Litter Production of Cocoa-Based Agroforestry in West Sumatera, Indonesia

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ABSTRACT

Litter is a fragment of aboveground carbon stocks, a vital bridge to the belowground carbon cycle. Land conversion to agricultural purposes will affect litter production. This study aimed to compare the litter production of natural forests with cocoa-based agroforestry systems (AFS) in West Sumatra. Litter production was measured in five different types of ecosystems, namely natural forest (NF), cocoa-rubber-based AFS (CR), multistrata cocoa-based AFS (CM), cocoa-coconut-based AFS (CC), and cocoa monoculture (M). This study is quantitative research with the collection method. The difference in litter production between the five ecosystems observed was tested using ANOVA parametric statistical method. Litter was collected monthly for one year in which litter traps were evenly distributed in each research plot. Ecosystems of NF and M produced the highest annual litter (6.04 Mg ha^{-1} and 4.65 Mg ha^{-1} respectively), while CR produced the lowest one (2.52 Mg ha^{-1}). Although this study did not perform comprehensive modeling of decomposition dynamics, the measurement of annual litter production can provide a further understanding of the dynamics of ecosystem carbon, especially in cocoa-based agroforestry.

Keywords: Agroforestry, Carbon stock, Cocoa, Litter

ABSTRAK

Serasah adalah bagian dari stok karbon di atas permukaan tanah yang merupakan penghubung penting pada siklus karbon di bawah permukaan tanah. Konversi lahan untuk kepentingan pertanian bisa mempengaruhi produksi serasah. Penelitian ini bertujuan untuk membandingkan produksi serasah dari hutan alami dengan sistem agroforestri (SAF) berbasis kakao di Sumatera Barat. Produksi serasah diukur pada lima tipe ekosistem yang berbeda, antara lain hutan alami (H), SAF berbasis kakao-karet (KK), SAF kakao multistrata, (KM), SAF berbasis kakao kelapa (KKel) dan ekosistem monokultur kakao (M). Penelitian ini merupakan penelitian kuantitatif dengan metode koleksi. Perbedaan produksi serasah di antara lima ekosistem diuji dengan pendekatan statistik ANOVA parametrik. Serasah dikoleksi per bulan selama satu tahun menggunakan perangkap serasah yang didistribusikan secara merata di setiap petak penelitian. Ekosistem H dan M memproduksi serasah tahunan tertinggi (6.04 Mg ha^{-1} dan 4.65 Mg ha^{-1} berturut-turut), sementara KK terendah (2.52 Mg ha^{-1}). Meskipun penelitian ini tidak menyediakan pemodelan dinamika dekomposisi yang komprehensif, pengukuran produksi serasah tahunan dapat menambah pengetahuan untuk lebih memahami dinamika karbon ekosistem, terutama pada sistem agroforestri berbasis kakao.

Kata Kunci: Agroforestri, Stok karbon, Kakao, Serasah

INTRODUCTION

Among the various components of the soil-plant system, nutrient cycling is related directly to aboveground system productivity. Litter is one of the aboveground system fragments, which is a vital bridge to the belowground carbon cycle. The cycle of carbon and nutrient is the main ecosystem process driven by plant litter decomposition (Bradford et al., 2017; Giweta, 2020). Therefore, apart in addition to the data on the vegetation biomass, the National Inventory Report and the Kyoto Protocol Report under the United Nations Framework Convention on Climate Change (UNFCCC) require separated measurements of litter and wood debris biomass (The United Nations Framework Convention on Climate Change [UNFCC], 2015).

Based on the structural parameters of vegeta-

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tion, such as species abundance and diversity, litter production provides key information about the functioning of a balanced ecosystem (Petraglia et al., 2019). Litter production patterns between ecosystems vary depending on altitude, latitude, soil fertility, standing structure, climate, and tree species composition (Apriyanto et al., 2021; Primo et al., 2021). Apart from these factors, land management of various types of human activities also provides dynamics to litter production and decomposition patterns. Regarding the effects of human activities on terrestrial ecosystems, land use categories and histories are the key factors in determining the level of carbon stock balance in the soil (Sleeter et al., 2018). Conversion of forest land to agricultural land reduces soil carbon stock because it will affect litter production (Auliyani et al., 2019 ; Yue et al., 2020). Thus, research is needed to compare litter carbon stocks in natural forests and agricultural land.

The Agroforestry System (AFS) is one of the best approaches to reduce pressure on natural forest while still meeting local economic needs. In Indonesia, one of the most common crops grown by AFS approach is cocoa (*Theobroma cacao* L.), which originally grows in tropical rain forests. This study aimed to compare the litter production of natural forest with cocoa-based agroforestry systems (AFS) and cocoa monoculture in West Sumatera. Cocoa-based agroforestry and other types of agroforestry can be awarded credit for its services in storing carbon (Roziaty & Pristiwi, 2020) . Carbon stocks of AFS with perennial mixtures such as cocoa and coffee vary between 12 and 228 MgC per hectare and have the potential to mitigate climate change (Madountsap et al., 2018; Santhyami et al., 2018; Besar et al., 2020; Batsi et al., 2021).

Estimates of annual litter production are a prerequisite for forest soil carbon stocks modeling and their associated changes in biodiversity, decomposition dynamics, and even energy cycles (Krishna & Mohan, 2017). Although this study did not carry out comprehensive modeling of decomposition dynamics, the measurement of annual litter production could provide further understanding of ecosystem carbon dynamics, especially cocoa-based agroforestry.

MATERIALS AND METHODS

Study Area

This study is quantitative research with the collection method. The study was conducted from March 2017 to March 2018. The research was conducted in cocoa-rubber based AFS (CR), multistrata cocoa-based AFS (CM), and natural ecosystem (NF) located in Nagari Simpang, Simpati Subdistrict, Pasaman Region. Meanwhile, the cocoa-based AFS grown under coconut (C. nucifera) (CC) and cocoa monoculture (M) are located in Sungai Geringging, Padang Pariaman Region, West Sumatera (Figure 1). Tree community composition and structure of each cocoa-based agroforestry has been studied by Santhyami et al., (2020). Natural forest was represented by Bukit Badindiang in Pasaman, a traditionally protected and managed by local community (Santhyami et al., 2021).

The location of the NF is at an altitude of 500 meters above sea level with hilly topography. The location of the CM and CR is at an altitude of 250 meters above sea level with a flat topography. The location of the CC and M is at an altitude of 180 meters above sea level with a flat topography. The soil in Simpati Subdistrict is classified as red and yellow litosol and podzolic (Badan Pusat Statistik [BPS] Pasaman, 2018). The soil in Sungai Geringging District is alluvial, podzolic, and peat (Pemerintah Kabupaten Padang Pariaman 2013). These two districts are classified in wet areas with type A rainfall (Schmidt & Ferguson, 1951).

Figure 1. Research location in West Sumatera, Indonesia: CM (Multi-strata Cocoa), CR (Cocoa-Rubber) and NF (Natural Forest) in Nagari Simpang Alahan Mati, Kabupaten Pasaman; CC (Cocoa-Coconut) and M (Monoculture) in Sungai Geringging, Padang Pariaman

Data Collection

The litter was collected monthly for one year with a litter trap, every beginning of the month. The traps were spread inside plots. The minimal area of plots for a natural forest in Indonesia is 1 ha (Rosalina et al., 2014), while for plantation land as agroforestry is ¼ ha (ForestWorks ISC, 2014). On this basis, 25 plots were designed in the forest and six plots on each agroforestry and monoculture practices with a size of 400 m2 for each plot (Badan Standar Nasional Indonesia [BSNI], 2011).

The litter trap is an open wooden frame with a size of 50x50 cm and a height of 30 cm. This wooden frame was covered with 1-mm nylon cloth material. Each plot consisted four litter traps, randomly distributed within the plot. Trap positions were changed monthly (Dawoe et al., 2010). Each litter trap was raised 10 cm above the ground surface to prevent decomposition (Figure 2). The collected litter was then dried until it reached a constant weight. Litter production is expressed in Mg ha^{-1}.

Figure 2. Litter trap design

The point intercept method (Mueller-Dombois and Ellenberg, 1974; Nunes et al., 2015; Thacker et al., 2015) was used to calculate the percentage of land canopy cover. A plot of 400m2 with a size of 20 x 20m was divided into 100 square frames and mapped on a piece of graph paper. This point interception method has the principle of reducing each small square to a midpoint and observing and calculating the cut point as a percentage of the tree canopy. The interception was measured by a simple periscope using a tube with a mirrored base to see if the canopy was closed.

Data Analysis

The difference in litter production between the five ecosystems observed was tested using the ANOVA parametric statistical method with a 95% confidence level for normally distributed and homogeneous data or the Kruskal Wallis non-parametric statistical method with a 95% confidence level for normally undistributed and non-homogeneous data. The post hoc tests were performed, namely Tukey's Honestly Significant Different (Tukey's HSD) for ANOVA and the Mann Whitney U test for Kruskal Wallis.

RESULTS AND DISCUSSION

Monthly litter production was measured from March 2017 to February 2018 in five different ecosystem types, namely natural forest (NF), cacao-rubber-based AFS (CR), multistrata cocoa-based AFS (CM), cacao-coconut-based AFS (CC), and cacao monoculture (M). Table 1 shows the comparison of annual litter production in four cocoa-based AFS and natural forest. This table also shows the comparison of the stand basal area (Santhyami et al., 2018) and the percentage of canopy cover (%) as the basis for analysis. Forest and monoculture ecosystems were the groups that produce the highest annual total litter, which was 6.04 Mg ha^{-1} and 4.65 Mg ha^{-1}, respectively, while the lowest was produced by CR (2.52 Mg ha^{-1}).

This study shows that litter production is related to the value of the basal area and the percentage of canopy cover (Table 1). Basal area is reflected by tree size, stand volume, and biomass (Torres & Lovett 2013), so forests have a higher litter production. Huang et al., (2018) reported that litter production in natural forests was strongly influenced by the stand basal area, age structure, stem volume, altitude, and seasonal and climatic factors. The stand basal area of cocoa-based AFS in this study was lower than in forests, therefore the litter production was also lower than in forests. This result is in line with the research of Owusu-Sekyere et al., (2006) and Triadiati et al., (2011), reporting that the annual litter production of primary or secondary forests is greater than that of cocoa plantations. The natural forest in this study had a litter production of 6.04 Mg ha^{-1} year^{-1}. The forest in this study was customary land in a protected area. The most dominant tree species in this forest was Tarok tree (Campnospera auriculata). This species has thickly leathery broad leaf blades. However, the natural forest litter production in this study was smaller than in the primary forest in Lore Lindu National Park, Central Sulawesi (13.67 Mg ha^{-1} year^{-1}) (Triadiati et al., 2011) and Ghana (8 Mg ha^{-1} year^{-1}) (Owusu-Sekyere et al., 2006).

Table 1. Litter carbon stock of natural forest and four cocoa-based AFS

Type of land use	Stand Basal Area (SBA) (m^2 ha^{-1})	Canopy cover percentages (%)	Annual litter production (Mg ha^{-1})
Cocoa – Rubber (CR)	22.27	79.50	2.52^a
Multistrata Cocoa (CM)	34.42	92.67	2.92^a
Cocoa Coconut (CC)	29.15	82.17	3.96^b
Cocoa Monoculture (M)	9.74	61.67	4.65^{bc}
Natural Forest (NF)	43.34	93.24	6.04^c

Remarks: Values followed by the same letters in the same column are not significantly different based on Tukey's HSD test

According to the results of the one-way ANOVA

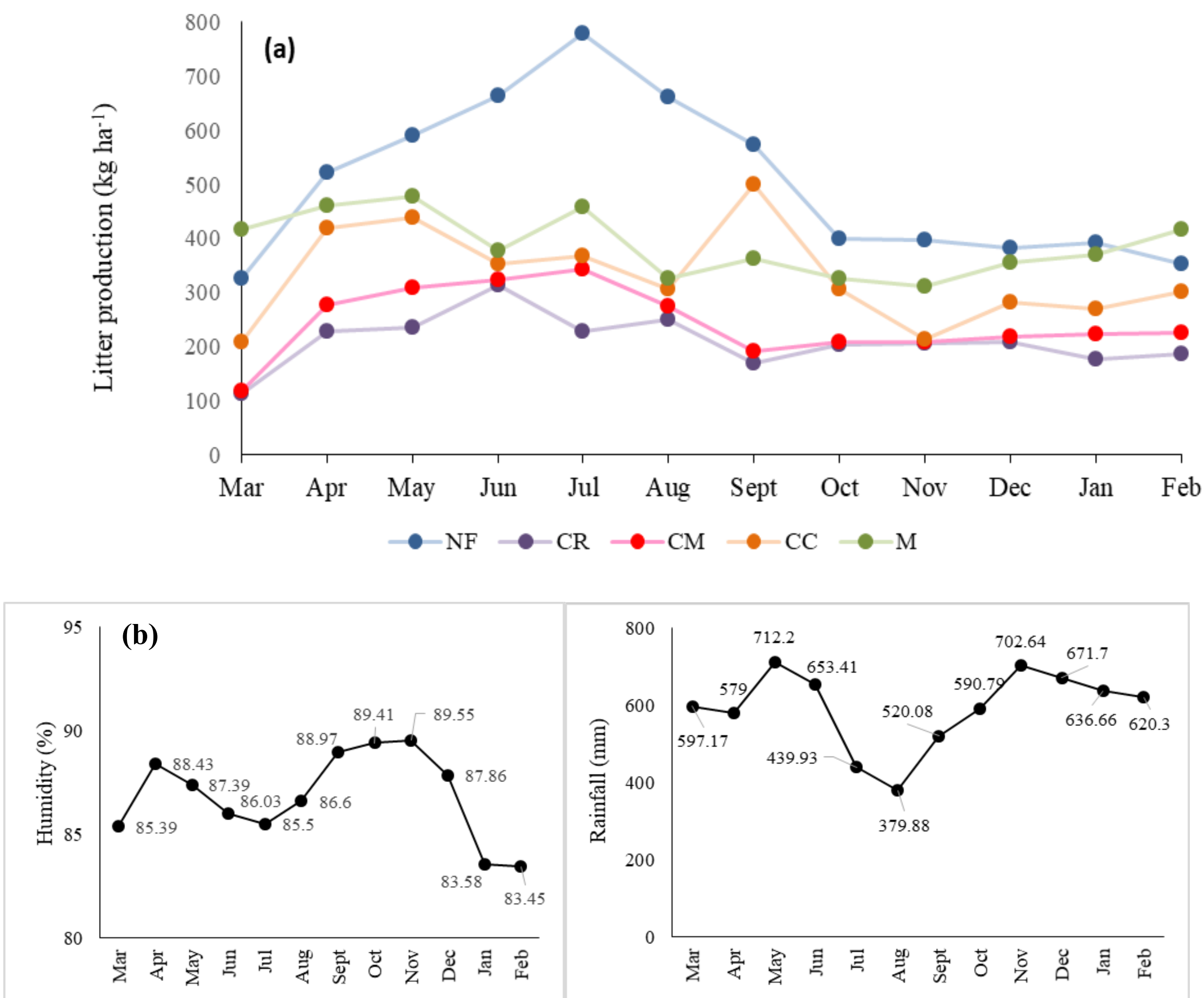

Figure 3. (a). Monthly litter production (March 2017 – February 2018), (b). Climatic condition of West Sumatera (March 2017 – February 2018) (Source: BMKG 2018)

test, the annual litter production of these five ecosystems was significantly different. Ecosystems based on the level of litter production from the lowest to the highest were grouped into three groups, namely CR - CM, CC - M, and M - NF. Statistically, the production of litter in cocoa monocultures was higher than in agroforestry practices and forests. In monoculture farming, farmers performed more intensive care than those in agroforestry. The action of pruning was done periodically. Some litter from this pruning process were netted into the trap.

Apart from the pruning factor, the high annual litter production in monoculture practices is also influenced by environmental pressures. Miyaji et al., (1997) mention that cocoa leaves have a shorter lifespan and easily fall when planted in an environment with high sunlight exposure. This theory is in line with the data of canopy cover percentages measured by the point intercept method. The monoculture cocoa ecosystem had the lowest canopy cover percentage, causing high exposure to sunlight (Table 1). Exposure to full sunlight can result in the stomata closure to reduce water loss so that photosynthetic activity and growth are slowed down. This sensitive response is related to the nature of cocoa as understory species of the forest. T. cacao is a C3 plant species that adapts to semi-shade on the forest floor. Full sunshine can be a growth stress factor rather than a stimulant factor. Photosynthesis in cocoa is saturated at a photon flux density of 400 μmol m^{-2} s^{-1} that is equivalent to 25% full light. The litter production data in this study fit the description of this theory. The production rate of monoculture litter is much higher than that of shaded cocoa indicating shorter leaves age as a form of pressure response to drought and high sunlight radiation (Kunikullaya et al., 2018).

The cacao - coconut and cacao monocultures produced higher litter production than the cacao-rubber and multistrata cocoa-based AFS. Cocoa has relatively broad leaves. Kuruppuarachchi et al., (2013) reported that forests dominated by broad-leaf trees were able to contribute higher litter as a nutrient source compared to forests dominated by narrow-leaf trees. This explains why the production of litter in cocoa monoculture is relatively high.

Litter production in cocoa-based AFS in West Sumatra is smaller than that at two other locations in Indonesia, namely in Central Sulawesi and Lampung. In Central Sulawesi, the type of cocoa-based AFS varied between cocoa planted under intentionally planted shade trees (*Glyricidium sepium*), cocoa planted between local trees, and cocoa planted under heavily shaded forests (rustic cacao agroforestry). The annual litter production ranged from 4.98 to 8.23 Mg ha^{-1} $year^{-1}$ (Triadiati et al., 2011). In Lampung, most cocoa-based AFS was dominated by durian and coffee trees as mixture plant. This AFS produced 11.56 Mg ha^{-1} $year^{-1}$ litter (Indriyanto, 2009). Otherwise, tree stand densities in CR, CM, and CC in West Sumatra were higher than that in cocoa agroforestry in Lampung and Sulawesi (Santhyami et al., 2020). Vegetation standing on fertile soils results in a higher rate of litter production because biomass input from litter contributes back to soil fertility (Dawoe et al., 2010). On this basis, agroforestry land in West Sumatra is likely to be less fertile compared to that in Lampung and Central Sulawesi, given the acidic soil conditions and relatively low nutrient content in the study sites (Santhyami et al., 2018).

Litter production fluctuates every month (Triadiati et al., 2011; Kitayama et al., 2020). This study supports this theory. Figure 3a shows the variation in monthly litter production in five ecosystem groups compared to variations in climatic conditions (air humidity and monthly average rainfall) in Figure 3b.

Forest (NF) and multistrata cocoa-based AFS (CM) produced the highest litter in July - September 2017 (0.66 - 0.78 Mg ha^{-1}). Other ecosystem types did not show a dominant trend of monthly litter production during certain seasons. Litter production in natural forest and multistrata cocoa-based AFS was influenced by the interaction of monthly climatic factors. In these two ecosystems, high litter production coincides with periods of low humidity and low precipitation. July - September of 2017 were the driest months, showing the lowest precipitation rate throughout the year in West Sumatra (Badan Meteorologi, Klimatologi dan Geofisika [BMKG], 2018). Seasonal patterns of litter production in primary forests and cocoa agroforestry in Ghana, which increase in the dry season, indicate a physiological response to drought/reduced humidity playing a major role in this process (Dawoe et al., 2010). This factor, along with the low night time temperature in the dry season, stimulates the synthesis of abscisic acid in leaves. Abscisic acid enhances the leaf fall (Yang et al., 2003). Most studies on litter production in tropical forests show a strong association between seasonal litter production and dry season as the peak litter production (Seta & Zerihun, 2018; Giweta, 2020; Primo et al., 2021). The litter season pattern generally depends on factors related to leaf shedding (Lian & Zhang, 1998).

The pattern of litter production in forest and multistrata cocoa-based AFS in this study is in line with the pattern of litter production in other tropical natural forest. On the other hand, the cacao - rubber, cocoa - coconut and cacao monoculture did not show any peak of litter production pattern. This contradictory finding was also reported in forests without dry seasons, such as the tropical rain forest of Atlantis in Brazil where the peak of litter production occurs during the rainy season. This indicates that the litter loss is due to mechanical factors (de Moraes et al., 1999). The mechanical factors referred to in the three groups in this study (CR, CC and M) were all anthropogenic factors, such as maintenance, pruning, and harvesting that trigger leaf fall. Fertilization was done routinely by Pariaman farmers once a year, while the cocoa-based AFS in Pasaman was generally not fertilized. To keep the soil moisture, especially during the period before flowering and fruiting, farmers carry out pruning practice. Cocoa farmers will at least carry out the maintenance process three to four times a year. The pruning rejuvenates cocoa trees and increases higher cacao yields. By pruning, the trees have been re-grown to optimal crown shape and height (Rouse et al., 2017). The pruning allows the efficiency of cultivation management and harvest. The open canopy allows the shift of a full-sun plantation to agroforestry. The light can penetrate the land floor, thereby facilitating the growth of planted tree seedlings and other crops (Riedel et al., 2019).

CONCLUSION

Litter is one of the aboveground system fragments, which is a vital bridge to the belowground carbon cycle. Natural forest and cocoa monoculture ecosystems produced the highest annual total litter of 6.04 Mg ha^{-1} and 4.65 Mg ha^{-1}, respectively, while the lowest production was in CR (2.52 Mg ha^{-1}). Ecosystems based on the level of litter production from the lowest to the highest were grouped into three, namely Cocoa-Rubber – Multistrata Cocoa, Cocoa-Coconut – Cocoa Monoculture, and Cocoa Monoculture – Natural Forest. Litter production in cocoa monocultures was higher than in agroforestry practices and natural forests. Cocoa-based monoculture farmers performed more intensive care than those in agroforestry one. The pruning increased the litter production trapped into the net. Litter production fluctuated every month. The NF and CM ecosystems produced the highest litter during the dry season, around 0.66 - 0.78 Mg ha^{-1}. Other ecosystem groups did not show a dominant trend of litter production during certain seasons.

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