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Leaf Litter Decomposition and Nutrient Release is Faster in a Tropical Rainforest than Cacao Plantation

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Abstract: The study determined litter decomposition and microbial species involved in litter decomposition and their dynamics during decomposition in natural forest and cacao plantation. This was with a view to providing comprehensive understanding of nutrient cycling via litter in the ecosystems due to their different management practices. The study was carried out in 0.063 ha sample plots, three each in natural forests and cacao plantations adjacent to each other in Ile-Oluji, Ile-Oluji/Okeigbo Local Government Area of Ondo State. Litter decomposition was studied using the litterbag method. Thirty six labeled and numbered litter bags each were placed on the litter layer in each sample plot. Three litter bags were retrieved randomly from each plantation plot of cacao and natural forest at monthly intervals for twelve months. One of the retrieved litter bags from each sample plot was transported aseptically to Microbiology Laboratory for the isolation and identification of the microbial decomposers (bacteria and fungi) in addition to the estimation of the microbial load of the sample. The contents of the other two bags were emptied, oven-dried at 80° C to a constant weight, weighed and ground for chemical analyses The results showed that Litter decomposition rate in the forest, 3.497, was higher than 1.568 in cacao plantation. There were lower number of fungal (16) but higher number of bacterial species (18) involved in litter decomposition in forest than those in cacao plantation (fungi, 17, bacteria 16). The densities (cfu/g) of bacterial species 6.15 x 106-9.95 x1017 and fungi 4.45 x105-3.25 x107 involved in litter decomposition in the forest were higher than those in cacao plantation (bacteria, 8.9 x 105- 3.05 x 109; fungi, 1.75 x105 -1.0 x 107). This study concluded that nutrient cycling via litter decomposition is more efficient in natural forests than in cacao plantations and that clearing forests to establish cacao plantations is adversely affecting nutrient cycling.

Keywords: Decomposition; Forest; Cacao Plantation; Microbial Community.

INTRODUCTION

Litter decomposition and subsequent nutrient release represent major biological pathways for element transfer from vegetation to soils, and play an important role in regulating nutrient cycling, and in maintaining soil fertility in forest and agro-ecosystem (Yang et al., 2003). It is a major pathway for return of organic matter and nutrients from aerial parts of plant to the soil surface (Odiwe and Muoghalu, 2003). The litter on the forest and plantation floor acts as input–output system of nutrient and the rates at which litter falls and subsequently decomposes contribute to the regulation of nutrient cycling and primary productivity, and to the maintenance of soil fertility in forest and plantation ecosystems (Isaac and Nair 2006, Pandey et al., 2007; Onyekwelu et al., 2008).

The release of nutrients from forest litter through natural decomposition process is recognized as being a very important part of nutrient cycling, whereby essential minerals locked up in plant biomass are made available for further plant growth (Maclean and Wein 1978) In forest ecosystems, more than 90 % of net above-ground primary production returns to the forest floor as litter fall which constitutes the major substrate for plant species and soil decomposers (Swift et al. 1979). The decomposition of plant litter at the soil surface is brought about by a combination of diverse of variety of microorganisms including bacteria, fungi, actinomycetes, protozoa and nematodes (Slater and Lovatt 1984). Microorganisms play an essential role in many soil biological processes, including organic matter decomposition (Cycon and Piotrowska-Seget 2007). About 80–90 % of net primary production in terrestrial ecosystems is recycled by decomposers (Giller et al. 1997). Decomposition processes can begin before the dead plant material reaches soil surface, as both fungi and bacteria, which are the key agents involved in litter breakdown and mineralization (Kuehn et al. 1999), may attack standing dead material. Most decomposition, however, occurs once the plant materials have reached the litter layer where soil arthropods break up the plant materials and render them more suitable for the microbial decomposers (Walksman 1952). As a result of microbial attack and activity, the litter is subjected to chemical changes like oxidation, hydrolysis, reduction and condensation (Walksman 1952). The degree to which microorganisms are able to fulfil their role as decomposers depends upon the chemical and physical characteristics of the plant materials and the environment in which the decomposers live. Natural or man-made changes in soil environment therefore, can cause either an increase in or suppression of decomposition. The pesticidal chemicals which ultimately reach the soil either via application, careless handling or as run-off from treated crop plants influence soil biochemical processes and as the pesticides represent a relevant stressor for many aquatic and terrestrial species (Liess et al. 2005). They ultimately have effects on litter decomposition, incorporation of organic matter into the soil, soil fertility and plant growth (Bharat and Srivastava 1983). They interact with the microbial community in a variety of ways generally affecting the microbial community in a variety of ways generally affecting the microbial population by controlling the survival and reproduction of individual species, reducing their numbers, biochemical activity and changing the microbial community structure (Cycon and Kacaynska 2004; Cycon 2006) and causing harm to microorganisms and plant growth (Shafiani and Malik 2003).

Nutrient cycling in the plantations might not be same as in the natural forest they replaced. Cacao agroforestry has been predicted to have different nutrient cycling from that of natural forests (Xu and Hirata, 2005). This is compounded by management practices in the plantation such as the widespread use of pesticides in these plantations to control pest and diseases which affect organisms especially microorganisms, bacteria and fungi involved in the decomposition processes of litters and, therefore, bring about disruption of nutrient cycling in the cacao plantations (Muoghalu and Odiwe, 2011). The mono species nature of the plantation will likely affect the quantity and quality of litter produced and microbial community involved in decomposition in the plantations. Thus, it is vital to understand the nutrient cycling via litter in the plantation in relation to that of natural forest. Of tree crop plantations (cacao, oil palm, rubber, kolanut, coffee etc) in Nigeria, cacao plantation is the most common and abound in the South-western Nigeria. leaf-litter decomposition (Sundarapandian and Swamy, 1999; Koledoye, 2012; Osewole and Muoghalu, 2016), there is dearth of studies which have compared nutrient cycling dynamics via litter decomposition between natural forest and cacao plantation during the same period. Hence, this study aims at investigating litter decomposition in natural rain forest and cacao plantation in same environment and during the same period.

MATERIALS AND METHODS

Study Area

The study was undertaken in Ile-Oluji, Ondo State, Southwest, Nigeria. Ondo State lies between longitudes 4° 31' and 6° 00' E of the Greenwich Meridian and latitudes 5° 15' and 8° 15' N of the equator while Ile-Oluji lies between latitudes 6° 40' N and 7° 14' N, and longitudes 4° 38' E and 4° 53' E. The tropical climate of the State is broadly of rainy season (between April and October) and dry season (between November and March). Temperature throughout the year ranges between 21°C to 29°C and humidity is relatively high. The annual rainfall varies from 2, 000 mm in the southern areas to 1,150 mm in the northern areas. The monthly rainfall and temperature for the study area during study periods, 2016 and 2017. The State enjoys luxuriant vegetation with rain forest in the south and sub-savanna vegetation in the northern fringe (Falola et al., 2013). The major soil types found in Ondo State are alluvial, ferralsols and ferruginous tropical soils. The alluvial soil types are not important agriculturally. Areas with ferruginous soils are particularly suitable for cacao production. The soil has an exceptional clayey texture, combined with good drainage and aeration with good properties of moisture and nutrient retention. Ile-Oluji is underlain by the basement complex terrain of the crystalline rocks of Nigeria (Adebawore et al., 2017). The major rock is mainly the medium grained granite gneisses that are strongly foliated and commonly occurring as out crops. The surface of these outcrops is severely contorted with alternation of band of dark and light coloured minerals. The light coloured band contains minerals that are essentially feldspar and quartz while the dark well drained with a medium texture (Adebawore et al., 2017).

Table 1: Geographical positioning of the sample plot

Plot	Forest	Cacao plantation
1	7° 13'5″N ; 4°52'22″E	7° 13'15″N ; 4°52'11″E
2	7° 12'45″N ; 4°51'59″E	7° 12'43″N ; 4°51'58″E
3	7° 13'11″N ; 4°53'47″E	7° 13'24″N ; 4°53'53″E

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Sample Collection Procedure

Litter decomposition was studied using the litterbag method. freshly fallen leaf litter was collected from under the crowns of trees, in the forests and cacao plantations, air-dried for one week and 20 g weighed into 1 mm mesh size nylon litter bags, 20 cm x 30 cm in size, which were then be closed. Thirty six labeled and numbered litter bags each were placed on the litter layer in each sample plot. Three litter bags were retrieved randomly from each plantation plot of cacao and natural forest at monthly intervals for twelve months. One of the retrieved litter bags from each sample plot was transported aseptically to Microbiology Laboratory for the isolation and identification of the microbial decomposers (bacteria and fungi) in addition to the estimation of the microbial load of the sample. The contents of the other two bags were emptied, taking care not to lose any material. Extraneous materials such as visible animal materials and fine roots were removed. The rest was be oven-dried at 80° C to a constant weight, weighed and ground for chemical analyses for carbon, nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. Sub-samples of the air-dry litter were oven-dried at 80°C to constant weight and weighed to obtain a conversion factor for calculating the oven-dry weight of litter for each bag.

Statistical Analysis

Significant difference in decomposition of litter in forest and cacao plantation and nutrient release were tested using two-way analyses of variance (ANOVA) with repeated measurement design with month and site as factors. The tests were performed using System Analysis Software version 10.0 (SAS 2004).

RESULTS

Litter decomposition in the forest and cacao plantation

Decomposition rate and percentage weight loss of leaf litter in the forest and cacao plantation

Decomposition rate and weight loss of the leaf litter of cacao plantation and forest were studied from January 2016 to December 2016. Decomposition rate in the cacao plantation and forest decreased insignificantly during the first two months of decomposition, followed by increasing decomposition in the remaining months in cacao plantation and forest litter. Monthly loss of weight in the decomposing leaf litter of cacao plantation and forest differed significantly ($F_{1,11}$ = 14.764; $p < 0.05$) with forest decomposing litter losing more weight than cacao plantation litter (Fig 1a). The percentage weight loss in the decomposing leaf litter of cacao plantation and forest increased with increasing month of decomposition

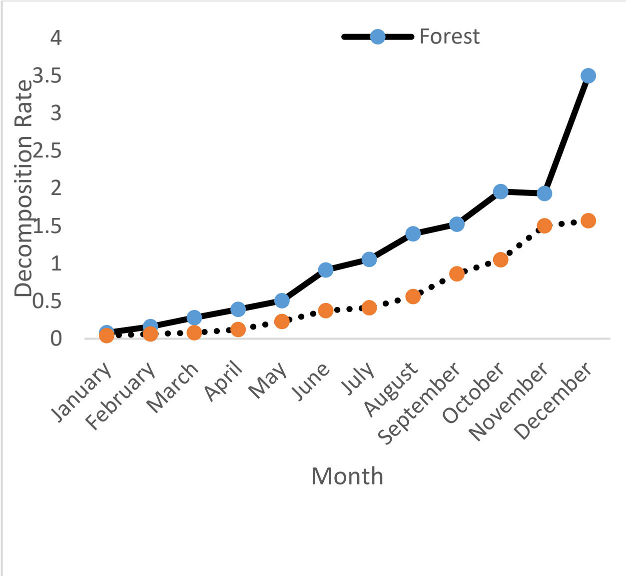

Fig 1a: Rate of decomposition of leaf litter in the forest and cacao plantation

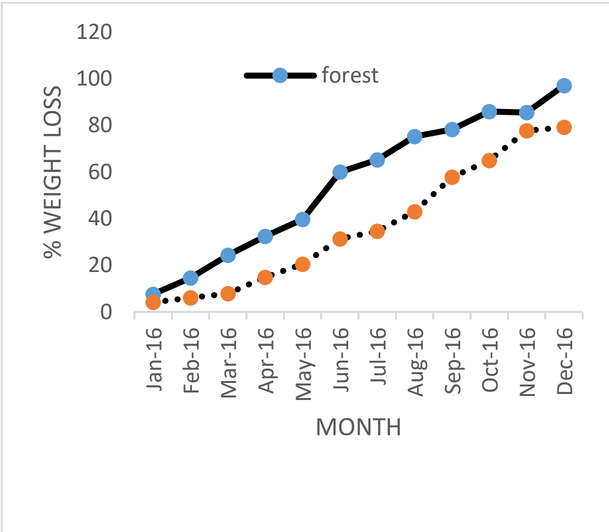

Fig 1b: Percentage weight loss of decomposing leaf litter in the forest and cacao ecosystems

Table 2: Summary of Decomposition Parameters of Decomposing Leaf Litter of Forest and Cacao Plantation

PARAMETERS	FOREST	CACAO PLANTATION
Percentage Decomposition (%)	97.0	79.1
Rate of Decomposition (Direct)	3.497	1.568
Rate of Decomposition (Indirect 2016)	1.81	1.39
Rate of Decomposition (Indirect 2017)	2.51	1.65

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leaf litter of the forest was 18 while in cacao plantation it was 16 (Table 3). The total number of fungi isolates in the decomposing leaf litter of forest was 16 while in cacao plantation litter it was 17 (Table 3). There were more bacterial species in forest (18) than cacao plantation decomposing litter (16) (Table 3) and more fungal species in cacao plantation (17) than forest decomposing litter (16) (Table 3).

In cacao plantation, the bacterial species identified were: *Acinectobacter calcoaceticus, Acinectobacter mallei, Acinectobacter paraperfussis, Agrobacterium tumefaciens, Citrobacter freundii, Klebsiella aeruginosa, Klebsiella edwardsii, Klebsiella oxytoca, Klebsiella ozoenae, Klebsiella pneumonia, micrococcus luteus, proteus mirabilis, Pseudomonas aeruginosa, Pseudomonas peudomallei, Pseudomonas stutzeri, Staphylococcus aureus* while in forest decomposing litter the bacterial species identified were *Acinectobacter calcoaceticus, Acinectobacter iwoffi, Acinectobacter mallei, Acinectobacter paraperfussis, Agrobacterium tumefaciens, Alcaligenes Faecalis, Gaffkya tetragena, Klebsiella aeruginosa, Klebsiella edwardsii, Klebsiella oxytoca, Klebsiella ozoenae, Klebsiella pneumonia, Pseudomonas aeruginosa, Pseudomonas peudomallei, Pseudomonas stutzeri, Sarcina lutea, Shigella boydii, Shigella sonnei* (Table 3).

However, some bacteria species are distinct with specific ecosystem those species are; *Agrobacterium tumefaciens, citrobacter freundii, Micrococcus luteus, Proteus mirabilis and Staphylococcus aureus* for cacao plantation and *Acinectobacter iwoffi, Alcaligenes faecalis, Gaffkya tetragena, Sarcina lutea, Shigella boydii and Shigella sonnei for forest physiognomy* (Table 3)

Table 3: Composition of heterotrophic bacteria species in forest and cacao plantation decomposing litter

SPECIES	FOREST	CACAO PLANTATION
Acinectobacter calcoaceticus	+	+
Acinectobacter iwoffi	+	-
Acinectobacter mallei	+	+
Acinectobacter paraperfussis	+	+
Agrobacterium tumefaciens	+	+
Alcaligenes Faecalis	+	-
Citrobacter freundii	-	+
Gaffkya tetragena	+	-
Klebsiella aeruginosa	+	+
Klebsiella edwardsii	+	+
Klebsiella oxytoca	+	+
Klebsiella ozoenae	+	+
Klebsiella pneumonia	+	+
Micrococcus luteus	-	+
Proteus mirabilis	-	+
Pseudomonas aeruginosa	+	+
Pseudomonas peudomallei	+	+
Pseudomonas stutzeri	+	+
Sarcina lutea	+	-
Shigella boydii	+	-
Shigella sonnei	+	-
Staphylococcus aureus	-	+
TOTAL	**18**	**16**

In cacao and forest ecosystems, the genus Acinectobacter, Klebsiella and Pseudomonas dominated the decomposer organisms while Agrobacterium, Alcaligenes, Citrobacter, Gaffkya, Micrococcus, Proteus, Sarcina, Shigella and Staphylococcus also took part in the decomposition process (Table 3).

The fungal species isolates in cacao decomposing litter were: *Aspergillus flavus, Aspergillus fumigatus, Aspergillus niger, Byssochlamys fulva, Cephalosporium sp, Cladosporium werneckii, Fusarium sp, Neurospora sitiphila, paecilomyces variotii, Penicillum camembarti, Penicillum voquefortii, pullularis sp, Rhizopus glaucus, Rhizopus japanicus, Rhizopus oryzae, Rhizopus stolonifer, Scopulariopsis brevicaulis, Tricholerama sp* and in the forest are; *Aspergillus flavus, Aspergillus fumigatus, Aspergillus glaucus, Botrytis cinerae, Byssochlamys fulva, Cephalosporium herbarium, Cladosporium werneckii, Mucor eretus, Penicillum camembarti, Penicillum digitatum, Pullularis sp, Rhizopus japanicus, Rhizopus oryzae, Scopulariopsis brevicaulis, Tricholerama sp, Trichophyton schoenleinii* (Table 4). The fungal species that were common to decomposing litter of forest and cacao plantation were; *Aspergillus flavus Aspergillus fumigatus, Byssochlamys fulva,Cephalosporium sp, Cladosporium werneckii, penicillium camembarti, Penicillium voquefortii, Pullularis sp, Rhizopus glaucus, Rhizopus japanicus, Rhizopus oryzae, Scopulariopsis brevicaulis, Trichoderma sp* (Table 4)

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Table 4: Composition of total heterotrophic fungal species in decomposing litter in forest and cacao plantation

SPECIES	Forest	Cacao plantation
Aspergillus flavus	+	+
Aspergillus fumigatus	+	+
Aspergillus glaucus	+	-
Aspergillus niger	-	+
Botrytis cinerae	+	-
Byssochlamys fulva	-	+
Cephalosporium sp	+	+
Cladosporium herbarium	+	-
Cladosporium werneckii	+	+
Fusarium sp	-	+
Mucor eretus	+	-
Neurospora sitiphila	-	+
Paecilomyces variotii	-	+
Penicillium camembarti	+	-
Penicillium digitatum	+	-
Penicillium voquefortii	-	+
Pullularis sp	+	+
Rhizopus glaucus	-	+
Rhizopus japanicus	+	+
Rhizopus oryzae	+	+
Rhizopus stolonifer	-	+
Scopulariopsis brevicaulis	+	+
Trichoderma sp	+	+
Trichophyton schoenleinii	+	-
Total	16	17

The fungal species that are specific to forest decomposition litter were: *Aspergillus glaucus, Botrytis cinerae, Mucor eretus, Penicillium digitatum* and *Trichophyton schoenleinii* while in cacao plantation decomposing litter were: *Aspergillus niger, Cephalosporium sp, Fusarium sp, Neurospora sitiphila, Paecilomyces variotii, Penicillium voquefortii, Rhizopus glaucus* and *Rhizopus stolonifer* (Table 4).

In cacao plantation decomposing litter, the highest total number of heterotrophic bacterial species was in February and November and lowest in March and July (Table 5a) while in the forest the highest number of total heterotrophic bacterial species was in January and lowest in March, April, August and July respectively (Table 5b). In cacao plantation the monthly dynamics of fungal species occurrence in the decomposing leaf litter was highest in July and lowest in May and November (Table 5c) while in forest ecosystem the monthly dynamics of fungal species occurrence in the decomposing leaf litter was highest in September and lowest in March (Table 5d)

In cacao plantation and forest decomposing leaf litter, the bacterial that had the highest occurrence was *Klebsiella edwardsi* (occurred throughout the litter decomposing period except in December in forest litter) (Table 5a and b) while the fungi was *Penicillium camemberti and Rhizopus japanicus* (Table 5 c and d)

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Table 5a: Heterotrophic Bacterial species composition and dynamics in decomposing leaf litter of cacao plantation

Bacterial Species	January	February	March	April	May	June	July	August	September	October	November	December
Acinectobacter calcoaceticus	-	-	-	-	-	-	-	-	-	-	+	-
Acinectobacter mallei	-	-	-	-	-	-	-	+	-	-	-	+
Acinectobacter paraperfussis	+	-	-	-	-		-	+	+	-	+	-
Agrobacterium tumefaciens	+	-	-	-	-	-	-	-	-	-	-	-
Citrobacter freundii	-	-	-	-	-	-	-	-	+	-	-	-
Klebsiella aeruginosa	-	-	-	+	-	-	-	-	-	+	-	-
Klebsiella edwardsii	+	+	+	+	+	+	+	+	+	+	+	+
Klebsiella oxytoca	-	-	-	-	+	-	-	+	-	+	-	+
Klebsiella ozoenae	-	+	-	+	-	+	-	-	-	-	-	-
Klebsiella pneumonia	-	+	-	+	-		-	+	+	-	+	+
micrococcus luteus	-	-	-	-	-	-	-	-	-	-	+	-
proteus mirabilis	-	-	-	-	-	+	-	-	-	-	-	-
Pseudomonas aeruginosa	-	+	+	-	+	-	+	+	-	-	+	-
Pseudomonas peudomallei	-	+	+	-	-	-	-	-	-	-	-	-
Pseudomonas stutzeri	-	+	-	-	-	-	-	-	-	-	+	-
Staphylococcus aureus	-	+	-	-	-	-	-	-	-	-	-	-
TOTAL	3	7	2	4	3	3	2	6	4	3	7	4

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Table 5b: Heterotrophic Bacterial species composition and dynamics in decomposing leaf litter of natural forest

Bacterial Species	January	February	March	April	May	June	July	August	September	October	November	December
Acinectobacter calcoaceticus	-	-	-	-	-	-	-	-	-	+	-	-
Acinectobacter iwoffi	-	-	-	-	-	-	-	+	-	-	-	-
Acinectobacter mallei	-	-	-	-	-	-	-	-	-	-	-	+
Acinectobacter paraperfussis	+	-	-	-	+	-	-	-	-	-	+	+
Agrobacterium tumefaciens	-	-	-	-	-	-	-	-	-	-	-	-
Alcaligenes Faecalis	-	-	+	-	-	-	-	-	-	-	-	-
Gaffkya tetragena	-	-	-	-	-	+	-	-	-	-	-	-
Klebsiella aeruginosa	-	-	-	-	-	-	-	-	-	-	-	-
Klebsiella edwardsii	+	+	+	+	+	+	+	+	+	+	+	-
Klebsiella oxytoca	-	+	-	+	+	-	+	-	+	+	-	-
Klebsiella ozoenae	-	-	-	+	-	-	+	-	-	-	-	-
Klebsiella pneumonia	+	-	-	-	-	+	+	-	+	+	+	+
Pseudomonas aeruginosa	+	+	+	-	+	+	+	+	+	-	+	-
Pseudomonas peudomallei	-	+	-	-	-	-	-	-	-	-	-	-
Pseudomonas stutzeri	-	-	-	-	-	-	-	-	-	-	+	-
Sarcina lutea	+	-	-	-	-	-	-	-	-	-	-	-
Shigella boydii	+	-		-	-	-	-	-	-	-	-	-
Shigella sonnei	+	-	-	-	-	-	-	-	-	-	-	-
TOTAL	7	4	3	3	4	4	4	3	4	4	5	3

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Table 5c: Heterotrophic fungal species dynamics in decomposing leaf litter of cocoa plantation

Fungi	January	February	March	April	May	June	July	August	September	October	November	December
Aspergillus flavus	-	-	-	+	-	-	-	-	-	-	-	-
Aspergillus fumigatus	+	+	-	+	-	-	+	-	+	+	-	-
Aspergillus niger	-	-	-	-	-	-	-	-	+	-	-	-
Byssochlamys fulva	+	-	-	-	-	-		-	-	-	-	-
Cephalosporium sp	-	-	-	-	-	-	-	-	+	-	-	-
Cladosporium werneckii	+	+	+	-	-	+		-	-	-	-	-
Fusarium sp	-	-	-	-	-	-	+	-	-	-	-	+
Neurospora sitiphila	-	-	-	+	-	-	-	-	-	-	-	-
Paecilomyces variotii	-	-	-	-	-	+	-	-	-	-	-	-
Penicillium camembarti	+	+	+	+	+	+	+	+	+	+	+	+
Penicillium voquefortii	-	-	-	-	-	-	-	-	-	-	-	+
Pullularis sp	-	+	-	-	-	-	+	+	-	+	-	-
Rhizopus glaucus	-	-	-	-	-	-	+	+	-	-	-	-
Rhizopus japanicus	-	-	+	+	+	+	+	+	+	+	+	+
Rhizopus oryzae	+	+	+	+	-	-	+	-	+	+	-	-
Rhizopus stolonifer	-	-	-	-	-	-	-	+	-	-	-	+
Scopulariopsis brevicaulis	+	-	-	-	-	-		-	-	-	-	-
Trichoderma sp	-	-	-	-	-	+	+	-	+	-	-	-
Total	6	5	4	5	2	5	8	5	6	5	2	5

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Table 5d: Heterotrophic fungal species composition and dynamics in decomposing leaf litter of natural forest

Fungi	January	February	March	April	May	June	July	August	September	October	November	December
Aspergillus flavus	-	-	-	-	-	-	-	-	-	-	+	-
Aspergillus fumigatus	+	+	-	+	+	+	-	+	+	+	-	-
Aspergillus glaucus	-	-	-	-	-	-	+	-	-	-	-	-
Botrytis cinerae	-	-	-	+	+	+	-	+	-	-	-	-
Cephalosporium sp	-	-	-	-	-	-	-	-	-	-	-	+
Cladosporium herbarum	-	-	-	-	-	-	-	-	-	-	-	+
Cladosporium werneckii	+	-	+	-	-	-	-	+	+	+	+	+
Mucor eretus	-	-	-	-	-	-	-	-	-	+	+	+
Penicillium camembarti	-	+	+	+	-	+	+	+	-	+	-	-
penicillium digitatum	-	-	-	-	-	-	-	-	+	-	-	-
Pullularia pullularis	+	+	-	-	-	-	-	-		-	+	-
Rhizopus japanicus	-	-	+	+	+	+	-	+	+	+	+	-
Rhizopus oryzae	+	+	-	-	-	+	+	-	+	-	+	+
Scopulariopsis brevicaulis	+	-	-	-	-	-	-	-	-	-	-	-
Trichoderma sp	-	-	-	+	+	+	+	+	+	-	-	-
Trichophyton schoenleinii	-	-	-	-	-	-	-	-	+	+	-	-
Total	5	4	3	5	4	5	4	6	7	6	6	5

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Population density of heterotrophic bacterial and fungi

The total heterotrophic bacterial and fungi was higher in the forest than cacao plantation (Table 6). The total heterotrophic bacterial in the forest was $1.9 \times 10^{18} \pm 3.6 \times 10^{17}$ while cacao plantation was $8.2 \times 10^{9} \pm 7.4 \times 10^{8}$ (Table 6). The total heterotrophic fungi in the forest was $1.03 \times 10^{8} \pm 8.3 \times 10^{6}$ while cacao plantation was $3.9 \times 10^{7} \pm 8.1 \times 10^{6}$ (Table 6).

The range of total heterotrophic bacterial count and total heterotrophic fungal count observed in decomposing leaf litter of forest and cacao plantation differed. The total heterotrophic bacterial count range between 6.15×10^{6} cfu/g and 9.95×10^{17} cfu/g in the forest, 8.9×10^{5} cfu/g and 3.05×10^{9} cfu/g in cacao plantation. The total heterotrophic fungal count range between 4.45×10^{5} cfu/g and 3.25×10^{7} cfu/g in forest while 1.75×10^{5} cfu/g and 1×10^{7} cfu/g in cacao plantation.

Table 6: Total hetetrophic bacterial and fungal counts (cfu/g) in decomposing litter of cacao plantation and natural forest

	Bacterial count (mean ±sd cfu/g)		Fungal count (mean ±sd cfu/g)	
Month	Cacao	Forest	Cacao	Forest
January	$8.9 \times 10^{5} \pm 1.4 \times 10^{4}$	$6.15\times 10^{6} \pm 1.5 \times 10^{5}$	$1.75 \times 10^{5} \pm 2.1 \times 10^{4}$	$2.8 \times 10^{5} \pm 1.4 \times 10^{4}$
February	$2.49\times 10^{8} \pm 2.1 \times 10^{6}$	$9.95 \times 10^{9} \pm 1.5 \times 10^{9}$	$1 \times 10^{5} \pm 1.4 \times 10^{4}$	$6 \times 10^{5} \pm 1.4 \times 10^{4}$
March	$1\times 10^{8} \pm 1.4 \times 10^{7}$	$2.6 \times 10^{10} \pm 1 \times 10^{10}$	$3.85 \times 10^{5} \pm 2.1 \times 10^{4}$	$5.5 \times 10^{5} \pm 7.07 \times 10^{4}$
April	$3.3 \times 10^{8} \pm 1.4 \times 10^{7}$	$5.9 \times 10^{15} \pm 1 \times 10^{16}$	$1.2 \times 10^{6} \pm 1.4 \times 10^{5}$	$9 \times 10^{5} \pm 1.4 \times 10^{5}$
May	$4\times 10^{8} \pm 1.4 \times 10^{7}$	$1.05 \times 10^{15} \pm 1.5 \times 10^{14}$	$1.5 \times 10^{6} \pm 7.1 \times 10^{5}$	$1.75\times 10^{6} \pm 7.07 \times 10^{5}$
June	$2.85\times 10^{9} \pm 2.1 \times 10^{8}$	$5.2 \times 10^{17} \pm 1 \times 10^{14}$	$2.5 \times 10^{6} \pm 7.1 \times 10^{5}$	$1.12 \times 10^{7} \pm 2.1 \times 10^{5}$
July	$3.05 \times 10^{9} \pm 2.1 \times 10^{8}$	$2.95 \times 10^{15} \pm 1.5 \times 10^{14}$	$1 \times 10^{7} \pm 1.4 \times 10^{6}$	$1.15 \times 10^{7} \pm 7.07 \times 10^{5}$
August	$1\times 10^{9} \pm 1.4 \times 10^{8}$	$1.35 \times 10^{15} \pm 5 \times 10^{13}$	$4.5 \times 10^{6} \pm 2.1 \times 10^{6}$	$1 \times 10^{7} \pm 1.4 \times 10^{6}$
September	$3.9 \times 10^{7} \pm 1.4 \times 10^{6}$	$1.4 \times 10^{11} \pm 1 \times 10^{10}$	$6 \times 10^{6} \pm 1.4 \times 10^{6}$	$9 \times 10^{6} \pm 1.4 \times 10^{6}$
October	$6.35 \times 10^{7} \pm 2.1 \times 10^{6}$	$5.5 \times 10^{8} \pm 1.5 \times 10^{8}$	$5.95 \times 10^{5} \pm 7.07 \times 10^{3}$	$3.2 \times 10^{5} \pm 1.4 \times 10^{4}$
November	$8.25 \times 10^{7} \pm 2.1 \times 10^{6}$	$2.05 \times 10^{8} \pm 1 \times 10^{6}$	$1.4 \times 10^{5} \pm 1.4 \times 10^{4}$	$3.25 \times 10^{5} \pm 2.1 \times 10^{4}$
December	$3 \times 10^{7} \pm 1.4 \times 10^{6}$	$5.2 \times 10^{7} \pm 1 \times 10^{6}$	$1.75 \times 10^{5} \pm 2.1 \times 10^{4}$	$4.45 \times 10^{5} \pm 1.5 \times 10^{3}$
Total	$8.2 \times 10^{9} \pm 7.4 \times 10^{8}$	$1.9 \times 10^{18} \pm 3.6 \times 10^{17}$	$3.9 \times 10^{7} \pm 8.1 \times 10^{6}$	$1.03 \times 10^{8} \pm 8.3 \times 10^{6}$

The chemical composition of decomposing leaf litter of forest and cacao plantation

The initial and final chemical compositions in the decomposing leaf litter of forest were significantly higher than those of cacao plantation ($p < 0.05$; $F_{1, 11}$= 167.50 N; $F_{1, 11}$= 51.70 P; $F_{1, 11}$=25.04 K; $F_{1, 11}$= 42.78 Ca; $F_{1, 11}$= 67.13 Mg; $F_{1, 11}$= 47.16 S; $F_{1, 11}$= 50.46 C) (Table 7). However, initial % ADF concentration was higher in forest than in cacao litter (Table 7). The orders of initial and final chemical compositions of the leaf litter of forest and cacao plantation were: C > Ca > N > K > S > Mg > P (Table 7).

The monthly concentrations of these chemical constituents in decomposing leaf litter in the forest were greater than that of cacao throughout the period of decomposition except for K and Lignin in cacao that had a greater concentration in month of November (Fig 3a and 3c).

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The concentration of the chemical constituents in the decomposing leaf litter of cacao plantation and forest almost decreased with increasing month of decomposition except for forest that had a slight increase in the month of July and cacao plantation that had a slight increase in the month of September and November (Fig 3a-b). Also, for the forest, there was a slight increase in the concentration of N in the month of November and lignin and ADF in the month of December (Fig 3a-b). There were significant difference in the monthly concentrations of all the chemical constituents in the decomposing leaf litter of forest and cacao plantation ($p < 0.05$; $F_{1, 11}= 48.78$ N; $F_{1, 11}=7.304$ P; $F_{1, 11}=10.94$ K; $F_{1, 11}= 10.70$ Ca; $F_{1, 11}= 4.27$ Mg; $F_{1, 11}= 12.34$ S; $F_{1, 11}= 5.76$ C).

Table 7: Initial and final concentrations of chemical constituents of decomposing litter of cacao plantation and natural forest

VEGETATION	Chemical constituent						
	% N	P (PPM)	% K	% Ca	% Mg	% S	% C
CACAO (INITIAL	3.665	703.629	1.959	4.754	0.328	0.965	43.977
FOREST (INITIAL)	4.395	843.921	2.350	5.702	0.393	1.157	52.745
CACAO (FINAL)	1.745	412.674	1.149	2.788	0.192	0.566	25.792
FOREST (FINAL	2.795	577.143	1.445	3.681	0.294	0.960	36.924

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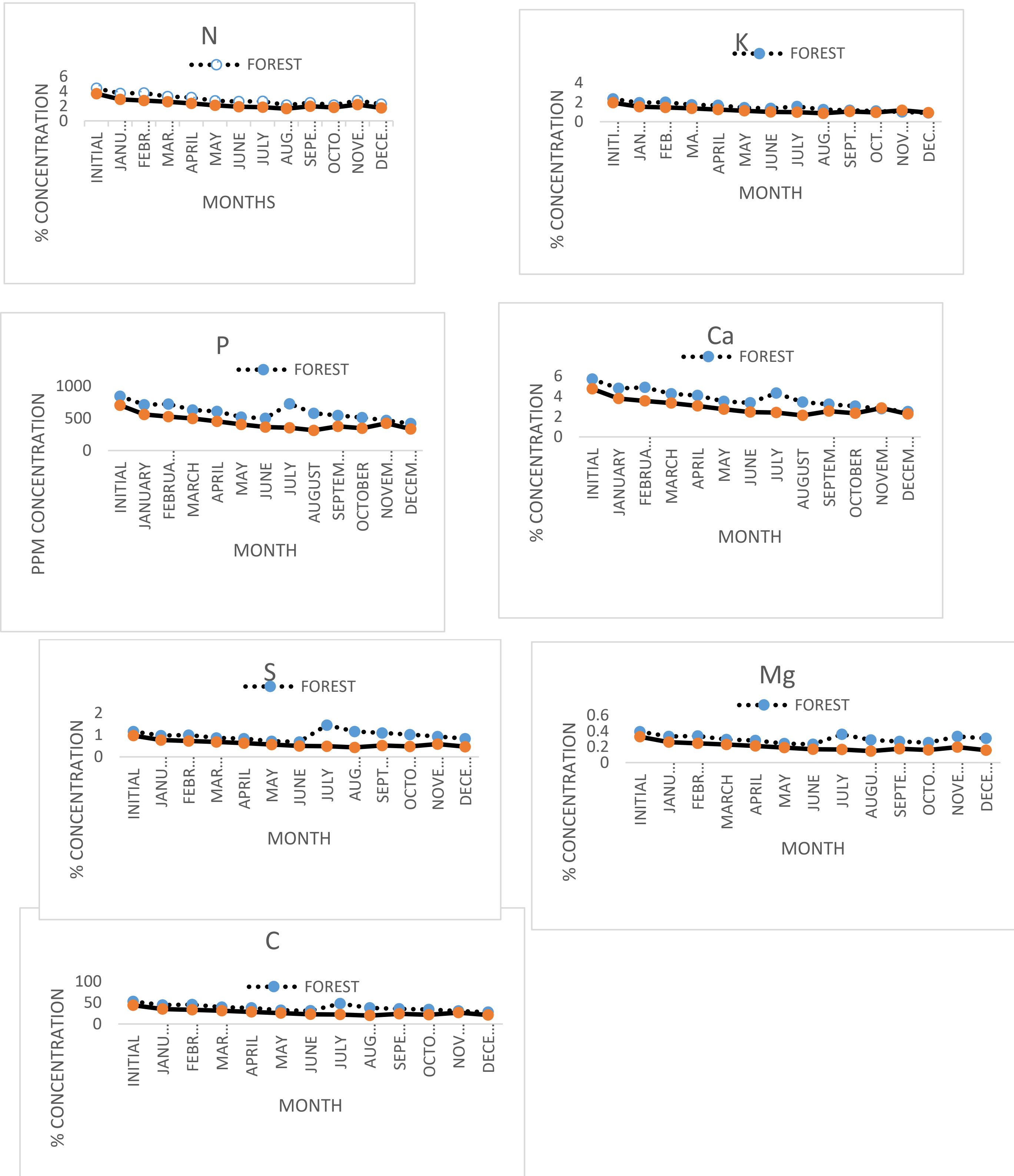

Fig 3b: Monthly variations in concentrations of chemical constituents of decomposing leaf litter of forest and cacao plantation

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Nutrient release pattern in decomposing leaf litter in forest and cacao plantation

The amount of nutrients released via leaf litter decomposition showed significant difference between initial and final release of nutrient elements in the two ecosystems with final release significantly higher than the initial in the two ecosystems (Table 8) ($p < 0.05$; $F_{1, 11}= 52.51$ N; $F_{1, 11}=45.23$ P; $F_{1, 11}=55.71$ K; $F_{1, 11}= 58.56$ Ca; $F_{1, 11}= 50.46$ Mg; $F_{1, 11}= 29.18$ S and $F_{1, 11}= 52.81$ C). Forest decomposing leaf litter released almost 98 % of chemical constituents in decomposing forest leaf litter while 90% was released in decomposing cacao leaf litter. (Table 8). In cacao ecosystems, Mg released highest percentage of the highest nutrient element (Table 8) while in forest ecosystems, K released highest percentage of nutrient element (Table 8)

The monthly chemical constituents released/decomposed pattern in decomposing forest and cacao leaf litter showed similar trend for all the constituents during decomposition in the two ecosystems. For all the constituents, the release/decomposition increased with decomposition (lower at the beginning of the decomposition and increased with decomposition and being highest the end). (Fig 4a- b)

Table 8: Release of chemical constituents from decomposing litter in forest and cacao plantation.

VEGETATION	Chemical constituent						
	N	P	K	Ca	Mg	S	C
CACAO (INITIAL)	7.16	0.14	3.83	9.29	0.64	1.89	85.93
CACAO (FINAL)	0.71	0.02	0.38	0.92	0.06	0.18	8.54
AMOUNT RELEASED	6.45	0.12	3.45	8.37	0.58	1.71	77.39
% RELEASED	90.1	85.7	90.1	90.1	90.6	90.5	90.1
FOREST (INITIAL)	8.44	0.162	4.51	10.95	0.76	2.22	101.27
FOREST (FINAL)	0.13	0.002	0.05	0.14	0.02	0.05	1.59
AMOUNT RELEASED	8.31	0.160	4.46	10.81	0.74	2.17	99.68
% RELEASED	98.5	98.8	98.9	98.7	97.4	97.8	98.4

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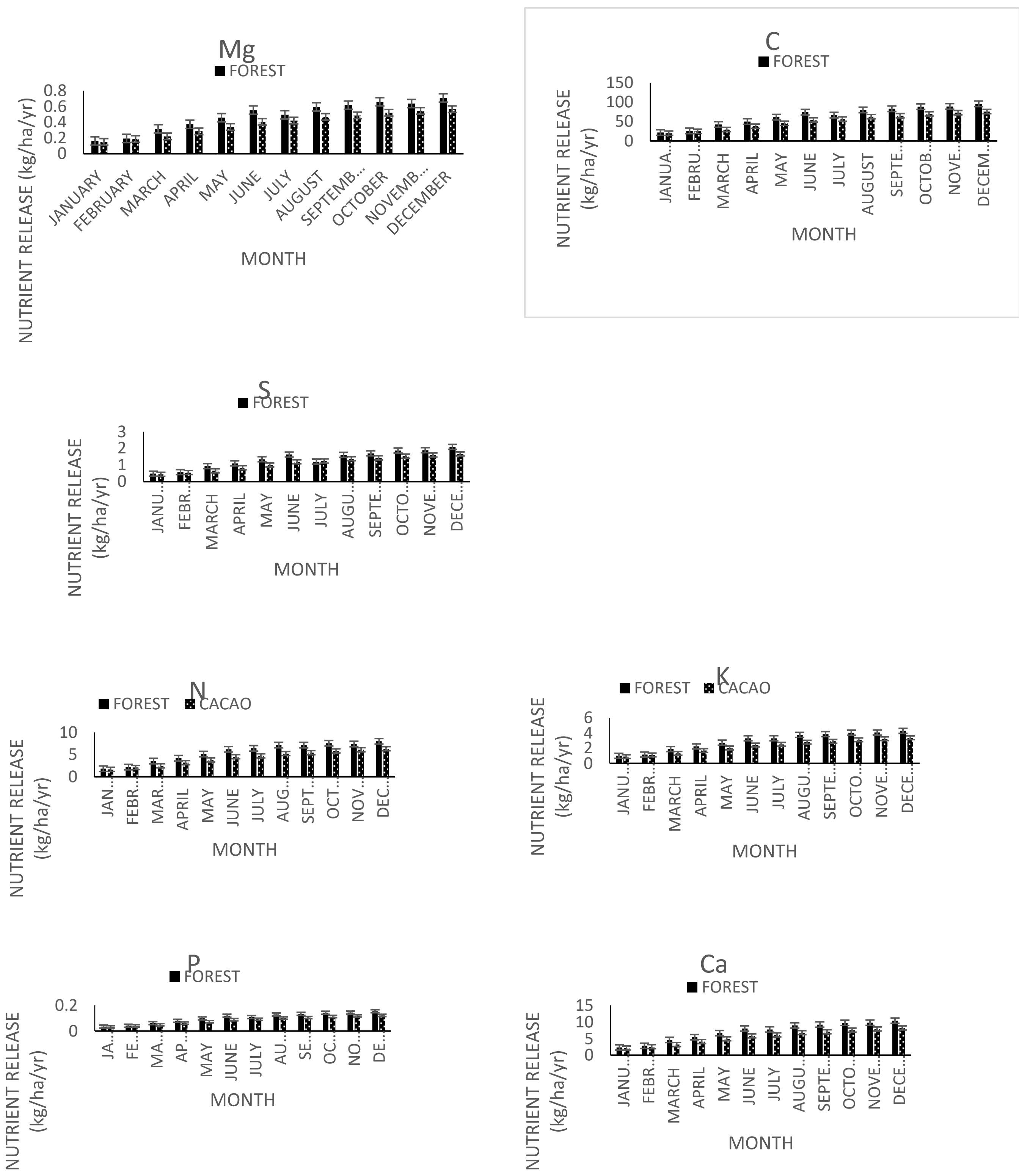

Fig. 4b: Monthly Changes in Chemical Constituents of Decomposing Forest and Cacao Leaf Litter

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DISCUSSION

Decomposition rate in forest and cacao plantation

In present study, the decreasing remaining mass of the leaf-litter with decomposition is similar to those reported by Triadiati *et al*. (2011); Alhamd *et al*. (2004) and Attignon *et al*. (2004). This could be as a result of action of the decomposers on the substrate. However, the decomposition rate in the forest was higher than cacao plantation (Table 2). Similar trend was also reported by Owusu-Sekyere *et al*. (2006) and Dawoe (2010) for cacao agroforest and lowland humid natural forest in Ghana, Triaddiati *et al*. (2011) for natural forest and cacao agroforestry for central Sulawesi in Indonesia, and Swarnalatha and Reddy (2011) for Puducherry Forest region and other plantations in India. The significantly higher annual decomposition rate recorded in the forest compared with cacao agroforestry may reflect the structural and litter quality differences of natural forest litter and cacao plantation litter with forest litter being of higher quality than litter in cacao system. Furthermore conversion of forest to cacao land-use results in reduction of decomposition rates, litter quality changes and that decomposition will correlate to litter quality differences in cacao and forest ecosystems (Dawoe, 2010; Ibrahim *et al*., 2011), differences in physicochemical properties of the substrate in ecosystem, palatability of the substrate to the decomposer (Gosz *et al.,* 1973) and abundant availability of the active decomposer in the ecosystem will influence decomposition. Microbial and other decomposition processes depend upon the type of material available for decomposition and on other factors such as climate and water availability (Bardgett *et al*., 1999).

In this present study, during the first three months in each ecosystem decomposing rate was slow and; thereafter, followed by faster rate (Fig 1). The relatively slower rate at the early stage is due to non-availability of moisture which inflences decomposition in the tropics (Muoghalu *et al*. 1994) due to rainless period (dry season) from January –March but with onset of rainy season subsequently (April – October) moisture became available and decomposers multiplied in abundance and decomposition became faster.

Decomposition constant in the forest and cacao plantation

In this study, the decomposition constant in the forest was higher than that of cacao plantation (Table 2). Similar trend was also reported by Dawoe (2010) for Cacao agroforest and lowland humid natural forest in Ghana, Triaddiati *et al*. (2011) for natural forest and cacao agroforestry for central Sulawesi in Indonesia, Swarnalatha and Reddy (2011) for Puducherry Forest region and other plantations in India. The significantly higher annual decomposition constant recorded in the forest compared with cacao agroforestry may reflect structural and litter quality differences with litter on natural forest floor being of higher quality than litter in cacao system (Dawoe, 2010 and Ibrahim *et al*., 2011), differences in physicochemical properties of the substrate in ecosystem, palatability of the substrate to the decomposer (Gosz *et al*., 1973) and abundance availability of the active decomposer in the ecosystem (Owusu-Sekyere, 2006).

However, the decomposition constant 3.497 in this study was higher than the average annual decay rate coefficients (k) for temperate and tropical forest ecosystems estimated respectively at k = 0.9 and k = 1.8 (Torreta and Takeda, 1999); for regionality in decomposition rates within the tropics, k = 1–2 (medium to high) for forests in Southeast Asia and the Neotropics (Anderson and Swift 1983), and slightly higher than 3.05 for Puducherry Forest region in India (Swarnalatha and Reddy, 2011) but agrees with K >2 (high) for African forests (Anderson and Swift, 1983) and the range of 3-4 reported by Olson (1963).

Percentage weight loss of the leaf litter of forest and cacao plantation

In this study the percentage weight loss in the forest was significantly higher than cacao plantation. Similar trend was reported for by Owusu-Sekyere *et al*., 2006) for cacao plantation and natural forest in Ghana. This higher weight loss could be influenced by abundance soil and forest floor microorganisms (Owusu-Sekyere *et al*., 2006) and climate especially rainfall in the year of study.

Microbial composition in forest and cacao plantation

There is paucity of information on the culturable microbes in the decomposing forest and cacao litter. However, the composition of culturable heterotrophic bacteria and fungi observed in this study was not much different from the few available reports in cacao plantation by Akpor *et al*. (2006) and Osewole and Muoghalu (2016). This could be that they are the microbe peculiar to cacao plantation ecosystem. However, the slight disparity in the composition of bacteria and fungi in this study in cacao plantation and those of previous reports might be as a result of age of the plantations, spatial differences (Krivtsov *et al*., 2005) and management practices in the different cacao plantations such as pesticide application.

Microbial population dynamics

The microbial population (bacteria and fungi) in forest was significantly higher than that in cacao plantation in this study. Similar trend was also reported by Pandey *et al*. (2007) for forest plantation in northeast India forest; Akpor *et al*., 2006 and Osewole and Muoghalu, 2016 for cacao plantation in Ile Ife

The higher microbial population in the forest than cacao plantation might be attributed to the high richness and diversity of the plant species in these ecosystem. The appreciable lower population in the cacao plantation compared with the forest ecosystem might as a result of management practices in this ecosystem which include application of chemical like pesticide with has direct or

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indirect effect of the detritus microorganisms that facilitate decomposition process (Osewole and Muoghalu, 2016).

However, the range of microbial count 6.15 x 10^6- 5.2 x 10^{17} for bacteria and 2.85 x 10^5- 1.15 x 10^7 for fungi in the forest ecosystem in this study was higher than the value 1.86 x 10^5 for bacteria and 3.48 x 10^4 for fungi reported by Pandey *et al*. (2007) for northeast India forest. This higher value might be as a result of spatial and temporal differences (Krivtsov *et al*., 2005), soil water content (Qui *et al*., 2005) and age of the forests.

The range 8.9 x 10^5 – 3.05 x 10^9 in cacao plantation for bacteria and 1.75 x 10^5 – 1 x 10^7 for fungi is higher than 1.2 x 10^6- 8.1 x 10^7 for bacteria and 2.1 x 10^3 – 9.4 x 10^4 reported by Akpor *et al*. (2005) for kolanut plantation for tropical setting in Nigeria, 8.0 x 10^5 – 5.1 x 10^7 for bacteria and 3.0 x 10^3 – 7.5 x 10^4 by Akpor *et al*. (2006) for cacao plantation for tropical setting in Nigeria but fall within the range 4.7 x 10^7 -1.60 x 10^{10} for bacteria and 1.8 x 10^3 – 8.47 x 10^7 reported by Osewole and Muoghalu (2016) for cacao plantation in south-western Nigeria. The variation in the microbial population might be as a result of spatial and temporal differences (Krivtsov *et al*., 2005).

The higher microbial population was observed in the rainy season than in the dry season (Table 6). Similar trend was reported by Akpor *et al*. (2005) for kolanut plantation for tropical setting in Nigeria, Akpor *et al*., (2006) for cacao plantation for tropical setting in Nigeria and Osewole and Muoghalu (2016) for cacao plantation in Ile-Ife, Nigeria. It is reasonable to deduce that this may have resulted from at least in that extremely wet conditions experienced in the months due to high rainfall and temperature. Aert (1997) reported that temperature and moisture affect the population of microorganisms during decomposition.

Nutrient release via leaf litter of forest and cacao plantation

Nutrient released from decomposing plant litter is vital for the maintenance of fertility in forest soils. The well-known general model for this process involves initial leaching of nutrients followed by a phase of nutrient immobilization and finally the release of nutrients into the soil (Weerakkody and Parkinson, 2006).

In this study the concentration and nutrient release for a decomposing leaf litter in the forest was higher than those of cacao plantation and a similar trend was also reported by Owusu-Sekyere *et al*. (2006) for natural forest and cacao agroforest in Ashanti Ghana. The higher concentration and nutrient release in the forest might be attributed to better litter quality of the forest species over that of cacao plantation litter. Shangha *et al*. (2006) reported that quality of litter influences microbial processes and nutrient retention in a system. The effects of soil properties also can play an important role in moderating nutrient return to a system (Shangha *et al*., 2006). Decomposition of litter and release of nutrients not only depends upon litter composition but also upon soil type, microbial communities, incubation time and soil properties (Sangha *et al*., 2006).

CONCLUSION

This study concluded that nutrient cycling via litter decomposition is more efficient in natural forests than in cacao plantations and that clearing forests to establish cacao plantations is adversely affecting nutrient cycling. Management practices in the cacao plantation has adverse effect on microbial diversity.

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Conflict of Interest

There is no conflict of interest to declare

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