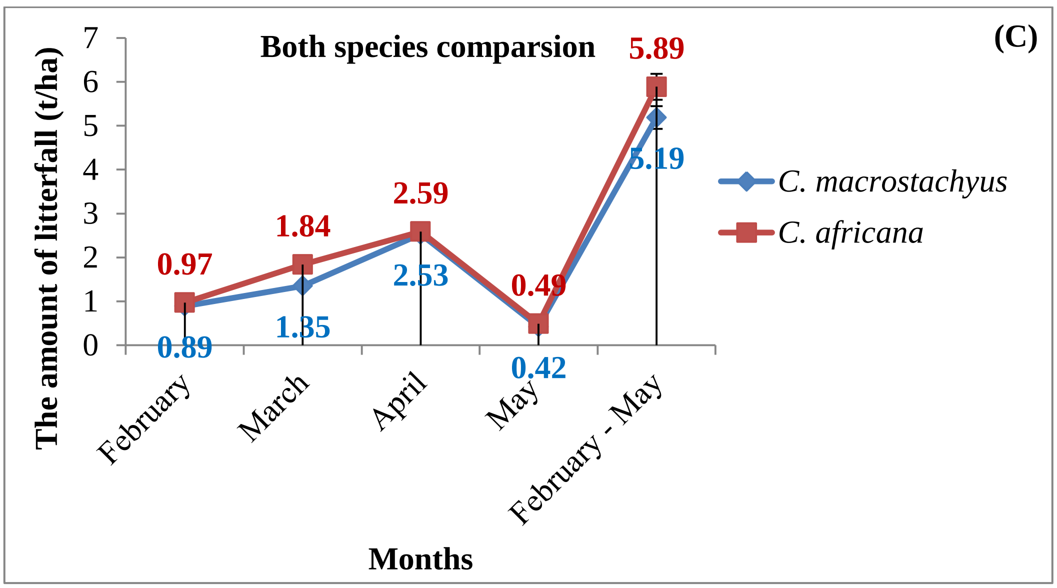


Figure 4. 1: A) The amount of litterfall *Croton macrostachyus*, B) the amount of *Cordia africana* litterfall, and C) the total amount of litterfall for both species throughout four months in Aba Gerima watershed.

It was reported from the present study that the mean total litterfall in *Cordia africana* and *Croton macrostachyus* of the Aba Gerima watershed was 5.89 tha^{-1} and 5.19 tha^{-1}, respectively. This finding is supported by studies carried out in the tropics by many different researchers who reported comparable results (Staelens et al., 2011; Chave et al., 2010; Zhou et al., 2007; Vitoussek & Sanford, 1986). According to (Vitoussek & Sanford, 1986), they reported 3.6 to 12.4 t/ha/year litterfall in the tropical moist forest. In addition reported by Talemos Seta et al., (2018), the mean annual dry mass of litterfall was 10.76 t/ha/yr and 6.64 t/ha/yr in lower-distributed and high-distributed sites, respectively. The high value of reproductive parts as a fraction of litterfall was recorded in March, April, December, January, and February in both lower-distributed and high-distributed sites of the forest, which might indicate the flowering and fruiting seasons of some of the forest species. Moreover, a significant difference in the mean dry weight of litterfall was observed between lower-distributed and high-distributed sites of the forest (Talemos Seta et al., 2018). In Southern Ethiopia, Ambachew Demessie et al., (2012), found that among deciduous plantation species and natural forests, litter production rates ranging from 9.7 to 12.6 t/ha/year occurred. In the Ethiopian Highlands, Lisanework & Michelsen, (1994), reported the annual fine litter production ranging from 5.0 to 6.5 t/ha in tree plantations and 10.9 Mg/ha in a natural forest relatively higher than the present value.

4.2 The Rate of Decomposition of the Litterfall for *Croton macrostachyus* and *Cordia africana*

4.2.1 The effect of tree species on mass loss for 120 days of the dry and wet season

The result showed that the dry and wet season maximum mass remaining for *Cordia africana* was lower than *Croton macrostachyus* over the entire experimental period (figure 4.2). In the dry season, the mass loss in the first 30 days was 3.9 % for *Cordia africana* and 10.3% for *Croton macrostachyus*. On the 60th and 90th days, the leaf litter mass loss for *Cordia africana* was 15.3% and 30.4%, respectively, compared to 44.3% and 72.5%, respectively for *Croton macrostachyus*. During the wet season, the percentage of remaining mass loss after the initial 30 days showed variations from 55% for *Cordia africana* and 76.3% for *Croton macrostachyus*. Subsequently, on the 60th and 90th days, the mass loss of leaf litter still present was recorded at 80.3% and 97.7% for *Cordia africana*, respectively. In contrast, for *Croton macrostachyus*, these values were 85.3% and 99.7% for the 60th and 90th days incubation periods, respectively. The mass losses of the rate of decomposition after 120 days of the dry season were 47% and 94% for *Cordia africana* and *Croton macrostachyus*, respectively. However, during the 120-day incubation period of the wet season, there was a constant mass loss due to the decomposition of both tree species. Additionally, *Croton macrostachyus* experienced greater mass loss throughout the sampling days than *Cordia africana* (Table 4.1). The decomposition rates of the two species were higher significantly different except for 120 days of the wet season. Besides, the litter mass loss during the dry season was lower than that of the wet season.

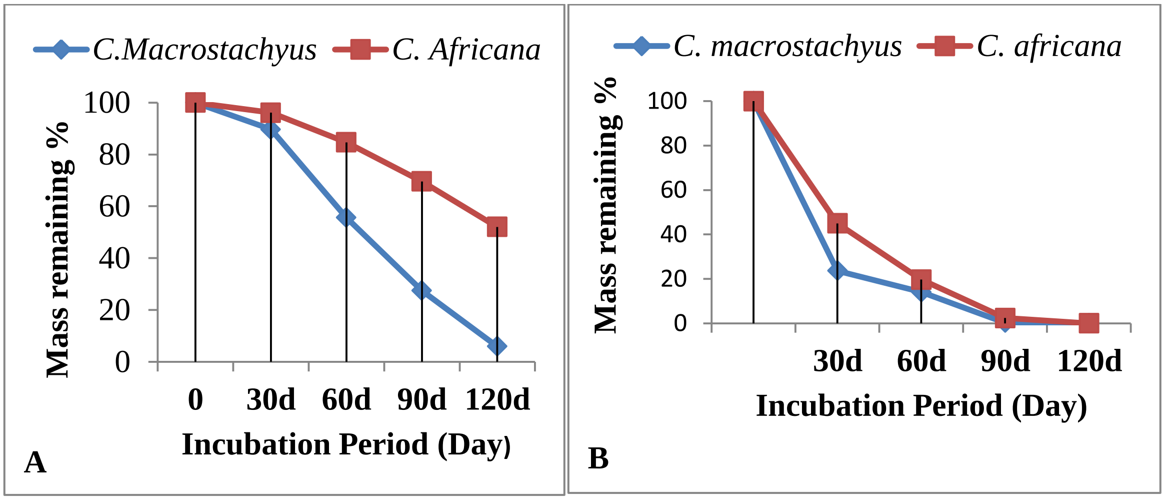


Figure 4.2: The dry season (A) and wet season (B), the mass remaining for *Cordia africana* and *Croton macrostachyus* during the decomposition of the incubation period for 120 days.

Table 4. 1 The effect of species on litter mass loss at different stages of decomposition for 120 days in the dry and wet seasons

Species ±	Incubation period (day) ………K_D (gday^{-1})……			
	30D	**60D**	**90D**	**120D**
The dry season mass loss % of mean value and std dev. Respectively				
C. Macrostachyus	10.33 ± 3.44867	44.33 ± 4.22532	72.53 ± 2.90057	94.00 ± 3.34066
Cordia Africana	3.87 ± 1.50111	15.33 ± 1.94251	30.40 ± 4.27551	47.93 ± 8.01332
R-Square	0.956	0.995	0.992	0.991
CV	19.952	5.825	6.207	5.259
LSD(0.05)	4.977*	6.105**	11.244**	13.11**
The wet season mass loss % mean value and std dev. Respectively				
C. Macrostachyus	76.33 ± .90185	85.93 ± .50332	99.70 ± .08718	100.00 ± .00000
Cordia Africana	55.00 ±1.24900	80.33 ±1.10151	97.66 ± .30551	100.00 ± .00000
R-Square	0.994	0.949	0.987	0
CV	2.179	1.361	0.209	0
LSD(0.05)	5.026**	3.975**	0724*	Ns

According to a research finding on the pattern of leaf litter decomposition (weight loss) of tree species (Tripathi et al., 2009), weight loss in alder was initially slower than in leaves of Khasi pine needles and Khasi mandarin for about a month. Comparisons of the potential nutrient content (N, P, and K) in the leaf litter of each tree species revealed that the leaf litter of *Croton macrostachyus* exhibited a significantly higher K value ($P < 0.05$) in comparison to the leaf litter of *Cordia africana* and *Hygenia abyssinica*. Moreover, both *Croton macrostachyus* and *Hygenia abyssinica* demonstrated a higher concentration of N and P than *Cordia africana* (Getachew et al., 2015). Soil organic matter content was determined from the mass loss process and decomposition rate to show a positive correlation of p=0.631 and an effect of 32.3% and 32.8%, respectively, on the CO_2 flux emitted from the soil (Darmawan et al., 2021). The maximum weight loss percentage was for *Acacia nilotica* at week seven (55.36%), followed by *Prosopis juliflora* (55.04%), and the differences in percentage mass loss of leaf litter from the first to the seventh week of decomposition decreased by 10.64, 7.69, 4.62, 4.5, and 3.95 percent, respectively due to winter conditions (Nivethadevi et al., 2022). This is substantiated, by Talemos Seta et al., (2018), who reported the components and the total litterfall also showed a significant difference between wet and dry seasons in the forest. This result was in line with Zenebe Argado et al., (2024), who reported a significant difference in litter production among studied species ($P < 0.05$). Also, there was a significant difference in decay constant among studied species ($P < 0.05$) and indigenous species such as *Coffea arabica*, *Cordia africana*, and *Millettia ferruginea* showed a greater value of the decay constant as compared to exotic species such as *Eucalyptus camaldulensis*, *Persea Americana*, and *Mangifera indica. Coffea arabica* showed the fastest decomposition with a decay constant of 2.4 while it was 1.1 for *Eucalyptus camaldulensis*. In addition reported by Ambachew Demessie et al., (2012), the reduction of residual litter mass in the bags at each sampling time (measured in months) showed an exponential decline across all plantation species and in the natural forest.

4.2.2 The effect of tree species on decomposition rate constant (K) for 120 days in the dry and wet season

The dry and wet season decomposition rate (g/day) of the studied foliage litter materials has shown a different pattern. In this study, the rate of decomposition constant (K) levels was significantly high ($P < 0.05$) for Croton *macrostachyus* and *Cordia africana* during the 120 days of incubation periods. In the dry season, the rate of decomposition during the first 30 days varied from 0.0172 g/day for *Croton macrostachyus* and 0.0064 g/day for *Cordia africana.* On the 60th day incubation period, the remaining leaf litterfall mass was 0.0369 g/day, and 0.0128 g/day, for *Croton macrostachyus* and *Cordia africana*, respectively. For the 90th and 120th days, the decomposition rate of leaf litter was 0.0169 g/day, and 0.0200 g/day in *Cordia africana*, respectively, compared to that of *Croton macrostachyus*, which was about 0.0403 g/day and 0.0392 g/day, respectively. The decomposition rates of *Croton macrostachyus* were recorded as the highest, ranging from 0.0172 to 0.0392 g/day for each 30-120 days sampling period. In contrast, *Cordia africana* displayed decomposition rates of 0.0064 to 0.0200 g/day for the same sampling period. During the wet season, the rate of decomposition for the 30-day incubation period varied from 0.1272 g/day and 0.0916 g/day for *Croton macrostachyus* and *Cordia africana respectively.* At the 60th day incubation period, the remaining leaf litter mass was 0.0716 g/day and 0.0669 g/day for *Croton macrostachyus* and *Cordia africana*, respectively. The decomposition rates of *Croton macrostachyus* were found to be the fastest with the range from 0.1272 to 0.0554 g/day for each 30-90 days sampling period, respectively. *Cordia africana* has decomposition rates in the range from 0.0916 to 0.0542 g/day for each 30-90 days incubation period respectively. Significant variation was not observed after the 90th and 120th days of the incubation period ($P<0.05$) for both tree species of *Croton macrostachyus* and *Cordia africana* with the range from 0.0554 to 0.0416 g/day and 0.0542 to 0.0416g/day, respectively (Table 4.2). *Croton macrostachyus* has a more rapid decomposition in the dry and wet seasons, than *Cordia africana*, because of the slow decomposition rate of *Cordia africana* despite the profuse leaf fall observed under its crowns. The rate of decomposition exhibited a significantly reduced pace during the dry season in comparison to the wet season in the case of these specific tree species. The shedding of reproductive components, namely fruits and flowers, displayed a pronounced seasonality, characterized by elevated quantities observed during the wet season.

Table 4. 2: The effect of species on decomposition rates at different stages of decomposition for 120 days in the dry and wet seasons

Species	Incubation period (day) ………K_D (gday^{-1})……			
	30D	**60D**	**90D**	**120D**
The dry season decomposition rate of mean value and std dev. Respectively				
C. macrostachyus	.0172^a ± .00575	.0369^a ± .00352	.0403^a ± .00161	.0392^a ± .00139
C. africana	.0064^b ± .00250	.0128^b ± .00162	.0169^b ± .00238	.0200^b ± .00334
R-Square	0.95788	0.9954	0.991917	0.989874
CV	19.48312	5.887841	6.477498	5.786078
LSD(0.05)	0.041*	0.000**	0.000**	0.001**
The Wet season decomposition rate of mean value and std dev. Respectively				
C. macrostachyus	.1272^a ± .00150	.0716^a ± .00042	.0554^a ± .00005	.0416 ± .000
Cordia africana	.0916^b ± .00208	.0669^b ± .00092	.0542^b ± .00017	.0416 ± .000
R-Square	0.994045	0.948773	0.986737	0
CV	2.178605	1.360911	0.208824	0
LSD(0.05)	0.0084*	0.0033**	0.0004**	Ns

Levels of significance: p<0.05(*), p< 0.001 (**) and NS is not significant

Whereas: D is the interval dates, and CV is the coefficient of variation

The mean daily decomposition rate constant of these two species in the dry season leaf litter ranged from 0.0064 to 0.0200 g/day, corresponding to 0.0172 to 0.0392 g/day of the present finding for *Cordia africana* and *Croton macrostachyus*. In addition, the wet season litterfall decomposition ranged from 0.0916 to 0.0416 g/day for *Cordia africana* and 0.1272 to 0.0416 g/day *for Croton macrostachyus*, respectively. Given that the experiment was conducted at three sites under the same climatic conditions, the difference that was found in the rate of decomposition values between the species can be a result of the different qualities of their litter. The result is supported by studies conducted in the tropics by many authors (Abraham Mahari, 2014; Nivethadevi et al., 2022). There were highly significant (P < 0.05) variations between the species in the mass loss from the leaves of *Cordia africana* and *Croton macrostachyus* (Table 4.2). According to Abraham Mahari, (2014), the mass loss in *Croton macrostachyus* was greater than that of *Cordia africana*. Decomposition processes in ecosystems presumably contribute to the enhancement of soil fertility and the sustainability of agricultural productivity. In leaf litter decomposition, there is a loss of carbon as the litter decomposes. The increase in CO_2 resulted from the activity of soil microorganisms and fauna. CO_2, produced by the decomposition of organic matter, is affected by temperature changes

(Darmawan et al., 2021). According to Ambachew Demessie et al., (2012), the decomposition rate of conifer species such as *Pinus patula* exhibited a relatively lower value compared to that of broadleaved ones. Conversely, the production of litter under broad-leaved *Eucalyptus* was notably higher in comparison to coniferous species. In general, the process of litter decomposition was observed to be rapid across all species (Ambachew Demessie et al., 2012).

4.3. The Effect of *Croton macrostachyus* and *Cordia africana* on Physicochemical Properties of Soil Nutrient Content from Watershed of Agroforestry System

4.3.1. Soil texture

Soil texture, as a factor that could affect soil physicochemical properties and to some extent soil biological properties, was significantly affected by the main effects of open area tree species and under the shade tree canopy. As the results of the texture analysis showed, there was a significant difference in the mean proportions of sand, silt, and clay between the soils under the canopy of the two shade trees and with their respective open areas (Table 4.3).

Therefore, the soils under the tree canopy are characterized as sandy loam, while those in open areas are characterized as sandy clay loam. This could be due to the soils being from the same parent material, under the same climate, similar topography, and vegetation cover. Furthermore, there was no difference in soil texture between the soils under the canopy of *Cordia africana* and *Croton macrostachyus* shade trees and outside the canopy of the shade trees. This could be due to the effects of homegarden agroforestry tree species being more prominent on the soil fertility rather than its physical structure. This finding was supported by (Zebene Asfaw & Ågren, 2007, Zebene Asfaw, 2008, Yadessa et al., 2009) who reported that there was no significant difference in soil texture among the canopies of *Milletia ferruginia*, *Cordia africana* and *Eucalyptus camaldulensis* when compared to the soil outside the canopy. This finding was also consistent with Agena et al., (2014) who reported that soil texture under the canopy of *Balanites aegyptiaca*, *Accacia tortolis*, and *Accacia seyal* does not show significant variation as compared to that outside the canopy.

Table 4. 3: The effect of *Croton macrostachyus* and *Cordia africana* on selected soil physical properties

Tree species	Type of sample	Soil Texture %				SMC
		Sand%	Silt%	Clay%	Textural class	
C. macrostachyus	Under canopy	64.00	18.67	17.33	Sandy Loam	12.6967^a
C. africana	Under canopy	63.00	18.33	18.67	Sandy Loam	13.8867^a
	LSD(<0.05)	1.757	0.680	0.239		0.573
C. macrostachyus	Under canopy	64.00	18.67	17.33	Sandy Loam	12.6967^a
	Open area	59.00	19.00	22.00	Sandy clay loam	10.2167^b
	LSD(0.05)	2.484	0.628	0.056		0.149
	CV	1.150	5.735	4.152		1.817
C. africana	Under canopy	63.00	18.33	18.67	Sandy Loam	13.8867^a
	Open area	61.00	19.00	20.00	Sandy clay loam	9.0433^b
	LSD(<0.05)	.0001	0.628	0.578		0.05
	CV	0	11.573	11.174		19.285

4.3.2. Soil moisture content (MC)

Analysis of variance in soil moisture content revealed that it was significantly affected by both tree species as there was a significant difference found between the soil moisture under the canopy and the open field far from the tree base ($p < 0.05$). However, the highest (13.87%) and lowest (12.70%) soil moisture values were recorded under the canopy of *Cordia africana* and *Croton macrostachyus*, respectively (Table 4.3). *Cordia africana* is a deciduous plant whose scales and leaves make good mulch for the soil during the dry season and add more leaf litter to the soil. This variation in soil moisture content between tree species could be due to variations in soil organic matter, which depends on the level of organic residues contributed by individual tree species. Concerning the effects of canopy area from the tree base, the highest (10.22%) and lowest (9.04%) soil moisture values were observed in the open area were recorded for *Croton macrostachyus* and *Cordia africana*, respectively (Table 4.3). The incorporation of organic matter allows the soil to retain water by increasing its surface area and improving soil structure to achieve better porosity (Chenchouni & Neffar, 2022). Tree canopies also resulted in less soil moisture loss through evaporation, which contributed to higher soil moisture content under the tree canopy. This result agreed with (Komicha et al., 2018) who reported moisture levels near the base of *Faidherbia albida (Delile)* and *Acacia tortilis (Forssk.)* trees are greater than in open fields in Ethiopia's central rift valley. Belay Manjur et al (2014), reported an insignificant difference between *Croton macrostachyus and*

Faidherbia albida in moisture content between radial distances from the tree trunk and open cultivated land in southern Ethiopia. In the same study, the result supported the same species selection and the result also evaluated the status of selected soil properties under the canopies of three indigenous tree species (*Acacia abyssinica*, *Cordia africana*, *and Croton macrostachyus*) in the croplands of soil moisture content were significantly higher under the canopy of *Cordia africana* than the other two tree species (Abey et al., 2023).

4.3.3. Soil pH

In this study, it was found that soil pH is significantly affected by the type of shade trees and under the canopy. The soil pH was significantly higher ($P<0.05$) under the canopy of *Croton macrostachyus* and *Cordia africana* than outside the canopy. The pH under the canopy of *Croton macrostachyus* and *Cordia africana* were 6.69 and 6.59, respectively, and that outside the canopy were 6.33% and 6.38% for *Croton macrostachyus* and *Cordia africana*, respectively (Table 4.4). the pH value of the categorical of the soil under the canopy is neutral and the open area is moderately acidic soils. The main reason for the higher pH of the soil under the canopy of both shade trees than outside the canopy could be due to above-ground litter deposition and the decomposition of their subterranean fine roots, which have a positive effect on subsequent mineralization and release action in the under canopy soil system. Similar studies showed that there is a significant difference in soil pH between the soils under the canopy and outside the canopy for the *Acacia abyssinica*, *Cordia africana*, and *Croton macrostachyus* tree species (Abey et al., 2023). In line with this study, a significant difference in soil pH was observed under the canopy of *Millettia ferruginia, Cordia africana, Croton macrostachyus,* and *Faidherbia albida* compared to outside the canopy (Gindaba et al., 2005; Belay Manjure *et al*., 2014). Similar to this study finding, Alemayehu et al., (2017) for *Cordia africana* and *Erythrina abyssinica*, in Arsi Golelcha district, Ethiopia, and Souza et al., (2012) for soil properties in coffee agroforestry systems, in the Atlantic rainforest indicated that the soil pH value was higher under tree canopies than in an open area. In addition, Desalegn Mamo & Zebene Asfaw, (2017) reported that the soil pH under the crown of *Croton macrostachyus* was significantly higher than soils from the open area, at Gemechis District, West Hararghe Zone, Oromia, Ethiopia.

Table 4. 4: The effect of *Croton macrostachyus* and *Cordia africana* tree species on soil pH and SOC

Tree species	Type of sample	PH	SOC%	SOM%
C. macrostachyus	Under canopy	6.69^{a}	5.2650^{a}	9.07686
C. africana	Under canopy	6.59^{ab}	3.8025^{ab}	6.55551
	LSD(<0.05)	0.73	0.3211	
C. macrostachyus	Under canopy	6.69^{a}	5.2650^{a}	9.07686
	Open area	6.33	2.7495^{b}	4.74014
	LSD(0.05)	0.048	.020	
	CV	0.89	20.69	
C.*africana*	Under canopy	6.59^{ab}	3.8025^{ab}	6.55551
	Open area	6.38	2.7300^{b}	4.70652
	LSD(<0.05)	0.19	.012	
	CV	1.20	9.200618	

4.3.4. Soil organic carbon/matter

Soil organic carbon (SOC) has an important control over soil physical and chemical properties, soil fertility status, plant nutrition, and soil biological activity (Brady & Weil, 2002). Soil organic carbon (SOC) was determined to estimate the amount of organic matter in the soil. The soil organic carbon levels were found to be significantly higher ($P < 0.05$) under the canopy of the shade trees *Croton macrostachyus* and *Cordia africana* than outside the canopy. The SOC values under the canopy of *Croton macrostachyus* and *Cordia africana* were 5.27% and 3.80%, respectively. However, outside the canopy, it was 2.75% and 2.73% for *Croton macrostachyus* and *Cordia africana*, respectively (Table 4.4). The SOC was found to be under the category of extremely high (3-8.7%) (Hazelton & Murphy, 2007). The highest SOC under the canopy of *Croton macrostachyus* and *Cordia africana* may have been caused by high organic matter accumulation due to the increase in above and below-ground biomass under their canopy and the SOC of the open area was extremely lower as the soil has low organic matter content (Aschalew Emire and Zebene Asfaw, 2018). The SOC under the canopy of *Croton macrostachyus* was significantly higher ($P<0.05$) than that under *Cordia africana*. The higher SOC under a canopy of *Croton macrostachyus* can be due to the rapid decomposition of the litter and the underground decomposition of its fine roots and also while the lower SOC under a canopy of the shade-giving tree *Cordia africana* may be due to the slow decomposition of its leaf litter despite the plentiful leaf fall observed under its crowns. Similar to this study result, many authors also reported a higher SOC concentration under the canopy of different trees than outside the canopy (Abey et al., 2023). The results of other studies also showed that significantly higher SOC content was observed under the canopy of *Ficus thonningii, Ficus sur, and Cordia africana* than in the soil outside the canopy cover (Enideg Diress, 2008; Daniel Hagos et al., 2013; Aschalew Emire and Zebene Asfaw, 2018). The result of this study is also consistent with the study result conducted in Sidama, southern Ethiopia (Zebene Asfaw & Ågren, 2007). Their study showed that the SOC was significantly higher under the canopy of *Millettia ferruginia* and *Cordia africana* than outside the canopy. In contrast to this study, the results of previous studies in Bedesa, Eastern Ethiopia, and Oromia Region, Ethiopia showed that the SOC under the canopy of *Cordia africana* and *Croton macrostachyus* on cropland tree species were not significantly higher than outside the canopy area (Gindaba *et al*., 2005; Yadessa *et al*., 2009).

4.3.5. Total Nitrogen

As the results of the current study showed, the total N concentration under the canopy of the shade trees *Croton macrostachyus* and *Cordia africana* was significantly higher ($P < 0.05$) than outside the canopy. The total nitrogen concentration under the canopy of the shade trees *Croton macrostachyus* and *Cordia africana* were 0.52% and 0.34%, respectively. However, outside the canopy was 0.32% and 0.31%, respectively (Table 4.5). Based on analytical methods and interpretation of soil test results, an overall N value of 0.25-0.5% or greater than 0.5% is high or very high, respectively (Bruce & Rayment, 1982). Therefore, under the canopy of the shade tree species *Croton macrostachyus* and *Cordia africana*, the observed TN values could be very high and high, respectively. This variation in TN is quite logical since there is a higher accumulation of organic matter under the canopy and the decomposition of dead roots from the shade trees *Coffea arabica* and *Rhamnus prinoides*. As shown in Table 4.4 below, total nitrogen under a *Croton macrostachyus* canopy was significantly ($P<0.05$) higher than under the *Cordia africana* canopy. The higher total nitrogen content under the canopy of *Croton macrostachyus* could be due to the greater accumulation of litterfall and the rapid decomposition rate of the litterfall of *Croton macrostachyus*. Other studies conducted in the central rift valley of Ethiopia and southern Ethiopia showed that significantly higher total nitrogen was observed under the canopy of *Balanites aegyptiaca*, *Accacia tortolis*, *Accacia seyal*, *Faidherbia albida*, *Croton macrostachyus*, and *Cordia africana* than outside the canopy (Agena et al., 2014; Belay Manjur et al., 2014; Abey et al., 2023).

Table 4. 5: The effect of *Croton macrostachyus* and *Cordia africana* on TN and Av. P.

Tree species	Type of sample	TN%	Av. P(mg/kg, ppm)
C. macrostachyus	Under canopy	0.5180[a]	35.47[a]
C. africana	Under canopy	0.3360[ab]	34.67[a]
	LSD(<0.05)	0.3173	14.13
C. macrostachyus	Under canopy	0.5180[a]	35.47[a]
	Open area	0.322[b]	33.36[b]
	LSD(0.05)	.016	0.537
	CV	14.34	7.571
C.africana	Under canopy	0.3360[ab]	34.67[a]
	Open area	0.308[b]	33.82[b]
	LSD(<0.05)	.350	0.588
	CV	10.08	4.41

4.3.6. Available Phosphorus

Under the canopy of both shade trees, the amount of available phosphorus was significantly higher (P<0.05) than outside the canopy. The available phosphorus under the canopy of the shade trees *Croton macrostachyus* and *Cordia africana* was 35.47 ppm and 34.67 ppm respectively. However, outside the canopy was 33.36 ppm and 33.82 ppm, respectively (Table 4.5). The amount of available phosphorus was highly influenced by homegarden agroforestry for the shade tree species *Coffea arabica* and *Rhamnus prinoides* (Aschalew Emire and ZebeneAsfaw, 2018). The rating of available phosphorus in the soil is categorized as low (<5ppm), medium (5-15ppm), and high (>15ppm) (Landon, 1991). The higher levels of available phosphorus under the canopy and open area of both shade trees may have been caused by organic input from litterfall deposition, manure fertilizer, and release from mineralization, as well as a higher microbial population stimulated by organic matter input that aided phosphorus solubility through fixation (Abey et al., 2023). In support of the present study, research conducted in the central rift valley of Ethiopia, eastern Ethiopia, southern Ethiopia, and arid southern Tunisia indicates that significantly higher available phosphorus was observed under the tree canopy than in open areas (Gindaba et al., 2005, Zebene Asfaw & Ågren, 2007, Jeddi et al., 2009, Agena et al., 2014, and Belay Manjur et al., 2014). In contrary to this study finding, in North Western Ethiopia lower available phosphorus was observed under a canopy of *Croton macrostachyus* than outside the tree canopy (Yeshanew Ashagrie et al., 1998). However, the findings of the current study were in line with Desalegn Mamo & Zebene Asfaw (2017), who reported higher available phosphorus under the canopy of *Croton* *macrostachyus* tree species than in the open cultivated land in West Hararghe Zone, Oromia, Ethiopia. A similar study in other parts of Ethiopia such as Belay Manjur, (2014), for *Faidherbia albida* and *C. macrostachyus* tree, and Zeleke Asaye (2017), for *Acacia tortilis* trees reported higher available phosphorus under the canopy than the open area agroforestry practice.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study showed that the amount of litterfall, rate of decomposition, and consequent effect on selected soil physicochemical properties varies significantly between *Cordia africana* and *Croton macrostachyus*. The total amount of litterfall was greater for *Croton macrostachyus* than for *Cordia africana.* Besides, *Croton macrostachyus* was found to have a more rapid decomposition rate of litterfall than *Cordia africana*. Trees have induced a positive effect on the availability of nutrients in the soil. Mineralization of the organic matter added SOC, TN, and Av. P were higher under the canopy of the two indigenous trees than in closer open space. Soil pH, soil organic carbon, total nitrogen, and Available phosphorus under *Croton macrostachyus* were higher than *Cordia africana* could be due to the addition of higher leaf biomass. A higher amount of nutrients was recorded under the canopies than in the adjacent open area. This is due to the addition of nutrients through litterfall, root turnover, and microbial activities. In addition to social and economic benefits, *Cordia africana* and *Croton macrostachyus* based homegarden agroforestry contribute to improving soil fertility thereby enhancing productivity. Farmers maintained *Cordia africana* and *Croton macrostachyus* as agroforestry trees because of their economic, ecologic, and social importance.

5.2 Recommendations

Based on the above-provided conclusions, the following recommendations are forwarded;

- *Croton macrostachyus* is a fast-decomposing litterfall that is useful for compost preparation to supplement soil fertilizers than *Cordia africana*, therefore good decomposition and soil nutrient content and further research are required on the nutrient release aspect of other indigenous species.
- *Cordia africana* and *Croton macrostachyus* are important agroforestry tree species that contribute to enhanced decomposition rates and improved soil nutrient content and hence should be promoted for further development.
- The present study was limited by financial and time scarcity. However, it would have been more profound if the study included year-round data and more other species and

further research that related to these species: for example comparing with exotic species, age difference on litterfall amount and rate of decomposition.

- Farmers need to be educated on the benefits of using species with higher decomposition rates and nutrient cycling capabilities in their agroforestry systems to improve soil health and sustainable agricultural practices.

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7. APPENDICES

7.1 The Amount of Litterfall Four Months

7.1.1 Shows that the table of data collection in all months was data records

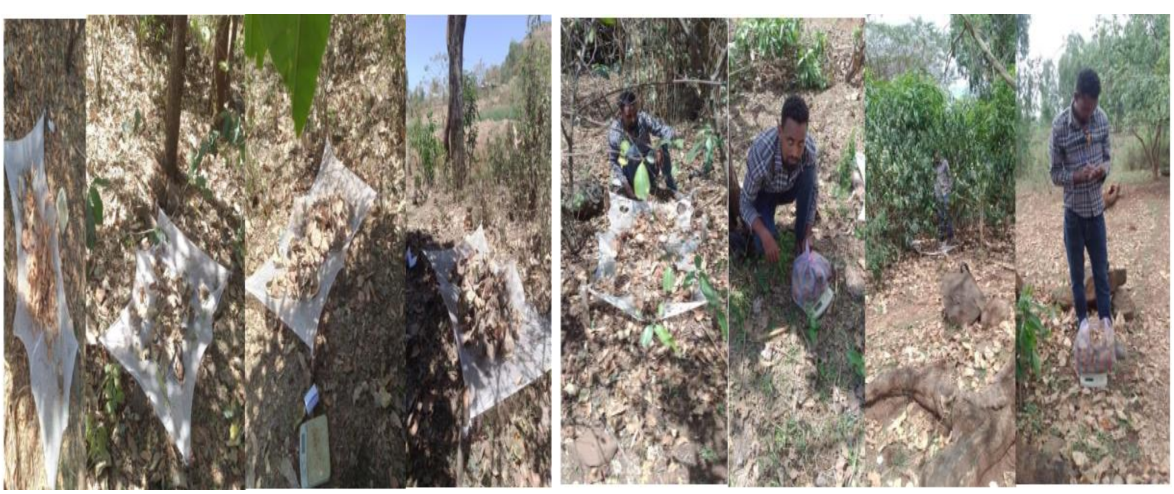
Table 7.1; The measurement of litter fall all months in the date of the interval was recorded

Months	Date of Interval	**Site One**				**Site Two**				**Site Three**			
		C. Macrostachyus (gm)		*C. Africana (gm)*		*C. Macrostachyus (gm)*		*C. Africana (gm)*		*C. Macrostachyus (gm)*		*C. Africana (gm)*	
	Area	**9**	**79.68**	**9**	**73.5**	**9**	**132**	**9**	**88.74**	**9**	115.5	**9**	59.5
Feb	15/06/2015	180	1593.6	220	1796.67	70	1026.67	96	946.56	96	1232	92	608.22
	30/06/2015	186	1646.72	208	1698.67	116	1701.33	142	1400.12	148	1899.33	112	740.44
	Total	**366**	**3240.32**	**428**	**3495.33**	**186**	**2728**	**238**	**2346.68**	**244**	**3131.33**	**204**	**1348.67**
March	15/07/2015	304	2691.41	300	2450	146	2141.33	264	2603.04	180	2310	176	1163.56
	30/07/2015	252	2231.04	390	3185	204	2992	290	2859.4	130	1668.33	244	1613.11
	Total	**556**	**4922.45**	**690**	**5635**	**350**	**5133.33**	**554**	**5462.44**	**310**	**3978.33**	**420**	**2776.67**
April	15/08/2015	378	3346.56	570	4655	464	6805.33	678	6685.08	290	3721.67	386	2551.89
	30/08/2015	182	1611.31	156	1274	502	7362.67	314	3096.04	470	6031.67	228	1507.33
	Total	**560**	**4957.87**	**726**	**5929**	**966**	**14168**	**992**	**9781.12**	**760**	**9753.33**	**614**	**4059.22**
May	15/09/2015	72	637.44	94	767.67	104	1525.33	118	1163.48	90	1155	62	409.89
	30/09/2015	26	230.19	44	359.33	38	557.33	96	946.56	46	590.33	32	211.56
	Total	**98**	**867.63**	**138**	**1127**	**142**	**2082.67**	**214**	**2110.04**	**136**	**1745.33**	**94**	**621.44**

Note: The area of description is $9m^2$ is plotted in the canopy litterfall and the other area is a canopy of trees the measurement was recorded of the litter fall data collection in each month.

7.1.2 Shows that the figure of data collection in all months was data records

Appendix 7.1: The installation of litter bag techniques and field data record litterfall collection



The installation and different dates of field observation data record of litterfall collection

7.2 The Rate of Decomposition Incubation Periods

7.2.1 The rate of decomposition and mass loss of tree species in the dry and wet seasons

Table 7.2: Decomposition rats K_D constant and mass loss in the leaf litter different stages over 120 days

Decomposition rats K_D constant in the leaf litter different stages over 120 days

rep	Treatment	W_o	**The incubation periods (day^{-1}) K_D**							
			30d		**60d**		**90d**		**120d**	
			W_t	Wo-Wt/30d	W_t	Wo-Wt/60d	W_t	Wo-Wt/90d	W_t	Wo-Wt/120d
1	CM1	5	4.45	0.018333333	2.81	0.0365	1.23	0.041888889	0.15	0.040416667
2	CM2	5	4.67	0.011	2.98	0.033666667	1.52	0.038666667	0.48	0.037666667
3	CM3	5	4.33	0.022333333	2.56	0.040666667	1.37	0.040333333	0.27	0.039416667
1	CA1	5	4.81	0.006333333	4.21	0.013166667	3.55	0.016111111	2.15	0.02375
2	CA2	5	4.88	0.004	4.34	0.011	3.65	0.015	2.91	0.017416667
3	CA3	5	4.73	0.009	4.15	0.014166667	3.24	0.019555556	2.75	0.01875
1	CM1	5	1.23	0.125667	0.73	0.071167	0.02	0.055333	0	0.041667
2	CM2	5	1.14	0.128667	0.68	0.072	0.012	0.055422	0	0.041667
3	CM3	5	1.18	0.127333	0.7	0.071667	0.013	0.055411	0	0.041667
1	CA1	5	2.18	0.094	0.93	0.067833	0.12	0.054222	0	0.041667
2	CA2	5	2.27	0.091	1.04	0.066	0.1	0.054444	0	0.041667
3	CA3	5	2.3	0.09	0.98	0.067	0.13	0.054111	0	0.041667

Mass loss of the leaf litter in different stages over 120 days

rep	**Treatment**	W_o	**The incubation periods (day^{-1}) Mass loss by this formula** Wo-Wt/W_O*100							
			30d		**60d**		**90d**		**120d**	
			W_t	Mass loss %	W_t	Mass loss %	W_t	Mass loss %	W_t	Mass loss %
The dry season of decomposition rate										
1	CM1	5	4.45	11	2.81	43.8	1.23	75.4	0.15	97
2	CM2	5	4.67	6.6	2.98	40.4	1.52	69.6	0.48	90.4
3	CM3	5	4.33	13.4	2.56	48.8	1.37	72.6	0.27	94.6
1	CA1	5	4.81	3.8	4.21	15.8	3.55	29	2.15	57
2	CA2	5	4.88	2.4	4.34	13.2	3.65	27	2.91	41.8
3	CA3	5	4.73	5.4	4.15	17	3.24	35.2	2.75	45
The wet season of mass loss										
1	CM1	5	1.23	75.4	0.73	85.4	0.02	99.6	0	100
2	CM2	5	1.14	77.2	0.68	86.4	0.012	99.76	0	100
3	CM3	5	1.18	76.4	0.7	86	0.013	99.74	0	100
1	CA1	5	2.18	56.4	0.93	81.4	0.12	97.6	0	100
2	CA2	5	2.27	54.6	1.04	79.2	0.1	98	0	100
3	CA3	5	2.3	54	0.98	80.4	0.13	97.4	0	100

7.2.2 The rate of decomposition of tree species in the picture

Appendix 7.2 The oven dry of the leaf litter and installation of nylon mesh in decomposition rate

After 65^{o} C 24 hours in the oven dry of the leaf litter

The installation of nylon mesh in the rate of decomposition

7.3 Soil Analysis of Selected Physiochemical Properties in Tree Species

7.3.1 Soil and plant analysis in the field

Appendix 7.3 Soil sampling of the field and sieve meshing of the data

The field data of soil sampling and Analysis sieve meshing of soil and plant laboratory

Bahir Dar University

College of Agriculture and Environmental Sciences

Department of Natural Resources Management

Soil and Plant Analysis Laboratory

Laboratory Report

No	Sample code	Textural				SMC	pH	SOM	TN	AvP
		% Sand	% Silt	%Clay	Class	%	(H_2o)	%	%	(ppm)
1	CMI1	64	20	16	Sandy loam	14.46294	6.71	11.09394	0.616	39.04
2	CMO1	59	19	22	Sand clay loam	12.15148	6.33	4.740138	0.322	33.36
3	CMI2	65	17	18	Sandy loam	11.37662	6.76	9.07686	0.476	31.68
4	CMO2	59	19	22	Sand clay loam	8.564536	6.33	4.740138	0.322	33.36
5	CMI3	63	19	18	Sandy loam	12.25389	6.6	7.05978	0.462	35.68
6	CMO3	59	19	22		9.935563	6.33	4.740138	0.322	33.36
7	CAI1	63	21	16	Sandy loam	11.47339	6.38	6.21933	0.287	33.38
8	CAO1	61	19	20		8.70149	6.48	4.70652	0.308	33.82
9	CAI2	63	19	18	Sandy loam	17.19069	6.6	7.39596	0.378	37.14
10	CAO2	61	19	20	Sand clay loam	8.75448	6.48	4.70652	0.308	33.82
11	CAI3	63	15	22	Sand clay loam	11.55689	6.7	6.05124	0.343	33.5
12	CAO3	61	19	20	Sand clay loam	8.39167	6.48	4.70652	0.308	33.82

Name of Chemist: Maman Shitaw Sign. Date 19/10/2016

Checked by: Maman Shitaw Sign. Date 19/10/2016

Approved by: Alek K Sign. Date 20/10/16

BIOGRAPHICAL SKETCH

The author was born on May 1986 E.C in Delbetgle Kebele, North Mecha Woreda, North Gojjam Zone, and Amhara National Regional State of Ethiopia. He attended his primary education at Nada primary school from 1996 to 2003 E.C. Then he moved to Dagi secondary school from 2004 -2005 E.C and he attended Colonel Tadesse Muluneh Fentie Memorial preparatory school from 2006-2007 E.C in Merawi Town. After successfully passing the Ethiopian Higher Education Entrance Examination, he joined Assosa University, College of Agriculture and Natural Resources in 2008 and graduated with a BSc Degree in Natural Resource Management (NaRM) in June 2010 with a CGPA 3.70. Upon graduation, he worked at Assosa University for three years. After serving for about Three years, he joined the regular Postgraduate program at Bahir Dar University, College of Agriculture and Environmental Sciences on October 2014 to pursue his MSc degree in the field of Agroforestry and completed in June 2016 CGPA 3.70.