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Litter Fall, Leaf Litter Decomposition, Soil Microfungi and Nutrient Content in Cocoa and Food Crop Agroforest Farmlands in Southeastern Ghana

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Abstract: This study is a comparison of the litterfall, litter decomposition and soil microfungi species diversity in cocoa and mixed food crop agroforest farmlands. The study was carried out in the Atewa and Fanteakwa districts of the Eastern region of Ghana. A total of thirty six sampled plots size of five 25 m x 25 m were randomly demarcated in cocoa agroforest, mixed food crop agrorest and the natural forest reserve. Data collected on litterfall mass and leaf litter decomposition at monthly intervals for a period five months. Soil microfungi species diversity was analyzed from soil samples collected at two depths 0-5cm and 0-10 cm respectively using pour plate method. The reduction in mass of cocoa leaf litter was significantly negatively correlated with the number of days of decomposition. The rate of release of NPK was positively correlated with litter mass. Litter mass production significantly declined in the cocoa agroforest and mixed food crop agroforest farmlands. Initial rate of litter decomposition was generally slow in the cocoa and mixed food crop farmlands than in the natural forest. Soil microfungi species diversity was high in natural forest and low in the cocoa and mixed food crop agroforest farmlands.

Keywords: Litter Fall, Leaf Litter Decomposition, Microfungi, Cocoa Agroecosystems, Tropics

1. Introduction

Cocoa (*Theobroma cacao* L) is one of the most important crop systems in tropical areas of South and Central America. Traditionally, the crop is grown under diversified native tree shade, increasingly viewed as a means of contributing to biodiversity conservation within agricultural landscapes [18] and complementing conservation in protected areas. It is evident that traditional cocoa plantations conserve birds, bats, insects and other wildlife to a greater extent than alternative land uses such as cocoa with little shade [18]. Unfortunately the cultivation of cocoa over the past decades has been associated with high levels of deforestation which has led to increase in secondary forest [28] and full sun cocoa production. According to [36], full-sun cocoa farming is currently the most widespread cocoa cultivation system in humid and sub-humid regions of the world.

Litterfall and litter decomposition in agroforestry systems and subsequent nutrient release represent major biological pathways for soil nutrients transfer and play an important role in regulating nutrient cycling and in maintaining soil fertility in tropical agro-ecosystems [33]. Litter decomposition is a set of processes in which dead organic matter is converted into its components: carbon dioxide, mineral nutrients, and water. Knowledge of the decomposition of organic matter is of great importance in the management of areas under natural, agricultural, or silvicultural systems [31]. Most tropical soils are highly weathered, leached and nutrient poor [24], but the role of nutrients as factor determining decomposition process are largely unclear. Plant litter production and decomposition are the two important processes which provide the main input of organic matter in soil and regulate the patterns of

nutrient cycling in forest ecosystems [10, 21, 26]. According to [2], the key process in nutrient recycling within ecosystems is decomposition, consisting of a series of physical and chemical processes by which leaf litter and foliage are reduced to their elemental chemical constituents. This is one of the most important events in ecosystems for their contribution of nutrients to the soil [1].

In the agroforestry systems, nutrients enter through various sources such as rain, fertilizers, and organic residues, and these can accumulate either in the shade trees, cultivation, soil, or litter. At the same time, interactions occur between crop layers such as residue deposition, infiltration, absorption, and mineralization; likewise, outputs can occur by crops yields, leaching, runoff, and denitrification processes. The study of the nutrient cycle in cocoa agroecosystems is fundamental to understand the dynamics of the elements and their availability in the sustainable management of the productive system.

Recent studies underlined the importance of microbiota for cycles of major elements and showed that global soil carbon projections could be improved by modelling microbial processes [20]. Fungi are the major decomposers of dead organic matter and contribute significantly in recycling of nutrients in natural and modified ecosystems [12]. Attempts have been made to review the underlying principle of fungal occurrence by studying the species composition of fungal communities during decomposition of various plant substrates [17]. High species diversity and spatial heterogeneity of decomposer fungi on decaying leaf litters in tropical forests have been reported [18]. These decomposer fungi play a vital role in maintaining the fertility and sustainability in the tropical forests [15].

In this study litterfall, litter decomposition and soil microfungi in mixed food crop agroforest and cocoa-based agroforest systems was investigated in order to make a comparison. This is useful information for farmers in the management of their farms and help as a decision support tool for farmers who decide to cultivate mixed food crops and cocoa-based agroforest system.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Eastern Region of Ghana. Two sites were sampled intermittently during the study. The first site was the Atewa Range Forest Reserve in the Atewa District which represents the natural forest. The reserve is located between latitude 6° and 6° 10´ N and longitude 0° and 0° 36´ W and is about 232 km² in size. Mean monthly temperature is between 24- 29°C and the with the second occurring in September to November. The second site was at Adjeikrom in the Fanteakwa District where the traditional farming methods are practiced. The district lies within the equatorial region. Mean annual rainfall of the area accounts

for about 1500mm to 2000mm. The major season starts around March to April and ends at August to September. The minor season ends at October or first week of November. The mean annual temperature is between 26-27°C. The vegetation in the Fanteakwa district is very typical of wet- semi deciduous forest, which covers about 80% of the total vegetation cover. Intense farming activities are therefore bringing about transition to this vegetation. Common tree species found in the area include *Terminalia ivorensis* A. Chev, *Khaya ivorensis* A. Chev, *Triplochiton scleroxylon K.* Schum*, Cedrela odorata* Blanco and *Milicia excelsa* Welw) C. C. Berg. Other food crops grown within the area are *Musa sapientum* L*, Musa paradisica* L., Prospe & C. Jeffrey, *Manihot esculenta* Crantz*, Zea* mays L*, Colocasia* esculenta (L) Schott and *Elaeis guineensis* Jacq.

2.2. Litter Mass Production

The amount of litter mass production was monitored over a period of five months from November, 2008 to March, 2009 in the cocoa agroforest, mixed food crop agroforest and natural forest using litter trap of dimension (1.0 × 1.0 × 0.2 m raised 50 cm) above the ground. I randomly placed five (5) litter traps on five selected plots per land use. Thus a total fifteen (15) traps were used for the study. The position of the trap was constantly changed at every collection period to ensure the even distribution of litter. Litter intercepted by the traps was emptied monthly and sorted out into shaded tree leaf litter, cocoa leaf litter, flowers and twigs, and subsequently oven dried at 73.5°C until constant weight was achieved.

2.3. Litter Decomposition

To determine the rate of litter decomposition, cocoa leaf litter were collected and oven dried at 80°C for 24 hours. Ten grams (10g) of the cocoa litter were weighed and evenly spread in each litter bag. For each land use type, five litter bags were arranged on the floor in order to undergo a period of decomposition. The litter bags were collected monthly from each land use type, oven dried and weighed. A portion of each decomposed litter was ground and sieved using a 0.5 mm sieve for the determination of nitrogen using the Kjeldahl method [8], available phosphorus following Bray1 method [7], exchangeable potassium determined using flame emission photometry (FEP) and organic carbon was determined by wet combustion method of [25].

2.4. Soil Microbial Studies

Soil microflora diversity was analyzed from soil samples collected at two depths, namely; 0-5cm and 0-10cm. Two soil core samples were collected per 25 m x 25 m plot in October, 2008. Soil microflora was determined using the "Pour Plate" method [3] and the media was prepared using the modified Cooke's medium [9]. Species of soil microflora were identified and counted with the aid of mycologists from the Department of Botany, University of Ghana by consulting relevant literature [6].

2.5. Statistical Analysis

Statistical difference in the rate of litter mass among the different land-use types was analyzed using Analysis of Covariance (ANCOVA). The initial time (t=0) was removed from the analysis. Difference in mean total nitrogen, % carbon, available phosphorus and exchangeable potassium in the three land-use types were analyzed using ANOVA and Tukey HSD test to compare means. The assumption of normality was assessed using the Shapiro-Wilk test [29]. The R software version 3.1.1 was used. The relationship between litter mass and number of days of decomposition was analyzed using Spearman correlation test. The rate of release of NPK was calculated as follows:

$$\frac{A-B}{A} \times 100$$

Where A= chemical content of non decomposed litter
B= chemical content of decomposed litter

3. Results

3.1. Litter Mass Studies

The amount of different litter types produced over a period of 150 days in the three land-use types is presented in Table 1. Total mean litter produced was not significantly different (ANOVA, p > 0.05) among the three land use types, but the amount of different litter types in most cases was significantly different among land-use types (ANOVA, p < 0.001. Shade tree litter production was high throughout the period of the study. Cocoa litter produced was high between February and March.

The quantity of shade tree leaf litter produced was significantly (ANOVA, p < 0.001) different in the three land-use types. There were significant differences (Tukey HSD, p > 0.001) in the mean amount of shade tree leaf litter between the mixed food crops agroforest and the cocoa agroforest, and between the cocoa agroforest and natural forest (Tukey HSD, p > 0.001). Mean shade tree litter in the mixed food crops agroforest was twelve times higher than that found in the cocoa agroforest. However, there were no significant differences in the mean shade tree litter between the mixed food crops agroforest and the natural forest (Tukey HSD, p = 0.98). The mean amount of shade tree flowers and twigs produced in the different land-use types was not significantly different (p > 0.05). Cocoa and food crops litter were only found in cocoa agroforest and mixed food crops agroforest, respectively. The mean amount of cocoa leaf litter produced was significant (ANOVA, p < 0.01). The quantity of cocoa flowers and twigs litter produced in the cocoa agroforest were, however, not significantly greater than zero (ANOVA, p > 0.05). The mean amount of food crop leaves produced in the mixed food crops agroforestry was significant (ANOVA, P < 0.05).

Table 1. Summary of litter mass production statistics in the Cocoa Agroforest, Mixed Food crop Agroforest and Natural Forest in Southeastern Ghana.

| Litter type	Natural forest (kg / ha)	Cocoa agroforest (kg / ha)	Mixed food crops agroforest (kg / ha)	Statistical method of comparison of means post hoc pair wise comparisons)
Cocoa leaf	-	27.19± 3.53	-	ANOVA, P< 0.001
Cocoa flower	-	0.33± 0.21	-	ANOVA, P= 0.188
Cocoa twig	-	0.43± 0.22	-	ANOVA, P= 0.298
Food crop leaf	-	-	0.18 ± 0.23	ANOVA, P = 0.375
Shade tree leaf	34.68 ± 5.15	3.46 ± 0.95	14.92 ±5.15	ANOVA, P< 0.001
Shade tree flower	0.34± 0.14	-	0.38 ± 0.19	ANOVA, P= 0.271
Shade tree twigs	1.42±0.21	-	0.44± 0.21	ANOVA, P=0.286
Total annual litter	36.44± 5.5	31.41± 4.91	15.92± 5.78	

3.2. Litter Decomposition

The pattern of loss of dry matter during decomposition of cocoa leaf litter in the three land use types are shown in Figure 1. There was an initial rapid loss of litter mass followed by gradual reduction. The reduction in mass of cocoa leaf litter was significantly negatively correlated with the number of days of decomposition (r = - 0.78, p < 0.001). After 151 days of decomposition the percentage cocoa leaf litter mass remaining was 65.4%, 68.6% and 70.4%, respectively, for natural forest, mixed food crop agroforest and cocoa agroforest. There was a significant (ANCOVA, p > 0.001) land use times number of days interaction in the decomposition of cocoa leaf litter mass.

The rate of release of NPK was positively correlated with litter mass loss (r =, p < 0.05). The initial mean amount of NPK in the cocoa leaf litter before decomposition was $0.17 \pm 0.39\%$ for nitrogen, 0.11 ± 0.057 µg/g for phosphorous and 5.02 ± 2.24 K (cmol/ ($^+$)) for potassium. After the 151 days of litter decomposition, about 44.9% of nitrogen was released in the natural forest, 43.7% in the mixed food crops agroforest and 42.1% in the cocoa agroforest (Figure 2). The rate of release of phosphorus was about 80.9% in the natural forest, 76.7% in the mixed food crops agroforest and 74.3% in the cocoa agroforest (Figure 1). The rate of release of potassium was about 69.1% in the cocoa agroforest, 67.7% in the natural forest and 64.9% in the mixed food crops agroforest (Figure 3). The trends of nutrient release from litter decomposition in the different land-use types showed a faster rate of released of potassium followed by phosphorus and the nitrogen.
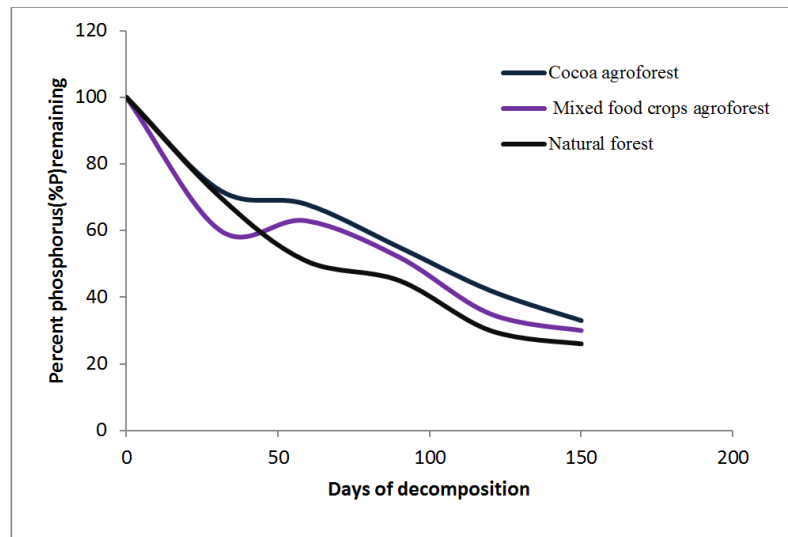
Figure 1. *Rate of release of phosphorus from litter decomposition in the different Land use types.*
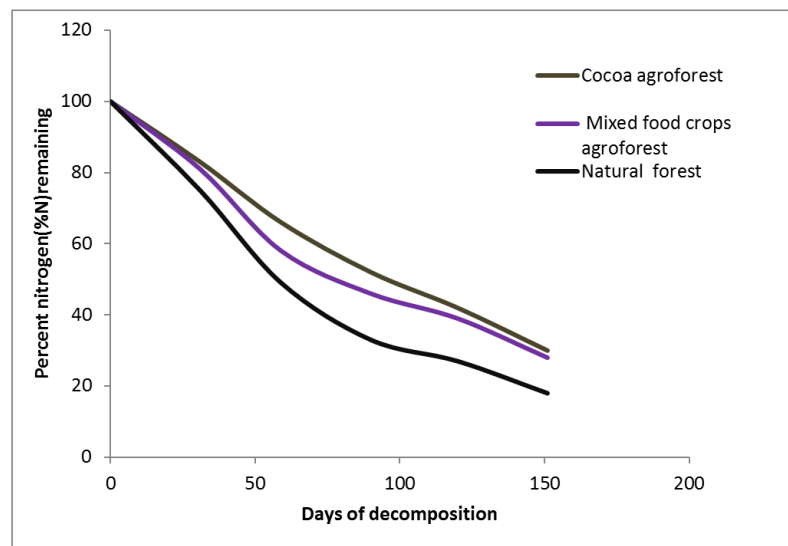
Figure 2. *Rate of release of nitrogen from litter decomposition in the different Land use types.*
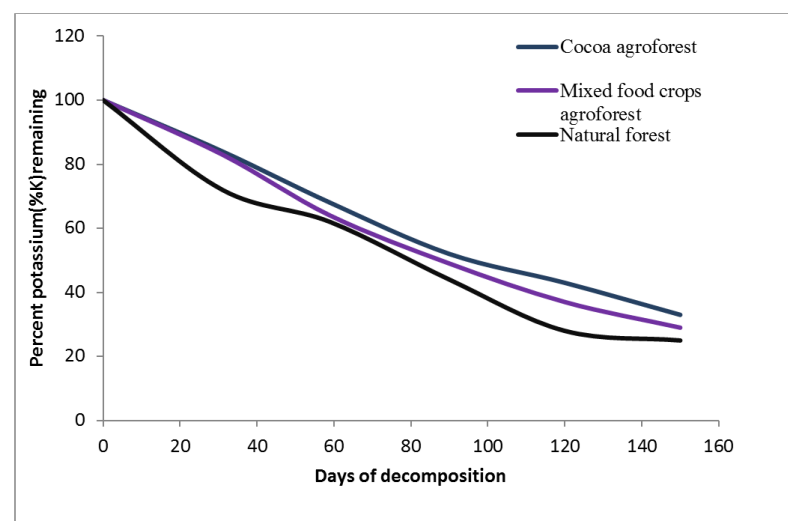
Figure 3. *Rate of release of potassium from litter decomposition in the different Land use types.*

3.3. Soil Microflora Diversity

A total of 2892 individuals of soil microfungi belonging to 17 species in 8 families were identified (Table 2). Ten of these species, namely, *Aspergillus flauvs, Aspergillus niger, Aspergillus giganteus, Aspergillus sulpherous, Cladosporium herbarium, Curvlaria lunata, Fusarium poae, Penicillium digitatum, Rhizopus oryzae* and *Rhizopus sterlonifer* were found in all the three land use types. Members of the family Trichocomaceae was the most predominant in terms of number of species. About 36.1% of the species were found in the natural forest, 33.9% in the cocoa agroforest and 30.0% in the mixed food crops agroforest. Thus soil microflora species richness was highest in the natural forest followed by the cocoa agroforest and then mixed food crops agroforest. The relative density of 58.8% of the species of soil microflora differed significantly ($p < 0.05$) among the three land-use types while that of 41.2% did not.

The population density of 41.2% of the species recorded was highest in the natural forest than in mixed food crops and cocoa agroforest. These species include *Aspergillus flavus, Aspergillus niger, Cladosporium herbarium, Curvlaria lunata* and *Rhizopus oryzae* and *Rhizopus sterlonifer*. The population density of 29.4% each was found to be higher in cocoa and mixed food crops agroforest.

Table 2. Diversity and relative abundance of soil microflora in the three land use types in an agroforestry landscape in southeastern Ghana.

Species	Families	Natural forest	Mixed food crops agroforest	Cocoa agroforest
Aspergillus alutaceus	Trichocomaceae	-	-	0.17±0.1
Aspergillus flavus Link	Trichocomaceae	7.84±0.39	6.17±0.46	10.28±0.28
Aspergillus giganteus	Trichocomaceae	0.04±1.81	0.22±1.19	0.17±0.91
Aspergillus niger Van Tieghem	Trichocomaceae	5.28±0.36	30.72±0.22	30.39±0.16
Aspergillus sulpherous	Trichocomaceae	-	0.56±0.83	0.83±0.52
Blastomyces sp	Onygenaceae	-	0.17± 0.89	0.72±0.99
Cladosporium herbarium	Loculoascomycetes	11.12±1.07	1.72±1.16	0.33±1.06
Cunnhemelia ellegans	Cunninghamellaceae	-	-	0.06±0.70
Curvularia lunata Leakey	Loculoascomycetes	11.48±0.71	0.67±1.31	1.89±0.67
Fusarium poae	Hypocreaceae	-	0.56±0.50	0.67±0.68
Fusarium solani	Hypocreaceae	1.5±0.33	-	-
Neurospora sitophila	Sordariaceae	1.0±1.41	-	-
Penicillium digitatum Currie &Thom	Trichocomaceae	-	1.17±0.57	0.94±0.49
Penicillium chryosogenum	Trichocomaceae	-	0.28±0.89	-
Rhizopus oryzae	Mucoraceae	4.08±0.19	2.89±0.23	4.44±0.14
Rhizopus sterlonifer (Ehrenb) Vuill	Mucoraceae	2.72±0.53	0.28±0.89	0.61±0.49
Trichoderma viride Bonn	Hypocreaceae	-	2.44±0.33	3.56±0.21

4. Discussion

4.1. Litter Fall Studies

Average total litterfall in this study was in the lower range of the values reported by the studies of [27, 28, 35] in a similar study. The pattern of litter fall production showed a drastic reduction of shade litter in the mixed food crop agroforest and cocoa agroforest farmlands compared to that of the natural forest. The reduction of shade litter in could be attributed to high levels of deforestation which has led to increase in secondary forest leading to full sun cocoa production [36]. The reduction of shade trees in the cocoa and mixed food crop agroforest could greatly influence litter decomposition process and subsequently the release of nutrients into the plantation floor and uptake by the plants roots. Cocoa litter mass contributed to total litter mass recorded in the cocoa agroforest as observed in a previous study by [34]. Generally, the months of December and February recorded the highest litter mass and this can be due seasonal variations and climatic conditions as observed by [32]. The pattern of litterfall in this study was broadly comparable to other tropical ecosystems [21, 23].

4.2. Litter Decomposition Studies

Initial litter mass loss in the different land use types gradually decreased during the period of decomposition, a pattern reported in other studies [5, 22, 34]. The rate of litter mass loss was faster in the natural forest compared to the cocoa and mixed food crop agroforest as reported by other authors [28, 35]. The initial rapid loss is attributable to leaching associated with other factors such as microbial population, soil temperature and presence of moisture. Initial lost of litter mass occurred within the first 30-50 days in different land use types and remain unchanged throughout the period of decomposition. This observation agrees with report by [5, 14] who reported that 30–50% of leaf biomass decomposes in the first 3–4 months in tropical agroforestry and plantation systems. Generally, the release of nutrients in the different land use types showed a faster rate release of nitrogen and phosphorus compared potassium.

4.3. Soil Microfungi Species Diversity

In the present study, soil microfungal species diversity in forest soil was significantly higher than that found of mixed food crop and cocoa agroforest farmlands. The anthropogenic disturbances have been reported to reduce the diversity of fungal species under varied ecosystems [4, 22]. The rate of

change in fungal population in the different land use types was attributed to vegetation type, variation in physico-chemical characteristics of the soil and environmental complex of the locality [30]. This implies that soil ecological research over the past two decades has demonstrated extremely high levels of biological diversity belowground, especially in soil microfungi group [16]. The patterns of microbial populations in soils can also vary spatially and temporally according to factors such as the nature of the soil, parent material, availability of carbon resources, seasonal and diurnal variations in temperature, porosity and water holding capacity [16]. The diversity of soil microfungi is a requirement for the decomposition of litter essential for the release of organic compounds necessary for plant growth.

5. Conclusion

In conclusion, litter mass production significantly declined in the cocoa agroforest and mixed food crop agroforest farmlands. Initial rate of litter decomposition was generally slow in the cocoa and mixed food crop farmlands than in natural forest. Soil microfungi species diversity was high in natural forest than in the agroecosystems.

Acknowledgements

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