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LITTER PRODUCTION AND DECOMPOSITION IN CACAO (*THEOBROMA CACAO*) AND KOLANUT (*COLA NITIDA*) PLANTATIONS

Joseph Ikechukwu Muoghalu & Anthony Ifechukwude Odiwe

Department of Botany, Obafemi Awolowo University, O.A.U. P.O. Box 1992, Ile-Ife, Nigeria

Abstract. Litter production and decomposition were studied at monthly intervals for two years in *Cola nitida* and *Theobroma cacao* plantations at Ile-Ife, Nigeria. Three plantations of each economic tree crop were used for the study. Mean annual litter fall was 4.73±0.30 t ha^{-1} yr^{-1} (total): 3.13±0.16 t ha^{-1} yr^{-1} (leaf), 0.98±0.05 t ha^{-1} yr^{-1}(wood), 0.46±0.12 t ha^{-1} yr^{-1} (reproductive: fruits and seeds), 0.17±0.03 t ha^{-1} yr^{-1} (finest litter) in *T. cacao* plantations and 7.34±0.64(total): 4.39±0.38 (leaf), 1.57±0.17 (wood), 1.16±0.13 (reproductive) and 0.22±0.01 (finest litter or trash) in *C. nitida* plantations. The annual mean litter standing crop was 7.22±0.26 t ha^{-1} yr^{-1} in *T. cacao* and 5.74±0.54 t ha^{-1} yr^{-1} in *C. nitida* plantations. *Cola nitida* leaf litter had higher decomposition rate quotient (2.00) than *T. cacao* leaf litter (1.03). Higher quantities of calcium, magnesium, potassium, nitrogen, phosphorus, sulfur, managenese, iron, zinc and copper were deposited on *C. nitida* than on *T. cacao* plantations. The low litter decomposition rates in these plantations implies accumulation of litter on the floor of these plantations especially *T. cacao* plantations. This accumulation of litter in the plantations has an impact on nutrient cycling in plantations of these economic tree crops because it is only when litter is decomposed that nutrients are recycled back into the soil for the maintenance or sustenance of soil fertility under these plantations.
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Keywords: Litter fall, decomposition, tree crop plantations, tropics.

INTRODUCTION

The stability of an ecosystem depends upon the orderly transfer of nutrients between the living and non-living components (Mehra *et al.* 1985). The material fixed in the above-ground biomass is sooner or later returned to the soil through litter fall and precipitation (Mehra *et al.* 1985). Nutrients are primarily transferred as leaves and other plant parts fall to the ground as litter, where they are subsequently leached by percolating water and decomposed by organisms (Eaton *et al.* 1973). The subsequent release of elements during decomposition completes the cycle of elements in plant litter within the soil-plant system (Attiwill 1968). Therefore, decomposition of organic matter and mineralization processes are responsible for virtually all of the nutrients taken up by vegetation. The widespread use of pesticides poses potential threat to the decomposing processes (Gottschalk & Shure 1979). Pesticide accumulation in the litter-soil ecosystem may disrupt detrital food webs and thus impair soil formation and the maintenance of soil fertility (Gottschalk & Shure 1979).

All natural forest ecosystems depend on cycling of nutrients to meet the nutritional demands of the growing plants (Grierson & Adams 1999). Productivity of individuals or whole ecosystems may be reduced by an inadequate supply of mineral nutrient (Chapin *et al.* 1986). In agricultural systems, nutrient supply rate and nutrient limitation are closely linked via management in contrast to natural systems where differences in species, plant life stage and moisture supply can uncouple low nutrient supply rates from nutrient limitation (Specht *et al.* 1983, Binkly & Vitousek 1989).

Of recent there has been clearing of natural forests for the establishment in plantations of economic tree crops such as cocoa, coffee, kola nut, oranges, rubber and fast-growing timber trees (*Eucalyptus spp., Gmelina,* Teak, etc.) which have contributed to deforestation in tropical countries because of the continuing demand for these especially in developed countries. It is only when a 'steady-state' stage is reached that the plantations can be considered to 'mimic' natural forests they replaced and the conse-

e-mail: jmuoghal@oauife.edu.ng

quent renewal of earlier immobilized nutrients take place (Ewel 1986, Ewel & Bigelow 1996, Grierson & Adams 1999,).

The forest areas may seem remarkably fertile and productive but once the forest is destroyed or removed, the soils that once supported it can rapidly lose its fertility and are incapable of supporting agricultural production for very long. Without constant turnover of nutrient elements from the plantations, these nutrients present in the soil proper can be quickly leached away by rain or exhausted by being removed in the production of a few years of crops. Also, farmers faced with the problems of pest and disease control in these plantations use pesticides to control them such as copper based fungicides to control *Phytophthora* pod rot in cacao plantations. Widespread use of pesticides in these plantations to control pests may cause the disruption of nutrient cycling by adversely affecting the microorganisms, especially bacteria and fungi, involved in decomposition processes thus altering normal nutrient cycling pattern in these ecosystems (Weary & Merriam 1978, Gottschalk & Shure 1979, Eijsackers & Van de Bund 1980). Appreciable litter accumulation would have profound implications, including a major reduction in nutrient cycling. In south-west Nigeria, plantations of cacao, kola nut and oranges abound. Mature tropical forests are regarded as steady state ecosystem where the decomposition of litter on the forest floor is in equilibrium with the production rate of litter or litter fall (Swift *et al.* 1981). It is to be expected that the decomposition rate in monoculture tree crop plantations will not be as rapid as in tropical forest because the microflora community is not likely to be fully developed and the management practices, such as the use of pesticides, in such tree crop plantations (Grierson & Adams 1999). There is therefore a need to investigate litter production and decomposition in tree crop plantations to determine litter fall, accumulation, and decomposition, as a contribution to the understanding of ecological functioning of tropical tree crop plantations. Our study reports data on litter production and decomposition in two economic tree crops: cacao (*Theobroma cacao* Linn) and kola nut (*Cola nitida* (Vent.) Schott & Endl.) from plantations in Ile-Ife, south-west Nigeria. It specifically addressed the patterns of litter fall, litter standing crop (accumulation of litter on the plantation floor), litter decomposition and nutrient element deposition via leaf litter, and compared these processes in plantations of the two tree species.

METHODS

Study area. The study was carried out in cacao and kola nut plantations in Aba Gboro village within the Obafemi Awolowo University Estate, Ile-Ife, Nigeria. The study area covers latitude 7° 32.654′ N, longitude 4° 30.661′ E and is situated at an elevation range of 253.2 to 292.5 m above sea level. The plantations lie within the same area, with plots no more than 4 km distant from each other. The actual ages of the plantations could not be ascertained because the owners had no record of when they were established. However, they were able to identify cacao and kola nut plantations that were established at about the same time as those selected for this study. The mean tree density in *T. cacao* plantations used for this study was 816 ± 144 plants ha^{-1} while in *C. nitida* plantations it was 192 ± 11 plants ha^{-1}. The mean circumference at breast height of trees in the *T. cacao* plantations was 43.0 ± 2.4 cm and in *C. nitida* 97.7 ± 10.4 cm. The area lies in the dry deciduous forest zone (Onochie 1979). White (1983) described the vegetation as Guineo-Congolian drier forest type. There are two seasons in the area, a short dry season from November to March and a rainy season from March to November. The mean annual rainfall in the area is 1413 mm (Duncan 1974). The annual rainfall measured in the experimental plots for the years of the study was 1880.7 mm between September 2001 and August 2002, and 1748.5 mm from September 2002 to August 2003. The mean annual minimum and maximum temperatures were 22.5° C and 31.4° C respectively.

The area is underlain by rocks of the Basement Complex which are of the Precambrian Age (Wilson 1922, De Swardt 1953). The soil has been classified as Lixisols (FAO/UNESCO 1974) and Ultisols (USDA 1975). The soils which are usually acid, contain less than 10% clay, mainly kaolinite and hence are characterized by low cation exchange capacity and low water holding capacity (Ayodele 1986).

Sampling procedure. Three sample plots, 25 m x 25 m each, were established in different cacao and kola nut plantations in the area, a total of six sample plots. Litter fall and standing crop of litter were measured at monthly intervals for two years in each of the plots. Leaf litter decomposition was studied for 15 months in kola nut plantation and for 20 months in cacao plantation using the litter bag method (Bocock & Gilbert 1957).

In each plot, twenty 1 m x 1 m x 50 cm nylon litter traps of 1-mm mesh size suspended 1 m above the ground were laid out at random to collect litter fall materials. The litter from these traps was collected every two weeks from September 2001 to August 2003. The collected litter of each tree crop species was sorted into (i) leaf, (ii) wood < 2.5 cm in diameter, (iii) reproductive parts: flowers, fruits, and seeds, and (iv) finest litter/trash (any material passing through a 2-mm sieve). These fractions were oven-dried at 80° C to a constant weight and weighed. The collections in each month were combined to obtain litter fall data per month.

Litter standing crop was sampled during the same period. Twenty 1 m x 1 m quadrats were laid out randomly on the litter layer in each plot at monthly intervals. The standing crop of litter within the quadrat was collected and sorted into (i) leaf, (ii) wood (< 2.5 cm in diameter), (iii) reproductive parts, and (iv) trash. These fractions were oven-dried at 80° C to a constant weight and weighed. The standing crop of litter was collected the same day and at the same time that litter traps were emptied during the second litter fall collection each month. The location of a sample collection for estimating the litter standing crop was marked to avoid repeated collections from the same point. The first sampling period coincided with the installation of the litter traps.

Litter decomposition was studied using the litter bag method. Freshly fallen leaf litter was collected from under the crowns of cacao and kola nut trees, air-dried for one week and 20 g weighed into 1 mm mesh nylon litter bags, 20 cm x 30 cm in size, which were then closed. One hundred and twenty labeled and numbered litter bags each were placed on the litter layer in cacao and kola nut plantations. Five litter bags were retrieved randomly from each plantation at monthly intervals for 20 months. The content of each bag was emptied, taking care not to lose any material. Extraneous materials such as visible animal materials and fine roots were removed. The rest was oven-dried at 80°C to a constant weight and weighed. Sub-samples of the air-dry litter of each species litter was oven-dried at 80°C to constant weight to obtain a conversion factor for calculating the oven-dry weight of litter for each bag. Freshly fallen oven-dried leaf litter of each species was ground and analyzed for nitrogen, phosphorus, sulfur, calcium, magnesium, potassium, manganese, iron, copper and zinc by the method of Tel and Rao (1982). The cations (Ca, Mg, K, Fe, Mn, Zn, Cu) were determined by digesting in mixed acid and reading the cations in Atomic Absorption Spectrophotometer, and K in a Flame Photometer. Total phosphorus was determined using the molybdovanadate method, utilizing the reaction between phosphorous and molybdovanadate to form a phosphomolybdovanadate complex that was measured colorimetrically at 420 nm using Technicon's Autoanalyzer (AA11). Total nitrogen was determined in sulfuric : peroxide mixture digest using Technicon's Autoanalyzer (AA11). Total sulfur was determined on the plant digest using the turbidometric-spectrophotometric method.

Data and statistical analyses. The annual decomposition quotient $K_L = 1/X$, where 1 is the annual litter input to the forest floor and X is the mean standing crop of litter (Olson 1963), was calculated for total, leaf, reproductive parts, wood, and finest litter/trash.

The decomposition constant of each species' leaf litter was calculated using the formula $K_t = -\ln(X_t/X_0)$, where K is a constant of overall fractional loss rate, X_0 is original mass and X_t is mass, remaining at time t (Olson 1963).

Two-way analysis of variance was used to test for significant species difference (first factor) and yearly variation (second factor) for litter fall and standing crop of litter in the plots. Two-way analysis of variance was also used to test for significant monthly variation and difference between litter fractions for litter fall and standing crop of litter in the plots. Here, the monthly values of each litter fraction (total, leaf, wood, reproductive, finest litter) constituted the second factor, while the plots from which the data were collected constituted the first or independent factor. The analyses were performed using SPSS (2001)

RESULTS

Litter production. The annual litter fall in the plantations (t ha^{-1} yr^{-1}) (Table 1) showed that there was a significantly higher total litter fall in kola nut plantation than in cacao plantation (Two way ANOVA, $F_{1,140} = 30.5469$, $p < 0.001$). There were significant differences in total litter fall (Two way ANOVA, $F_{2,22} = 5.3070$, $p < 0.01$), leaf litter fall ($F_{2,22} = 8.169$, $p < 0.01$), and reproductive parts ($F_{2,22} = 4.8287$, $p < 0.05$) between the kola nut plots but not between cacao plots.

The mean standing crop of litter in the plantations (t ha^{-1}) (Table 1) showed that there was a sig-

TABLE 1. Contribution of various litter components to total litter production in cocoa (*Theobroma cacao*) and kola nut (*Cola nitida*) plantations at Ile-Ife, Nigeria. Values are means ± standard error of mean of three plots of each plantation for two years. Values within parenthesis show percentage totals.

Litter components	Litter fall		Litter standing crop	
	Cocoa plantation	Kola nut plantation	Cocoa plantation	Kola nur plantation
Leaf (t ha^{-1} yr^{-1})	3.14±0.16 (66.1)	4.39±0.38 (59.8)	4.93±0.22 (68.2)	3.27±0.22 (57.0)
Wood (t ha^{-1} yr^{-1})	0.98±0.05 (20.6)	1.57±0.17 (21.4)	0.78±0.07 (10.8)	1.43±0.27 (24.9)
Reproductive parts (t ha^{-1} yr^{-1})	0.46±0.12 (9.8)	1.16±0.13 (15.8)	0.28±0.05 (3.9)	0.10±0.01 (1.7)
Trash (t ha^{-1} yr^{-1})	0.17±0.03 (3.5)	0.22±0.01 (3.0)	1.24±0.06 (17.1)	0.94±0.06 (16.4)
Annual total (t ha^{-1} yr^{-1})	4.73±0.30	7.34±0.64	7.22±0.26	5.74±0.54

nificantly higher standing crop of litter in cacao plantations than in kola nut plantations (Two way ANOVA, $F_{1,140} = 24.5782$, $p < 0.001$).

There were highly significant differences in litter fall (Two way ANOVA, cacao $F_{3,44} = 22.329$ $p < 0.001$; kola nut F3,44 = 14.9, $p < 0.001$) and litter standing crop (cacao $F_{3,44} = 86.9863$, $p < 0.001$; kola nut $F_{3,44} = 48.02$, $p < 0.001$) components, with leaf litter contributing the highest proportion to the total litter production in the plantations (Table 1). However, the orders of the relative contributions of the various litter components to total litter production differed between litter fall and standing crop of litter in the plantations. The orders were litter fall: leaf > wood > reproductive > trash, and standing crop of litter: leaf > finest > wood > reproductive (Table 1).

Seasonality in litter production. There were significant monthly and yearly variations in litter fall (Two way ANOVA, monthly: cacao $F_{11,22} = 5.65$, $p < 0.001$; kola nut $F_{11,22} = 12.264$, $p < 0.001$; yearly $F_{1,140} = 17.4288$, $p < 0.001$) and standing crop of litter (monthly: cacao $F_{11,22} = 7.279$, $p < 0.001$; kola nut $F_{11,22} = 11.5298$, $p < 0.001$; yearly $F_{1,140} = 4.3246$, $p < 0.05$) in the two plantations (Figs. 1-4). The highest litter fall in the two plantations occurred between November and February (Figs. 1 and 2) during the dry season, while the highest amount of standing crop of litter was between January and May (Figs. 3 and 4) during peak dry season (January to March) and the onset of the rainy season (April to May). The total litter fall in the plantations during the period was 2.01-2.21 t ha^{-1} (cacao plantations) and 2.95-3.86 t ha^{-1} (kola nut plantations), representing 42.9-48.9% and 44.1-46.8% respectively of the total annual litter fall. The instantaneous standing crop of litter during the period was 46.4-47.5% in cocoa plantations and 51.2-56.3% in kola nut plantations. Litter fall and standing crop of litter subsequently decreased after the period of the highest litter fall and accumulation on the floor of the two plantations (Figs. 1-4).

Disappearance and nutrient concentration of litter. Cola nitida leaf litter had a higher decomposition rate quotient(2.00) than that of *T. cacao* (1.03) after 15 months of decomposition, when the decomposition processes of *C. nitida* stopped. After 20 months of decomposition, *T. cacao* had a decomposition rate of 2.11. The rates of weight loss of decomposing leaf litter in the two species were linear for the first seven months, after which they declined and then started rising again (Fig. 5). After 15 months of decomposition, *C. nitida* litter had lost 86.5% of its initial weight while *T. cacao* had lost only 64.1% and 87.9% after 20 months of decomposition (Fig. 5).

The quotient values of annual decomposition rate (K_L) indicate that all *C. nitida* litter fractions had a higher rate of disappearance than those of *T. cacao* except for wood (Table 2). Reproductive litter (flow-

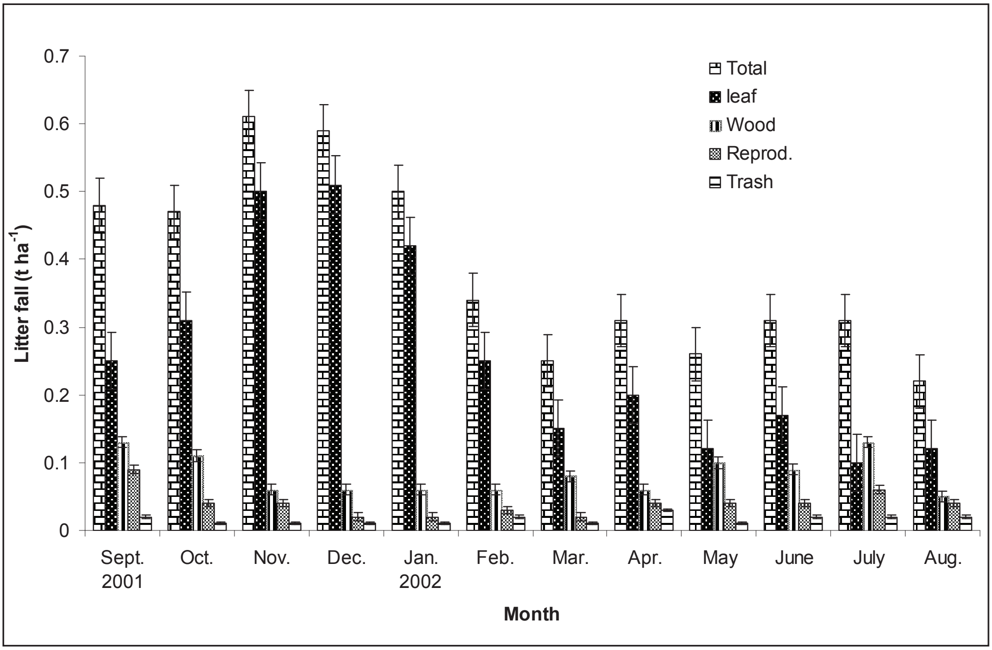

FIG. 1. Mean monthly litter fall in three cocoa plantations. Vertical lines are standard error of the means.

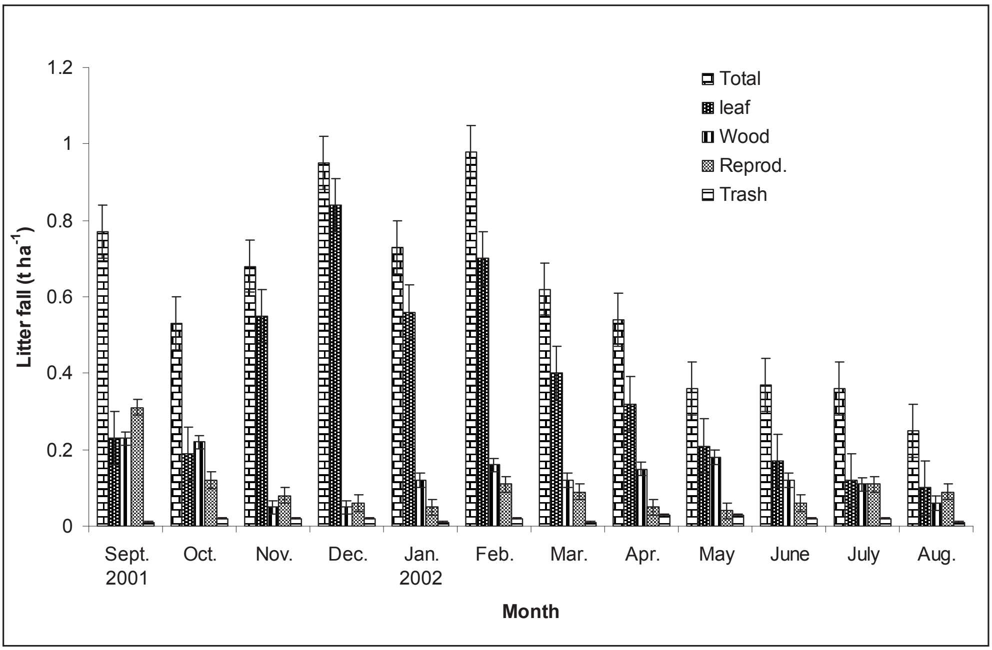

FIG. 2. Mean monthly litter fall in three kola nut plantations. Vertical lines are standard error of the means.

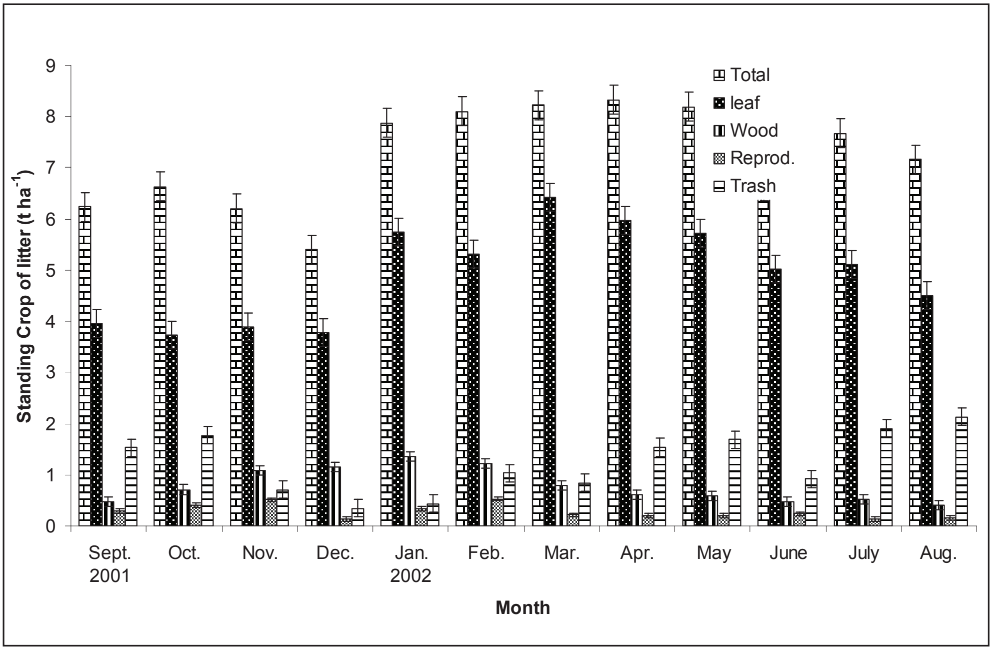

FIG. 3. Mean monthly standing crop of litter in three cocoa plantations. Vertical lines are standard error of the means.

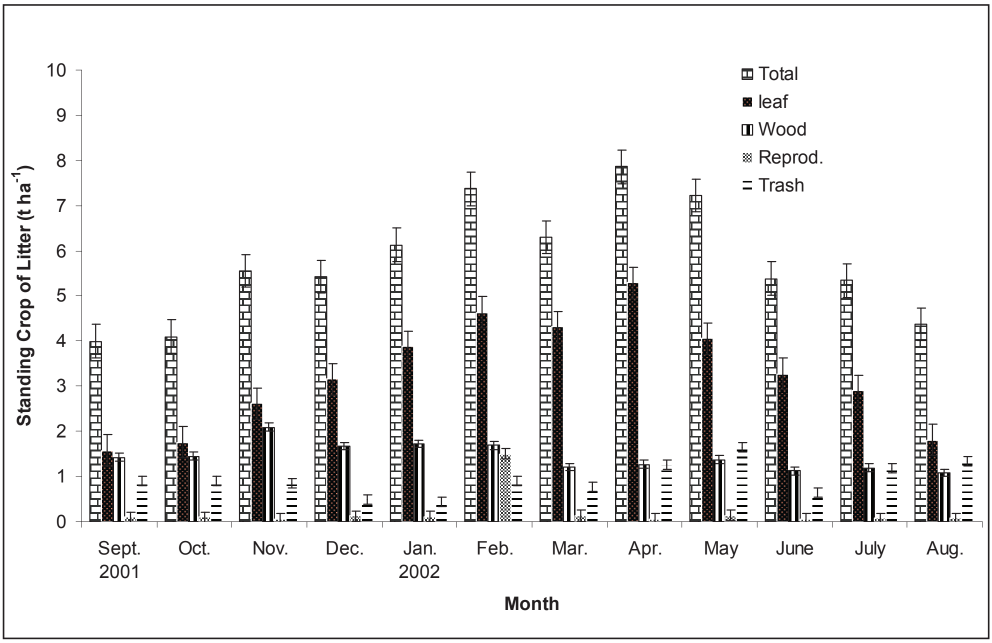

FIG. 4. Mean monthly standing crop of litter in three kola nut plantations. Vertical lines are standard error of the means.

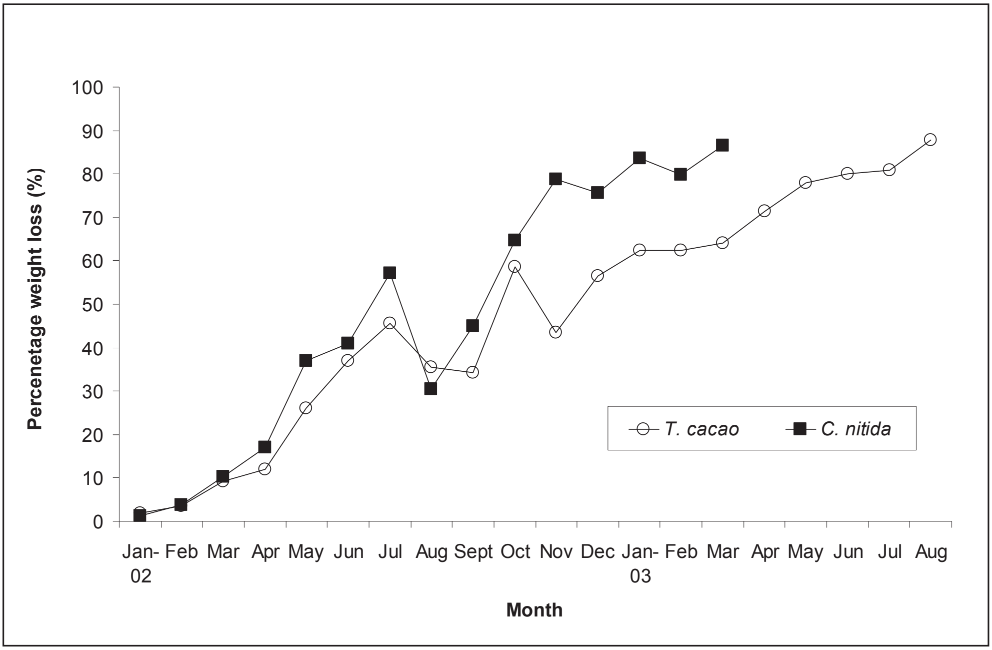

FIG. 5. Percentage loss in weight from original dry weight of decomposing leaf litter of *Theobroma cacao* (cocoa) and *Cola nitida* (kola nut) various periods in plantations.

ers, fruits, seeds) decomposed faster than all the other litter components, while finest litter/trash had the lowest decomposition rate in both plantations (Table 2).

TABLE 2. Annual decomposition quotient (K_L) for different litter components of cocoa (*Theobroma cacao*) and kola nut (*Cola nitida*) plantations. Values are mean ± standard deviation of means for three plots of each plantation.

Litter components	Annual decomposition quotient (K_L)	
	Cocoa plantation	Kola nut plantation
Leaf	0.63±0.02	1.34±0.03
Wood	1.27±0.14	1.13±0.09
Reproductive	1.64±0.26	12.74±2.21
Trash	0.13±0.02	0.23±0.02
Total	0.66±0.03	1.28±0.03

Cola nitida litter on the average had a higher nutrient concentration than *Theobroma cacao*, especially nitrogen (Table 3). Only 40% of the nutrient values (Mg, Mn, Zn, Cu) of *T. cacao* were higher than those of *C. nitida* (Table 3). Calcium concentrations in leaf litter of the species were highest, while the sulfur concentrations were the lowest among the macronutrients (Table 3). Among the micronutrients, manganese concentrations were highest while those of copper were the lowest (Table 3). The order of the concentrations of the nutrients in the leaf litter were the same, namely, Ca > K > N > P > Mg > S > Mn > Fe > Zn > Cu.

Deposition of nutrient elements on the floor of the plantations. The results of nutrient element deposition via leaf litter fall showed that higher quantities of the elements were deposited in the *C. nitida* plantation than in the *T. cacao* plantation (Table 4). Calcium was the most deposited element and copper the least. The order of deposition of the elements was the same in the tree crop plantations, namely Ca > K > N > P > Mg > S > Mn > Fe = Zn > Cu.

TABLE 3. Nutrient element composition of freshly fallen leaf litter in *Theobroma cacao* and *Cola nitida* plantations.

Plant species	Nutrient element									
	Ca	Mg	K	P	N	S	Fe	Mn	Zn	Cu
	%						ppm			
Cola nitida	1.48	0.39	1.32	0.45	0.72	0.24	50.07	101.33	37.03	7.84
Theobroma cacao	1.41	0.41	1.01	0.43	0.65	0.21	46.39	114.66	39.30	9.26

TABLE 4. Annual nutrient element fluxes (kg ha^{-1} yr^{-1}) via leaf litter fall in *Cola nitida* and *Theobroma cacao* plantations.

Plant species	Nutrient element input (kg ha^{-1} yr^{-1})									
	Ca	Mg	K	P	N	S	Fe	Mn	Zn	Cu
Cola nitida	6.50	1.71	5.80	1.98	3.16	1.05	0.02	0.04	0.02	0.003
Theobroma cacao	4.41	1.28	3.16	1.34	2.03	0.66	0.01	0.04	0.01	0.003

DISCUSSION

These perennial crop trees, cacao and kola nut, have been cultivated in plantations in the tropics for a long time, but despite the fact that they can produce considerable amounts of litter, it is not known whether litter fall per unit area in these plantations equals those of the natural forest they replaced. Also, it is necessary to establish if the quantities of nutrient elements removed by crop harvest would be replaced by the quantities deposited via litter fall. In this study, litter production in, and decomposition of two economic tree species plantations, *C. nitida* and *T. cacao*, were investigated under the same climatic conditions. Nutrient deposition via leaf litter fall was also estimated. Litter fall and decomposition in *C. nitida* plantations were higher than those of *T. cacao* plantations. However, litter standing crop is higher in *T. cacao* than in *C. nitida* plantations. This implies a higher accumulation of litter on the *T. cacao* plantation floor, which is a common sight in *T. cacao* plantations during the dry season. The total litter fall in *T. cacao* plantations (see Table 1) is comparable to the range of 5.09 to 7.63 t ha^{-1} yr^{-1} annual litter fall reported for other *T. cacao* ecosystems: Cameroon 5.09 t ha^{-1} yr^{-1} (Boyer 1973), Venezuela 7.63 t ha^{-1} yr^{-1} (Aranguren *et al.* 1982), Malaysia 5.46 t ha^{-1} yr^{-1} (Ling 1986) and Indonesia 6.2 t ha^{-1} yr^{-1} (Schwendemann *et al.* 2009). There are no litter production values in other *C. nitida* ecosystems with which to compare the results of this study. The annual litter fall in these plantations (Table 1) are lower than the range reported for a secondary rain forest in the same area of 9.9_ 12.5 t ha^{-1} yr^{-1} (Odiwe and Muoghalu 2003) and 9.3 t ha^{-1} yr^{-1} (Esan 2005). The values are also lower than the total litter fall range of 9.1-14.1 t ha^{-1} yr^{-1} reported for other West African tropical lowland rain forests (Bernhard 1970, John 1973, Songwe *et al.* 1988, 1995). The same marked seasonality in the amount of litter fall, which is the highest during the dry season and lowest during the rainy season, reported in *T. cacao* plantations in Malaysia (Ling 1986) and India (Sreekala *et al.* 2001), a secondary rain forest in our area (Odiwe and Muoghalu 2003), and other West African tropical rain forests (Hopkins 1966, John 1973, Songwe *et al.* 1988, Muoghalu *et al.* 1993a) has been recorded in these plantations. The peak of litter fall is restricted to November-January in *T. cacao* plantations and in *C. nitida* plantations. These tree crops shed their leaves under dry conditions.

The standing crop of litter has rarely been studied both in these crop plantations and in natural forest ecosystems in the West African sub-region. The standing crop of litter of 6.74- 7.64 t ha^{-1} recorded in *T. cacao* plantations and 5.03- 6.79 t ha^{-1} in *C. nitida* plantations are lower than the 8.3-9.4 t ha^{-1} reported for the nearby secondary rain forest (Odiwe & Muoghalu 2003) and 13.0 t ha^{-1} in a Ghanaian forest (John 1973), but do fall within the ranges reported for other tropical rain forests: 6.9-11.7 t ha^{-1} (Swift *et al.* 1981), 2.5-10.5 t ha^{-1} (Spain 1984), and 5.5 t ha^{-1} (Morellato 1992). There is also marked seasonality in the accumulation of litter on the floor of the plantations during the dry season (January-March) and early rainy season (April-May) (Figs. 3 and 4). The monthly fluctuations in litter standing crop observed in these plantations reflect a response to two simultaneously operating processes: transfer of fresh litter into the system and decomposition of material. The high values for January-March correspond to the maximum fresh litter fall during the period (Figs. 1 and 2) and of the strong reductions in litter decomposition rates during the dry season, resulting in an accumulation of litter on the plantation floors. The lower amounts in subsequent months are due to lower inputs of fresh litter and higher rates of decomposition of old litter during the rainy season (April-October), due to availability of the moisture needed by decomposers for the decomposition processes. Muoghalu *et al.* (1994) have reported that moisture availability is an important factor affecting litter decomposition in the tropics.

Litter fall and subsequent decomposition of litter is the main pathway for the return of nutrients to the upper soil layers, which accounts for a large part of the restoration of fertility. In this study there was variation in the rates of litter decomposition of these two species, with *C. nitida* leaf litter having a higher decomposition rate than that of *T. cacao*. Similar differences in the leaf litter decomposition rates of different species have been reported by previous workers (Madge 1965, Gosz *et al.* 1973, Ewel 1976, Muoghalu *et al.* 1994). It took 15 months to attain a decomposition rate quotient of 2.00 in *C. nitida* leaf litter and 20 months to attain a decomposition rate of 2.11 in *T. cacao* leaf litter in these plantations, while it took six months to attain a decomposition rate range of 1.01-3.84 in the leaf litter of four tree species in a secondary rain forest in the area (Muoghalu *et al.* 1994). It seems that management practices, such as widespread use of pesticides to control pests and diseases, have adversely affected the decomposition activities in these plantations, though these were not investigated in this study. Cacao production in Nigeria still depends on pesticides to attain acceptable levels of crop production (Asogwa & Dongo 2009). Cacao farmers in the area use fungicides like Perenox, Kocide, Bordeaux mixture, Funguran^{-OH}, Ridomil gold 66WP and Nordox 75WP to control black pod disease (Phytophthora palmivora) and other cacao fungi, insecticides such as Lindane, Capsitox, Diazinon, Propouxur and Basudin 600EC to control mirid and mealy bugs (carriers of cacao swollen shoot virus) as well as herbicides like Touchdown and Round-up to control weeds. It has been estimated that about 125 000 and 130 000 metric tons of pesticides are applied every year in Nigeria (Asogwa & Dongo 2009). Widespread use of pesticides has been reported to disrupt nutrient cycling by adversely affecting soil fauna and microorganisms, especially the bacteria and fungi involved in decomposition processes (Weary & Merriam 1978, Gottschalk & Shure 1979, Eijsackers & Van den Bund 1980, Kreutzwelser *et al.* 2009), thus altering normal nutrient cycling patterns in ecosystems. This depression is more pronounced in *T. cacao* plantations, where many pesticides are used to control pests and diseases, the most severe problems faced by cocoa farmers in the region. This difference in decomposition rates of tree leaf litter in secondary forest and those of the plantations could also be as a result of the differences in chemical composition of the leaf litter of the different species (see Table 3) reported to affect decomposition of litter (Singh & Gupta 1977, Berg & Staaf 1980, Meentenmeyer & Berg 1986, Muoghalu *et al.* 1993b). Litter accumulation has profound implications in nutrient cycling in the plantations. The fertility of soils under the plantations can only be maintained or sustained for fairly long periods due to the ability of the plantations to recycle nutrients back into the soil through litter fall and decomposition.

Also the decomposition quotient (K_L) values (an approximation of the proportion of the litter standing crop decomposed in one year), which are lower for all *T. cacao* litter fractions (leaf, wood, reproductive, trash) than those of *C. nitida* (Table 2), reflects the high standing crop of litter in *T. cacao* plantations. The highest values of K_L shown by the reproductive fraction (Table 2) in both plantations indicate the rapid decomposition rates of the fraction in litter layers in the plantations. The decomposition coefficient is also an indicator of functioning decomposer communities (Martius *et al.* 2004). In the *T. cacao* plantation which showed the larger litter accumulation despite a low litter fall, the decomposition processes were very slow. In contrast, in *C. nitida* plantation which had a high litter fall but low stocks, the decomposition rates were high. This implies that the decomposer communities in the *C. nitida* plantation seemed to perform better than in the *T. cacao* plantation.

The transfer of nutrient elements in ecosystems takes place via litter fall and precipitation. The amount transferred is determined by the rate of litter fall and nutrient element concentrations. Leaf litter has been used here to estimate the quantities of nutrient elements deposited on the plantations floor because it contributed 66.1% and 59.8% of annual litter fall in *T. cacao* and *C. nitida* plantations respectively. The higher quantities of the nutrients deposited on the floor of the *C. nitida* plantation is due to the higher quantities and element concentrations of *C. nitida* leaf litter than those of *T. cacao*. Most nutrients in these plantations are lost by the harvest of their pods. It has been reported that an average yield of 1000 kg ha^{-1} yr^{-1} of dry cocoa beans in Nigeria removed 38-39.8, 5.7-6.3, and 77-85.6 kg of N, P, and K respectively (Omotoso 1975, Wessel 1985), whereas the leaf litter fall in the T. cacao plantation contributed 2.03, 1.34, and 3.16 kg of N, P, and K ha^{-1} yr^{-1}. This implies that the nutrient deposition via leaf litter fall in the plantation is not enough to offset the quantities lost by harvest of cacao pods. Thus the total amounts of these nutrients deposited on *T. cacao* plantations via leaf litter fall are not enough for sustainability of *T. cacao* ecosystem for pod production.

In this study litter production and decomposition in *T. cacao* plantations were found to be lower than those of *C. nitida.* However, litter accumulation was higher in *T. cacao* plantations. Higher quantities of nutrients are deposited on *C. nitida* plantations than in *T. cacao* plantations. The quantities of nutrient elements deposited via leaf litter on *T. cacao* plantation may not sustain pod production. Leaf litter decomposition in the plantations is lower than in natural secondary rain forest in the same area which may be due to management practices in the plantations such as use of pesticides. Accumulation of litter on the floor of the plantations as a result of the decreased decomposition rates has many implications on the cycling of nutrients necessary for maintaining soil fertility. There is a need to assess the impact of management practices, especially pesticide use, on litter decomposition in these plantations.

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