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Litter Decomposition of Indigenous Agroforestry Tree Species, Jimma Zone, Southwest Ethiopia

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ABSTRACT

At the Jimma town's Boye nursery site in southwest Ethiopia, three selected indigenous agroforestry tree species were the subject of a study to determine how their foliage litter materials broke down over time. Using Pearson's correlation coefficient, the study used a single exponential model to calculate the rate at which decomposing litter materials decayed and the litter chemical quality indices that were investigated. *C. macrostachus* had a rate constant of 0.0400 day^{-1}, which was substantially faster than that of *F. vata* and *E. abyssinica*. It took 17.3 and 29.7 days, respectively, for *F. vata* and *E. abyssinica* to lose 50% of the initial dry matter. While nitrogen and phosphorus were found to be facilitators, the parameters of the chemical quality of the litter were found to be impeding biochemical parameters. The species with the fastest rate of nitrogen return in a short amount of time was found to be *E. abyssinica*, followed by *C. macrostachus* and *F. vasta*. *C. macrostachus* decomposes quickly, which may limit its ability to improve soil fertility over an extended period of time. It is important to take into account F. vasta and primarily *E. abyssinica for the long-term accumulation of soil organic carbon.*

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Introduction

The benefits of agroforestry include preserving soil erosion, enhancing the water-holding capacity of soil, and improving soil fertility through nitrogen fixation (Yadessa et al., 2001). The process of breakdown is crucial for the recirculation of our planet (Shi, 2013). The breakdown of tree species biomass, particularly foliage litter, can enhance soil fertility in tropical agroforestry systems.

Agroforestry land-use systems continue to benefit from selecting and employing desirable species based on their leaf litter decomposition characteristics. Litter materials with rapid decomposition characteristics are associated with slow to low quality (Palm et al., 2001). High-quality materials could be used for short-term soil fertility correction, whereas low-quality materials are used for long-term soil organic matter maintenance.

The most important factors influencing litter decomposition are litter quality and climatic factors like rainfall and temperature patterns (Mubarak et al., 2008). According to Mafongoya et al. (1998),the chemical parameters nitrogen (N), phosphorus (P), lignin, cellulose, hemicellulose, lignocellulosic index (LCI), and C/N are more important than nitrogen. Nevertheless, the composition of these chemicals can greatly differ depending on the species, growth stage, plant parts, and environmental factors in which the species are cultivated. Nevertheless, the composition of these chemicals can greatly differ depending on the species, growth stage, plant parts, and environmental factors in which the species are grown (Abidemi, 2017). There are both fresh and senescent plant materials in agroforestry, but in natural forests and agricultural systems, the senescent material dominates. Purposeful pruning of foliage material is more common than natural litterfall in agroforestry land use systems (Moumita et al., 2016; Nair et al., 1999).

The multipurpose tree *E.abyssinica* is used in traditional medicine by the native population to treat a wide range of illnesses, including infections, bronchitis, asthma, inflammation, cough, and malaria (Cui et al., 2008). Raising stall-fed sheep and goats to supplement low-quality diets with protein during the dry season and fix nitrogen from the atmosphere through their root nodules was an inexpensive and effective way to resource poor Ethiopian farmers (Aerts et al., 2008).

The tree species *F.vasta* can be used to fuel wood and livestock feed. The present result revealed that *F.vasta* exhibits a favorable effect on soil properties studies, indicating that the tree is crucial for enhancing soil fertility in the Hawassa Zuria district (Zeleke et al., 2015).

In order to conserve soil, *C. macrostachus* is used to provide shade and shelter. The useful shade that trees provide is what makes them popular for planting. The study by Manjur et al. (2014) revealed a significant alteration in maize yield under the canopy of C. macrostachus. There is a higher concentration of nutrients in foliage materials, which are thought to have superior potential to improve soil fertility. Despite this, there are few attempts to track the decomposition pattern of intentionally harvested agroforestry species' foliage biomasses. The objective of this study was to assess the rate of decay of foliage litter materials from three particular native Agroforestry tree species, namely, *C.macrostachus*, *F.vasta*, and *E.abyssinica*, grown at the Jimma Boye nursery site in southwest Ethiopia. The study also sought to ascertain the effect of foliage litter's chemical makeup on decomposition rates.

Materials and Methods

Study Site

The experiment took place at the Jimma Town Boye plant nursery. The research site is located about 4.5 km to the west of the administrative town of Jimma, lying between latitudes 7°40´ N and 36°50´ E.

Climate Conditions and Soil Types of the Study Area

The study area was located within the climatic zone, locally known as Weynedega, which is very suitable for agroforestry practices as well as human settlement (Abdela et al., 2017). The mean annual temperature ranges from 14 to 29 °C, with the mean annual rainfall ranging from 1200 to 2000 mm (Getachew et al., 2021). There is maximum precipitation during the three months from June to August, with minimum rainfall in December and January (Alemu et al., 2011).

According to Jafer et al. (2018), the study areas' most common soil types are nitosols (35%), vertisols (15%), cambisols, and miscellaneous (50%) with a pH of 4.5. Nitosoil dominates the area for experimental investigations.

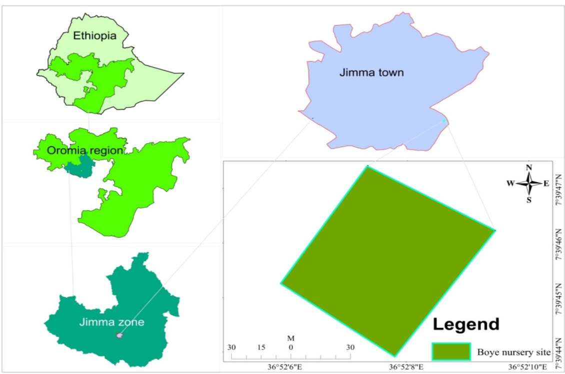

Figure 1. Location of the study area

Species Selection

Due to their ability to adapt to the conditions of the research area, Ficus vasta, Croton macrostachus, and Erythrina abyssinica were chosen for this study. In addition to its adaptability, Erythrina abyssinica was also selected for its capacity to preserve nitrogen.

Foliage Collection and Sample Preparation

The collection and preparation of foliage biomass was carried out following a routine sample process of wood perennial plant tissue, (Jones Jr., 2019). The species' most recent and completely formed live leaf biomass was collected. This leaf was exposed to direct sunlight before or at the start of the species reproductive stage. Three replicate leaf samples were obtained and allowed to air dry for three further days (Gindaba et al., 2004). The 50 g of dried plant biomass was put in nylon litter bags with a 2mm mesh size.

Experimental Design and Treatment Arrangement

A factorial RCBD design was used in the installation of the experiment. The main factor in the experiment was the species type (*C. macrostachus, F. vasta*, and *E. abyssinica*), while the sub-factors included incubation periods of (15, 30, 45, 60, 75, and 90 days, all with three replications. Each of the 3 blocks was assigned all the treatments, resulting in a combined total of 54 litter bags. As decomposition is faster in sub-soil, litter bags are placed beneath the soil at a depth of 0 - 15cm (Nair et al., 1999).

Litter Bag Collection

The litter bags were randomly picked up block by block, 15 days apart, for three consecutive months. After being recovered and transported to the laboratory, the bags were placed inside a paper envelope with a label. Samples were air dried and cleaned from attached soil particles carefully by hand and hair brush, then oven dried at 70°C until constant weight (Gindaba et al., 2004). The mass loss pattern of litter residues was analyzed by weighing oven-dried samples individually. At various sampling times, the proportion of ash-free dry matter that persisted was calculated using the following functions (Hossain et al., 2011):

$$\text{Mass remaining } (\%) = \frac{DMt}{DMo} \text{x}100 \qquad (1)$$

The dry matter at the time of sampling is referred to as DMt, and the initial dry matter of the litter sample kept for breakdown is referred to as DM0. The decomposition rate constant (k) of litter residues was determined using a single exponential model(Olson, 1963) as shown below.

$$\text{Wt} = Woe^{-kt} \qquad (2)$$

Where Wt is weight remaining at time t, and Wo initial weight, 'e' is the base of natural logarithm, k is constant, and t is time (days).

Chemical Analyses

Standard analytical procedures were used for the chemical analysis of the samples. Therefore, cellulose content was determined using sequential heating fiber extraction methods (Soest & Wine, 1967). The extraction was done in the order of acid detergent fiber to estimate cellulose.

The plant tissue was analyzed using the dry ashing technique to determine the carbon content. To do so, one gram of milled foliage litter biomass was weighed into a crucible and calcinated at 450ºC for 3 hours in Muffle Furnas. In the study, fifty percent of the ash-free dry matter was considered organic carbon (Anderson & Ingram, 1994). Additionally, the Kjeldahl distillation and (Olson, 1963) were used to determine the amount of nitrogen and phosphorus respectively.

Statistical Analysis

Statistical analyses were conducted using R. V. 3.6.3 (Wieduwilt et al., 2020) and Microsoft Excel computerized programs. We evaluated model fit using tree species in the sj plot and incubation period, tested for significance using the ANOVA function in the packaging car, and decomposition rate of selected agroforestry tree species using emmeans package (Wieduwilt et al., 2020). Any results declared statistically different were done at a 5% level of error tolerance (95% confidence interval). The correlation between decomposition rate and certain biochemical composition parameters was investigated using Pearson's correlation coefficient

Results and Discussions

Foliage Decomposition Rate of Croton macrostachus, Ficus vasta, and Erythrina abyssinica

The two parameters that have been used to describe the results for the decomposition pattern are loss of dry matter (percentage of original mass) and litter decomposition rates. The results of the Analysis of Variance (ANOVA) showed that the species type and incubation period had an influence on both parameters ($p < 0.001$).

The Effect of Tree Varieties on Mass Loss During a 90-Day Period

The results showed that during the first fifteen days of the study, *C. macrostachus* litter lost the most dry matter mass, while *Erythrina abyssinica* lost the least (Fig 2). The mass that was still in the litter bag at the time ranged from 41.87% in *C. macrostachus* to 63.81% in *E. abyssinica*. Because of their morphological characteristics, *F. vasta's* foliage dry matter dropped from 59.13% to 21.53% more quickly during that period than that of C. macrostachus and E. abyssinica after fifteen days. Other researchers have also stated that the structural differences in the leaves of plants present a possible source of variability in the amount of mass lost to soil (Prescott & Vesterdal, 2021). By the 60th day, the remaining mass of *F. vast* foliage was 5.08g, representing 10.16% and being less than the other two species. Specifically, *E. abyssinica* had approximately 22.07% (11.035 g) of decaying leaf litter left at the conclusion of the experiment.

As a result, during the monitoring periods, the species showed a biphasic weight loss pattern, with a rapid initial phase and a slower subsequent phase. Sarkar et al. (2016), the early stage's rapid mass loss may be due to leaching and microbial action on water-soluble components, whereas the later stage's slower mass loss may be caused by an increase in the recalcitrant fraction.

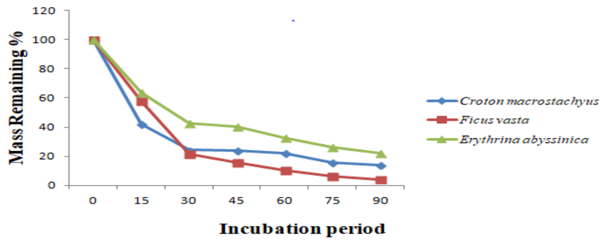

Figure 2. portrays the litter mass that stays during the decomposition of foliage litter materials in a span of 90 days.

The Effect of Various Tree Species Over A 90-Day Period on the Decomposition Rate Constant (K)

The decomposition rate (day^{-1}) of the leaf litter materials under examination showed different patterns. The researchers verified that, over each 15-day sampling period, *C. macrostachus* had the fastest decomposition rates, ranging from 0.0357 to 0.0404 day^{-1}. Additionally, it shows that it takes 17.3 days to lose 50% of its initial mass, which is the maximum net mean daily decomposition rate constant (k= 0.0400) (Table 1). Both *F.vasta* and *E.abyssinica* have the same decomposition rates of 0.0233 day^{-1} over each 15-day sampling period and are slower than *C.macrostachus*. Both *F. vasta* and *E. abyssinica* showed varying decomposition rate constants of 0.0266 to 0.0200 and 0.0200 to 0.0100 day^{-1} at 30 to 45 days. From the 60th day until the end of the incubation period, all three species (*C. macrostachus, F. vasta*, and *E. abyssinica*) exhibited a consistent decomposition rate constant of 0.0100 days. The study proved that both the C/N ratio and cellulose content are good quality indicators in decomposition studies. In this respect, *C.macrostachus* contains less cellulose. Liu et al. (2007) also suggested that in the initial stages of litter decomposition, N can be a good predictor of decomposition rate, whereas in later stages, chemical compounds such as lignin can play a more important role. This study also showed that the decomposition rate constants of *C.macrostachus* and *F.vasta* are significantly higher than those of *E.abyssinica*. This was indicated by fast weight loss.

Table 1. Impact of different species decomposition rates at various decomposition stages

Species	Incubation period (days) KD (day^{-1})					
	15	30	45	60	75	90
C.macrostachyus	0.0400^{a}	0.0266^{b}	0.0200^{c}	0.0100^{d}	0.0100^{d}	0.0100^{d}
F.vasta	0.0233^{bc}	0.0266^{b}	0.0200^{c}	0.0133^{d}	0.0100^{d}	0.0100^{d}
E.abyssinica	0.0233^{bc}	0.0200^{c}	0.0100^{d}	0.0100^{d}	0.0010^{d}	0.0100^{d}
LSD	0.00504277					

Table 2. Relationships between some litter chemistry parameters of the species foliage litter material and the decomposition rate constants (KDC.m, KDF.v, and KDE.a).

Parameter	Correlation Coeffient		
	KDC.m	KDF.v	KDE.a
	r	R	r
Cellulose	0.4ns	-0.53**	-0.79***
Nitrogen	0.78*	0.71*	0.98***
Phosphorus	0.218[ns]	0.69***	0.425ns
C/N	-0.58**	0.78**	0.95***

* Significant when P < 0.05, ** significant when P < 0.01, *** significant when p < 0.001, insignificant when NS is included. kDM.c=rate of *C.macrostachyus*, kDF.v=rate of *F.vasta*

Mean Values in Columns with Matching Letters are Not Significantly Different.

The examined species' overall KD values range from 0.0100 to 0.0400 days1, which is comparatively smaller than the domestic ranges for *S.sesban* and *F.macrophylla* that have been reported (Bekele et al., 2020). Since the experiment was conducted on a single site with consistent climatic conditions, the observed variation in K values may be explained by the differences in litter quality among the species (Table 1). This validates the results of the Mazaka and Shoko (2013) study on leaf litter from related legume tree species in Zambia. "The chemical compositions of *Leucaena leucocephala* and *Senna siamea* leaf litter materials influenced their decomposition rates more than climate factors," they concluded.

The Influence of Litter's Chemical Composition on Rates of Decomposition

The relationship between the breakdown rate and a few litter chemical parameters of the *C. macrostachus*, *F. vasta*, and *E. abyssinica* tree species was examined using the Pearson correlation coefficient. The species was found to be influenced by more than one litter chemical parameter (Table 2). As confirmed, *F.vasta* and *E.abyssinica* were significantly influenced by cellulose (-ve), C/N ratio, and nitrogen (+ve), whereas *C.macrostachus* influenced by N (+ve) and C/N (-ve). Accordingly, cellulose and the C/N ratio were reported as more reasonable parameters for retarding the decomposition rates of *F.vasta* and *E.abyssinica* than *C.macrostachus* whereas nitrogen's decomposition facilitation effect was more pronounced in the latter species. The negative effects of cellulose and the C/N ratio were more pronounced in *F.vasta* and *E.abyssinica* than *C.macrostachus* whereas the positive effect of nitrogen was more pronounced in the latter species foliage litter. This is attributable to the level of litter chemical variations observed among the tested species (Table 2).

The observed variation in the initial level of litter chemical quality indices among the tested species may be the reason for this (Bekele & Nigatu, 2019). The higher N content for both *E.byssinica* and *C.macrostachus*, and the probable higher P content for *F. vasta*, are based on the author's significantly higher cellulose report for *E. abyssinica*. This lends credence to the theory that, under some circumstances, one of the most significant determinants of foliage litter decomposition is its chemical quality, and that the effects may differ depending on the species (Sarkar et al., 2016).

Summary and Conclusion

Despite a few attempts to use native species, the litter decomposition of agroforestry tree species has not been thoroughly studied. The study examined the breakdown of three agroforestry tree species foliage litter town's at the Jimma town's Boye nursery site in southwest Ethiopia. The three species were *E. abyssinica*, *F. vasta*, and *C. macrostachus*. To achieve this, full-grown, green leaves with petiole foliage were collected from the entire crown of the mother plant and left to air dry for three days. After that, the litter-bag method was used to conduct the experiment in an open field. The impact of litter chemical quality indices on decomposition rates was also examined in this study.

The findings verified noteworthy ($p < 0.001$) variations in the amount of ash-free dry matter lost and the rates of decomposition among the various species. After the study, the final mass of leaf litter remaining varied from 4 to 22.07%, with an average of 13.05%, and the average daily decomposition rate was 0.025. Our knowledge of how the metabolic makeup of leaf litter material influences its rate of decomposition has also been broadened by the work. In fact, it was found that cellulose and C/N were impeding factors, while N and P were related to facilitation.

According to the study, *C. macrostachus* foliage litter decomposes the fastest, followed by *F. vasta* and *E. abyssinica*, in that order. The rapid decomposition of *C. macrostachus* litter may limit its long-term capacity to accumulate organic matter. As an alternative, *F. vasta* and mostly *E. abyssinica* may be taken into consideration for these reasons. Despite the fact that the experiment was only conducted in one place and one season, a more thorough investigation is suggested before making any firm recommendations. Furthermore, the study only looked at the foliage; more investigation is needed into the roots, stems, buds, and flowers.

Declarations

All information in this paper is true and correct to the best of our knowledge and belief. We hereby declare that all the above information is correct and accurate. I solemnly declare that all the information furnished in this document is free of errors to the best of my knowledge.

Author Contribution Statements

Kasu and Dargo conceived of the presented idea. Kasu, Dargo and Solomon developed the theory and performed the computations. Kasu and Dargo verified the analytical methods. Kasu, Dargo and Solomon to investigate [a specific aspect] and supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

Kasu, Dargo and Solomon conceived and planned the experiments. Kasu and Dargo. carried out the experiments. Kasu and Dargo contributed to sample preparation. Kasu contributed to the interpretation of the results. Kasu took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

Competing Interest Statement

We declare that there is no conflict of interest

Funding Declaration

The authors ensured that this study didn't get any financial support from any funding agencies

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