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Litterfall dynamics and forest floor litter as influenced by fire in a secondary lowland rain forest in Nigeria

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Abstract: Litter fall, litter standing crop and changes in litter fall were studied in a secondary lowland rainforest at Ile-Ife (7° 29′ N, 4° 34′ E), Nigeria 14 years after a ground fire ravaged the forest. Two sample areas, one in the burnt part of the forest (burnt area) and the other in the part of the forest not affected by fire (unburnt area) were used for the study. Annual litter fall (t ha^{-1} yr^{-1}) was 12.5 (total), 8.2 (leaf), 2.8 (wood ≤3.1 cm diameter), 0.9 (reproductive parts: fruits and flowers) and 0.6 (miscellaneous) in the burnt area and 9.9 (total), 6.3 (leaf), 1.9 (wood ≤3.1 cm diameter), 1.1 (reproductive parts) and 0.6 (miscellaneous) in the unburnt area. Litter production 14 years after the ground fire (11.8 t ha^{-1} yr^{-1}) was significantly higher ($P \leq 0.001$) than that seven years after the fire (4.6 t ha^{-1} yr^{-1}). The annual litter standing crop ranged from 8.3 to 9.4 t ha^{-1} yr^{-1}. Decomposition coefficient (K_L) values of litter on the forest floor showed that reproductive materials are the most rapidly and woody material least decomposed.

Resumen: La caída de hojarasca, la cosecha en pie del mantillo y los cambios en la caída de hojarsca fueron estudiados en un bosque lluvioso secundario de tierras bajas en Ile-Ife (7° 29’ N, 4° 34’ E), Nigeria, 14 años después de que un incendio superficial destrozó el bosque. Para el estudio se usaron dos áreas de muestreo, una en la parte quemada del bosque (área quemada) y la otra en la parte del bosque que no fue afectada por el fuego (área no quemada). La caída annual de hojarasca (t ha^{-1} $año^{-1}$) fue 12.5 (total), 8.2 (hojas), 2.8 (madera <3.1 cm diámetro), 0.9 (partes reproductivas: frutos y flores) y 0.6 (varios) en el área quemada, y 9.9 (total), 6.3 (hojas), 1.9 (madera <3.1 cm diámetro), 1.1 (partes reproductivas) y 0.6 (varios) en el área no quemada. La producción de hojarasca 14 años después del incendio superficial (11.8 t ha^{-1} $año^{-1}$) fue significativamente mayor ($P < 0.001$) que la correspondiente a siete años después del incendio (4.6 t ha^{-1} $año^{-1}$). La cosecha en pie anual de mantillo varió de 8.3 a 9.4 t ha^{-1} $año^{-1}$. Los valores del coeficiente de descomposición (K_L) del mantillo en el piso del bosque mostró que los materiales reproductivos son los que se descomponen más rápidamente, mientras que la madera es el material que menos se descompone.

Resumo: A queda de folhada, a folhada na cultura em pé e as mudanças na respectiva queda foram estudadas numa floresta secundária de chuvas nas terras baixas em Ile-Ife (7° 29′ N, 4° 34′ E), na Nigéria 14 anos depois de um incêndio de solo ter devastado a floresta. Duas áreas amostra, uma na zona queimada e outra na zona não afectada pelo fogo foram estudadas. A queda anual de folhada (t ha^{-1} ano^{-1}) foi de 12,5 (total), 8,2 (folhas), 2,8 (lenho <3,1 cm de diâmetro), 0,9 (componentes do sistema reprodutivo: frutos e flores) e 0,6 (misto) nas áreas queimadas e de 9,9 (total), 6,3 (folhas), 1,9 (lenho <3,1 cm de diâmetro), 1,1 (componentes do sistema reprodutivo: frutos e flores) e 0,6 (misto) na zona não queimada. A folhada produzida 14 anos depois do fogo de solo (11,8 t ha^{-1} ano^{-1}) era significativamente maior ($P<0.001$) do que sete anos depois do fogo (4,6 t ha^{-1} ano^{-1}). A folhada anual da cultura em pé variou entre os 8,3 e os 9,4 t ha^{-1} ano^{-1} . O valor do coeficiente de decomposição (K_1) da folhada no solo florestal

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mostram que os materiais do sistema reprodutivo são os que se decompõem mais rapidamente sendo os de natureza lenhosa os mais lentos

Key words: Decomposition, fire, litter fall, litter standing crop, Nigerian secondary rainforest.

Introduction

Two cardinal processes, energy flow and nutrient cycling are essential for the functioning of an ecosystem. Litter fall is the major pathway for the return of organic matter and nutrients from aerial parts of the plant community to the soil surface and has an important bearing on soil formation and fertility (Spain 1984). Transformed litter is also the basis of many food chains in tropical forests (Fittkau & Klinge 1973), and is a principal source of energy for the saprobiota of the forest floor and soil (Spain 1984). Litter production and nutrient cycling patterns are likely to change during succession and may be affected by gap size, intensity of disturbance and age (Chandrashekera & Ramakrishnan 1994).

Of recent, fire incidents are on the increase in the tropical rain forest zones of the world especially in seasonal forests where the dry season exceeds 3-4 months (Isichei *et al.* 1986; Kinnard & O'Brien 1998; Lieighton & Wirawan 1986). Forest fires destroy organic matter especially the litter and fallen forest debris on the forest floor and often smoulder rather than burn openly. The fires serve to accelerate the process of recycling nutrients by reducing litter especially components such as woody leaf litter and dead wood which decompose slowly. In January 1983, an accidental ground fire ravaged part of the secondary lowland rainforest near the Biological Gardens of Obafemi Awolowo University, Ile-Ife. Isichei *et al.* (1986) have reported on the tree species changes in the forest immediately after the fire and Muoghalu *et al.* (1993) have reported on litter production and nutrient dynamics in the forest seven years after the fire.

With the recent proliferation of forest fires and the widespread of these fires throughout the tropical rainforest zones of the world, it is necessary to understand litter production dynamics of tropical forest undergoing succession after it has been disturbed by fire. This study examines litter production dynamics in Nigerian tropical forest 14 years after a ground fire and the differences in litter fall quantity and litter standing crop in a burnt area of the forest relative to an unburnt area.

Materials and methods

Study area

The study was carried out in sample plots established in a secondary lowland rainforest at Ile-Ife (7°29′ N, 4°34′ E), Nigeria. The vegetation has been described as lowland rainforest or semi - deciduous moist forest zone (Onochie 1979) and as Guineo-Congolian rain forest of drier type (White 1983). The forest has a dense canopy close to the ground that casts shade too intense for many herbs to grow well in it. Through this canopy project relict trees, which were not removed in the initial clearance operation, their crowns quite clearly distinct from the vegetation below. In the more uniformly taller area of the secondary forest, this space between the canopy formed by the younger trees and shrubs and the older plants is less distinct. In this, there is a fairly readily recognizable space between the canopy formed by the younger trees and shrubs and the layer of herbs. Climbers and scramblers are abundant but in area with older secondary forest there is a gradual reduction in the abundance of scramblers and a corresponding increase in the abundance of climbers. Epiphytes are not very prominent but occur where their spores or seeds reach positions in the canopy where conditions are favourable for their development. The common trees of the forest are Albizia spp. (*A. adianthifolia; A. glaberrima; A. zygia*), *Alstonia boonei, Baphia nitida, Blighia sapida, Bosqueia angolensis, Celtis zenkeri, Funtumia elastica, Manihot glaziovii, Millettia thonningii, Ricinodendron heudelotii* and *Sterculia tragacantha* and the common shrubs are *Alchornia laxiflora, Carpolobia lutea, Ficus* spp. *Lecaniodiscus cupanioides* and *Microdesmis puberula*. Trees which are sometimes present as relicts from earlier plant communities are *Bombax buonopozense, Ceiba pentandra, Elaeis guineensis, Milicia excelsa* and *Triplochiton scleroxylon*. The trees shed their leaves throughout the year but shed most of them during the dry season, November – March, bring out new leaves (flush) with the onset of rain in March/April and attain full canopy leafiness between June and September. The deciduous species (*Bombax buonopozense, Ceiba pentandra, Manihot glaziovii, Ricinodendron heudelotii* and *Sterculia tragacantha* etc.) completely shed all their leaves remaining leafless for a period during the dry season.

There is a short dry season from November to March, and a rainy season from March to October. The mean annual rainfall in Ile-Ife is 1413 mm (Duncan 1974) and shows two peaks, one in May – June and the other in September – October. The number of rain-days is highest in the months when most rain falls while the amount of rain falling in a single day is very variable throughout the year. The rainfall and minimum and maximum temperatures during the study period are shown in Fig. 1. The mean annual minimum and maximum temperatures are 22.5 °C and 31.4 °C respectively. The soils are derived from parent material composed mainly of granitic metamorphosed sedimentary rock (Hall 1969).

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 which is mainly Kaolinite and hence are characterized by low cation exchange capacity and low water holding capacity (Ayodele 1986).

Botanical nomenclature is according to Hutchinson & Dalziel (1954-72).

Litterfall collection

Two sample areas, each of 50 m x 50 m were selected in the area. The first was in the area of the forest affected by a ground fire as defined by Isichei *et al.* (1986) which has been used for litter fall studies in 1990 (Muoghalu *et al.* 1993). The other sampling area was in the area not affected by the fire established during this study. These areas will further be referred to as burnt and unburnt areas, respectively. Litter fall and standing crop of litter were estimated in both areas.

In each area, twenty 1 m x 1 m x 30 cm litter traps 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 1 June 1997 to 31 May 1998. The collected litter was sorted into (i) leaf (ii) wood (<3.1 cm diameter), (ii) reproductive parts: flowers and fruits and (iv) miscellaneous (any material passing through 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.

The litter standing crop was sampled at monthly intervals for one year, from June 1997 to May 1998. On each occasion ten 50 cm x 50 cm wooden quadrat were randomly laid on the ground in each plot. The standing crop of litter within the quadrat was collected and sorted into (i) leaf (ii) wood (≤ 3.1 cm diameter) (iii) reproductive parts and (iv) miscellaneous. Miscellaneous was probably overestimated because it could not be distinguished from fractions of soil organic matter. 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 sampling collection sites to estimate 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.

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 part, wood and miscellaneous litter.

One-way analysis of variance was used to compare litter fall data in the burnt area between 1990 (seven years after the fire) and 1997 – 1998 (14 years after the ground fire), litter fall and standing crop of litter data within the same period of reference (14 years) between burnt and unburnt area for significant differences. Two – way analysis of variance was used to test for significant monthly variation (first factor) and difference among litter fractions (second factor) for litter fall and standing crop of litter in the plots.

Results

Litter fall

The annual litter fall (t ha^{-1} yr^{-1}) was 12.45 (total), 8.15 (leaf), 2.78 (wood), 0.89 (reproductive parts: fruits and flowers) and 0.64 miscellaneous

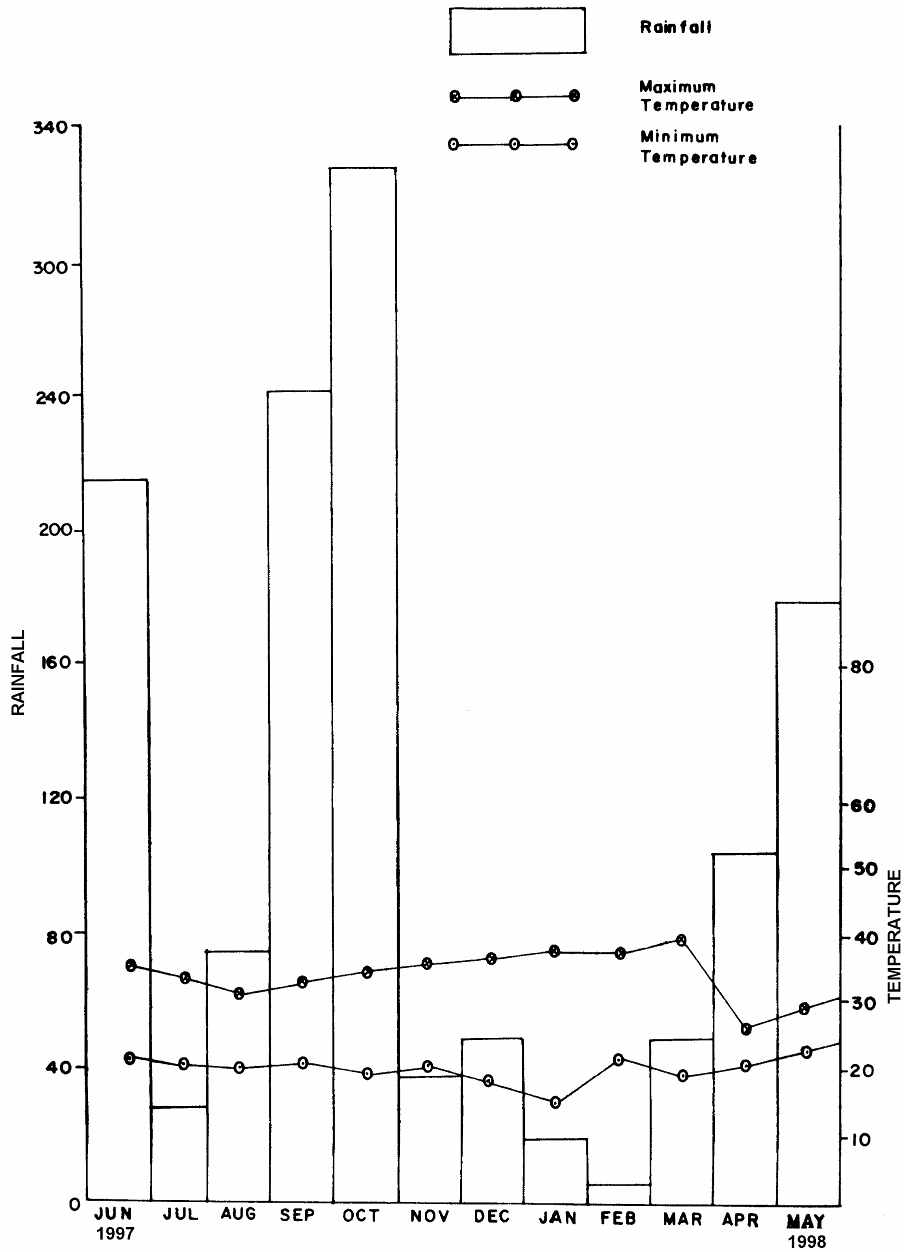

Fig. 1. Monthly rainfall and temperature (maximum and minimum) for Ile-Ife during the study period.

in the burnt area and 9.90 (total), 6.30 (leaf), 1.94 (wood ≤ 3.1 cm diameter), 1.07 (reproductive parts: fruits and flowers) and 0.58 miscellaneous in the unburnt area. The litter production in the burnt area was significantly higher than that in the unburnt area ($P \leq 0.01$ for and leaf litters, and ($P \leq 0.05$) for wood litter). There was no significant difference in reproductive parts and miscellaneous litter fall between both areas. The relative contribution of the various litter components to total litter production showed that for both areas leaf litter contributed the highest proportion (63.6 to 65.6%) followed by wood, reproductive and miscellaneous respectively. The reproductive parts and miscellaneous made only a small contribution to total litter fall (Table 1).

Table 1. Contribution of various litter components to total litter production in secondary lowland rainforest at Ile-Ife, Nigeria 14 years after a ground fire; values within parenthesis show % total.

Litter components	Litter fall			Litter standing crop	
	Burnt area		Unburnt area	Burnt area	Unburnt area
	Jan 1990 – Dec 1990	Jun 1997 – May 1998	Jun 1997 – May 1998	Jun 1997 – May 1998	Jun 1997 – May 1998
Leaf (t ha^{-1} yr^{-1})	4.2 (91.3)	8.2 (65.6)	6.3 (63.6)	4.0 (42.6)	3.6 (43.4)
Wood (t ha^{-1} yr^{-1})	0.3 (6.5)	2.8 (22.4)	1.9 (19.2)	3.9 (41.5)	2.9 (34.9)
Reproductive parts (t ha^{-1} yr^{-1})	0.1 (2.2)	0.9 (7.2)	1.1 (11.1)	0.2 (2.1)	0.4 (4.8)
Miscellaneous (t ha^{-1} yr^{-1})	–	0.6 (4.8)	0.6 (6.1)	1.3 (13.8)	1.4 (16.9)
Annual total (t ha^{-1} yr^{-1})	4.6	12.5	9.9	9.4	8.3

Fig. 2 shows the seasonal pattern of litter fall in the burnt and unburnt areas. The total litter fall ($P \leq 0.01$), leaf litter fall ($P \leq 0.001$) and miscellaneous litter fall ($P \leq 0.01$) showed significant monthly variation in both areas. The highest total and leaf litter fall occurred between December 1997 and March 1998 (dry season). The total leaf litter fall during this period was 2.9 (unburnt area) to 3.9 t ha^{-1} (burnt area) which are 46 to 48% respectively, of the annual leaf litter in the areas. The total litter fall in the areas for the 4 month period (December to March) was 3.9 t ha^{-1} (unburnt area) and 5.2 t ha^{-1} (burnt area), representing 39.8 to 42.0% respectively of the total annual litter fall. The period of heavy miscellaneous litter fall is not as restricted as for total and leaf litter. It occurred mainly in July, November and December in both areas. Though wood litter fall did not show significant monthly variation, its highest value (1.9 t ha^{-1}) (68%) in burnt area; 1.3 t ha^{-1} (68.5%) in burnt area) occurred mainly during the heavy rain months (April – October), which corresponded to the period of minimum leaf litter fall.

Changes in litter production between 7 and 14 years after the ground fire

To evaluate low litter production varied in relation to the time elapsed since the fire, litter fall data collected in 1990, seven years after the fire, study was compared with those of this study for the same burnt area. Because miscellaneous litter fall component was not determined in 1990, only the litter components determined then were used for the comparison. To ensure that data are comparable, the sampling area for the burnt part of the forest, selected in the present study was the same as the one used in the 1990 study. The litter fall collection methods were identical (frequency, number and type of litter traps and locations). Litter production in 1997 to 1998, 14 years after the fire (11.8 t ha^{-1} yr^{-1}) was significantly higher ($P \leq 0.001$) than that of 1990, seven years after the fire (4.6 t ha^{-1} yr^{-1}). There were also changes in the relative contributions of the different litter fall components to the total litter fall at the different periods. Percentage leaf litter decreased from 91.3% in 1990 to 65.6% in 1997 – 1998 while those of wood and reproductive litter increased.

Litter standing crop

There was no significant difference between the total, leaf and miscellaneous litter standing crop in burnt and unburnt area. However, the wood litter standing crop was sigificantly higher ($P \leq 0.01$) in the burnt area. The mean reproductive litter standing crop was significantly higher ($P \leq 0.05$) in the burnt area. The contribution of the various litter standing crop components to the total shows that there was no marked difference between the leaf litter and the wood litter, contrary to the case for litter fall, both fractions dominating the litter standing crop. The two fractions tended to contribute equal proportions to the total litter standing crop. Of note also is the higher contribution of miscellaneous fraction than reproductive material to total litter standing crop as against the reserve trend in litter fall. This is probably a result of inability to distinguish miscellaneous from soil

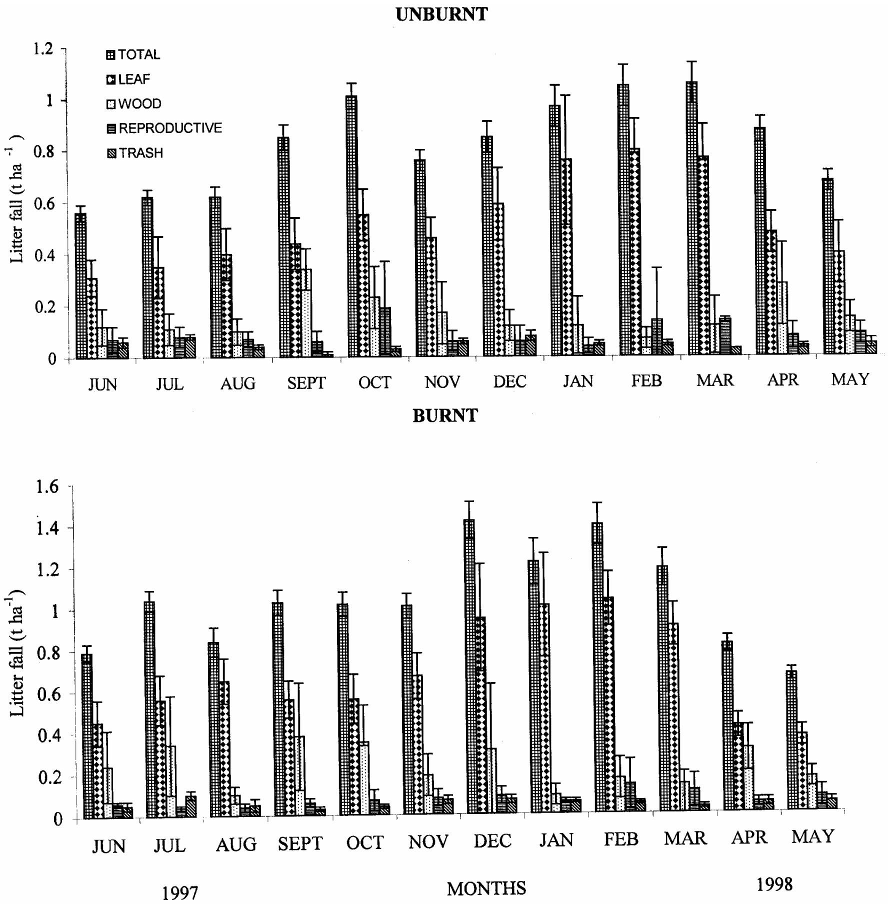

Fig. 2. Seasonal pattern of litterfall in unburnt and burnt plots in Nigeria Secondary Lowland Rainforest 14 years after a ground fire. The vertical bars indicate 95% confidence intervals.

organic matter and rapid disappearance of reproductive litter standing crop.

Fig. 3 shows the marked seasonality in the accumulation of litter standing crop. The highest monthly accumulation occurred from December to March (dry season) and April (beginning of the rainy season). The accumulation started decreasing from May (early rainy season month) and was lowest from July to October – the peak of the rainy season.

Disappearance of litter on forest floor

The index of annual decomposition rates (K_L) values for the various fractions of litter indicate higher decomposition rates for litter fractions (Total 1.3, leaf 2.1, wood 0.7, reproductive 4.5, miscellaneous 0.5) in the burnt than in the unburnt area (total 1.2, leaf 1.8, wood 0.7, reproductive 2.8, miscellaneous 0.4) with the exception of wood litter. Reproductive fraction has the highest rate while wood fraction has the lowest rate.

Discussion

The total litter fall and the percentage contribution of the different litter fractions (leaf, wood, reproductive), obtained in this study fall within the range reported for other west African tropical lowland rain forests (Bernhard 1970; John 1973; Songwe *et al.* 1988, 1995; total litter fall 9.1 – 14.1 t ha^{-1} yr^{-1}, leaf 61 – 81%, wood 10 – 38%, reproductive 4 – 12%). There is very little data on miscellaneous fraction of litter fall in the subregion with the exception of that reported by John (1973). The miscellaneous contribution of this study (5 – 6% of the total litter fall) is lower than values reported

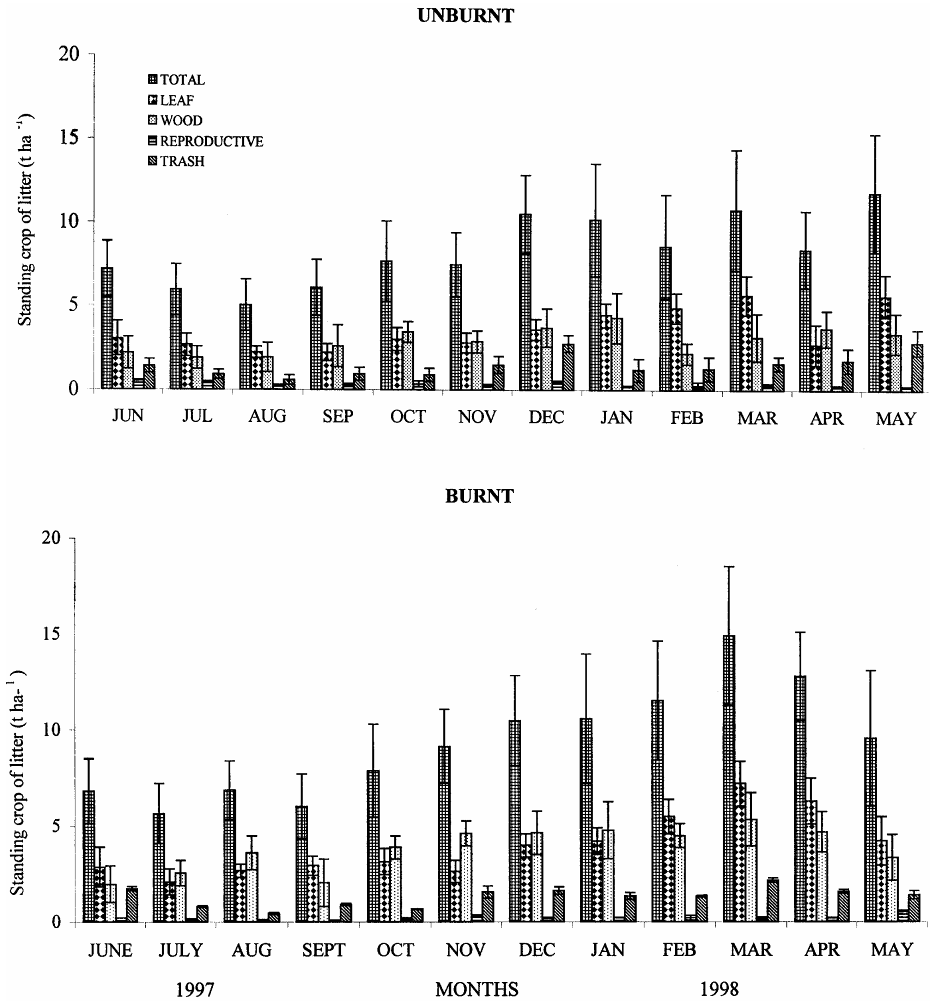

Fig. 3. Seasonal pattern of litter standing crop in unburnt and burnt plots in Nigeria Secondary Lowland Rainforest 14 years after a ground fire. The vertical bars indicate 95% confidence intervals.

for a Ghanaian forest (John 1973) (9%); a Sarawak lowland rainforest (Proctor *et al.* 1983) (11 – 24%) and Bornean rainforest (Burghouts *et al.* 1998) (6 – 10%). The strong seasonality in the amount of litter fall, which is the highest amount during the dry season and lowest amount during the rain season has been reported for West African tropical rain forest (Hopkins 1966; John 1973; Songwe *et al.* 1988; Muoghalu *et al.* 1993). Leaf litter fall is responsible for this because no other litter fraction showed significant monthly variation in litter fall in this study. Water stress and the deciduous habit of many tree species in this forest are probably responsible for the peak litter fall during the dry season (November – March) because there is little or no rainfall at that time and a low humidity. Therefore, the high evapotranspiration exceeds rainfall leading to water stress. Many deciduous species (*Bombax buonopozense, Ceiba pentandra, Celtis zenkeri, Cola millenii, Holarrhena floribunda, Ricinodendron heudelotii, Manihot glaziovii*) which occur in the forest shed their leaves between December and March. They bring out new leaves (flush) with the onset of rain in March/April and attain full canopy leafiness between June and September. Some species, such as *Ricinodendron heudelotii* and *Bombax buonopozense*, are completely leafless by December. The high wood litter fall recorded in this forest during the rainy season is due probably to the absorption of water by dead branches on the trees which increases their weight and their subsequent abscission and removal from crowns of trees by the force of the strong winds which accompany rains during this period. The strong winds seem to play a very prominent role in this regard because of the double peak of wood litter fall at the onset (April) and end (October) of the rainy season when these winds are strongest. Similar observations have been reported for a Ghanaian forest (John 1973) and for this forest (Muoghalu *et al.* 1993). The general trend in leaf, wood and reproductive litter fall has been reported by Swift *et al.* (1981) in a regenerating bush-fallow in Nigeria.

The significant higher litter fall in the forest 14 years (this study) after the ground fire compared to 7 years and the changes in litter fraction contribution to the total litter fall agrees with the assertion of Chandrashekera & Ramakrishnan (1994) that litter production and nutrient cycling patterns are likely to change during succession and may be affected by gap size, intensity of disturbance and age. The changes in the proportional contribution of the different litter fractions to total litter fall is due to the increased age of the forest with higher wood biomass production and more plants attaining flowering stage resulting in higher wood and flower litter fall 14 years later. There is also the death of some of the pioneer tree species (especially *Manihot glaziovii*).

There are few reports on litter standing crop in tropical rainforests. The litter standing crop of 8.3 to 9.4 t ha^{-1} recorded in this study fall within the ranges reported for other tropical rain forests (13.0 t ha^{-1}) (John 1973), 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). Also, the percentage contribution by various litter standing crop fractions (leaf, wood, reproductive) to the total falls within the range reported for an Australian forest (Spain 1984; leaf 37 – 46%, wood 40 – 45%, reproductive 1.5 – 3%).

There is a relationship between seasonal variations in litter standing crop with the seasonality of litter fall and the nature of climate in the forest. During the dry season (November – March) the highest monthly litter fall coincided with the maximum monthly accumulation of litter standing crop in the plots. This is a consequence of the high litter fall and of the moderate to strong reductions of the litter decomposition rates during this season, resulting in an accumulation of litter on the forest floor.

The litter decomposition coefficient (K_L) values (total 1.2 – 1.3; leaf 1.8 – 2.1; wood 0.7; reproductive parts 2.8 – 4.5; miscellaneous 0.4 – 0.5), an approximation of the proportion of the litter standing crop decomposed in one year are within those reported for other tropical forests: Sarawak forests, 1.3 – 1.7 (Anderson *et al.* 1983), lowland forests in the neotropics, 1.1 – 1.7 (cited by Anderson *et al.* 1983), more seasonal lowland forests of West Africa, 2.0 – 3.2 (John 1973; Laudelout & Meyer 1954; Madge 1965), and a montane forest in New Guinea, 1.0 – 1.4 (Edwards 1977), and a regenerating bush – fallow in Nigeria, 0.64 to 1.29 (Swift *et al.* 1981). In a mature forest, the mean annual standing crop of litter may be expected to be relatively constant from year to year and hence the amount lost by decomposition should equal the annual litter fall (Swift *et al.* 1981). Under these circumstances, K_L could be a useful ecosystem constant to characterize the successional status of a forest. From the K_L values obtained for this forest, it is obvious that it has not reached such an equilibrium, thus resulting in an accumulation of the litter standing crop. The highest decomposition rate of reproductive litter is probably due to its high nutrient content and the lowest rate of wood litter is due to its low nutrient content and high lignin content making it unattractive to decomposers and resistant to decomposition.

Tropical forest fires now appear to be a widespread pantropical phenomenon in many lowland rain forest areas that were previously considered to be immune to fires. Forests previously affected by ground fire are thus likely to burn again because of climate-induced changes provided that ignition sources continue to become available at the end of severe dry seasons. The results of this study indicate an increased litter production 14 years after a fire in a secondary forest compared to a mature forest, implying a probable higher nutrient return via litterfall during secondary succession.

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