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DECOMPOSITION, NUTRIENT RELEASE PATTERNS AND NUTRIENT FLUXES FROM LEAF LITTER OF SECONDARY FORESTS IN GHANA

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Abstract

Studies were conducted on leaf litter fall, decomposition, nutrient release patterns and nutrient fluxes of Akyaakrom (AS) and Dopiri (DS) secondary forest leaf litter in Dwinyama watershed. Leaf litter production were 9.1 and 6.8 t ha^{-1} y^{-1} in AS and 8.9 and 6.5 t ha^{-1} y^{-1} in DS in the 1st (September 1998-August 1999) and 2nd (September 1999-August 2000) years, respectively. Mean annual leaf litter production were 7.9 t ha^{-1} in AS and 7.7 t ha^{-1} in DS. Leaf litter fall was higher in the drier months (December-April) and lower in rainy months (June-September) in each year. Decomposition pattern of leaf litter did not show clear relation to the monthly rainfall. The leaf litter of *Griffornia simplicifolia* (legume) in AS showed rapid decomposition, and was decomposed by more than 90 per cent of its dry mass within 6 months of exposure on the soil surface. In DS, another leguminous tree species, *Albizia zygia,* showed slower decomposition than *G. simplicifolia. Albizia zygia* had a higher concentration of total extractable phenols (TEPH) than did *G. simplicifolia*. Mean annual N fluxes from the decomposed leaf litter to the soil were estimated as 170 and 226 kg ha^{-1} in AS and DS, respectively; and mean annual P fluxes were 5.3 and 5.2 kg ha^{-1} in AS and DS, respectively. Annual fluxes of K were 40 and 12 kg ha^{-1}. Annual fluxes of Ca were 114 and 142 kg ha^{-1} in AS and DS, whilst Mg were 18 and 39 kg ha^{-1}, respectively. The peak monthly fluxes of all the nutrients were mostly observed during March to June, overlapping with the rainy season. Monthly fluctuations of N fluxes were more pronounced. Nutrient imbalances of P and Ca fluxes from decomposed leaf litter in the forests suggested their scarcities. Temporal N starvation in May in AS, pronounced

Résumé

Owusu-Sekyere, E., Cobbina, J., Masunaga, T. & Wakatsuki, T.: *Décompositon, schéma de relâchement de substance nutritive et flux nutritives des litières de feuille des forêts secondaires au Ghana.* Les études sur la chute litière de feuille, la décomposition, le schéma de relâchement de substance nutritive et le flux nutritive des litières de feuille des forêts secondaires d'Akyaakrom (AS) et de Dopiri (DS) sur la ligne de partage des eaux de Dwinyama étaint faites. Les productions litières de feuille étaient 9.1 et 6.8 t ha^{-1} y^{-1} à AS et 8.9 et 6.5 t ha^{-1} y^{-1} à DS respectivement en première année (septembre 1998 - août 1999) et en seconde (septembre 1999 - août 2000). Les productions annuaires moyennes de la litière de feuille étaient 7.9 t ha^{-1} à AS et 7.7 t ha^{-1} à DS. La chute de litiere de feuille était plus élevée aux mois plus sècs (decembre à avril) et plus faible aux mois pluvieux (juin à septembre) de chaque année. Les schémas de décomposition de litière de feuille n'ont pas montré de rapport claire à la pluie mensuelle. La litiére de feuille de *Griffornia simplicifolia* (légumineuse) à AS montrait une décomposition très rapide et était décomposée de sa masse sèche par plus que 90 pour cent en 6 mois de son exposition à la surface du sol. A DS, une autre espèce d'arbre légumineux *Albizia zygia* montrait une décomposition plus lente que celle de *G. simplicifolia. Albizia zygia* avait une concentration plus élevée de la totalité de phénols extractibles (TOPE) que *G. simplicifolia*. Les flux annuels moyens d'azote (A) de la litière de feuille décomposée au sol étaient estimés comme 170 et 226 kg ha^{-1} respectivement à AS et DS et le phosphore (P) étaient 5.3 et 5.2 kg ha^{-1} respectivement à AS et DS. Les flux annuels de potassium (K) étaient 40 et 12 kg ha^{-1}. Les flux annuels de calcium fluctuation of N fluxes and nutrient imbalances may indicate the degradation of the ecosystems of the two forests.

(Ca) étaient 114 et 142 kg ha^{-1} à AS et DS alors que ceux de Magnésium (Mg) étaient 18 et 39 kg ha^{-1} respectivement à AS et DS. Les flux mensuels maxima de toutes les substances nutritives étaient souvent observés de mars à juin de se chevaucher avec la saison des pluies. Les flux mensuels d' A étaient plus marqués. Les déséquilibres des substances nutritives de flux de P et Ca de la litière de feuille décomposée dans les forêts suggéraient leurs raretés. L'inanition temporelle d' A en mai à As, les flux marqués d' A et les déséquilibres de substances nutritives pourraient indiquer la dégradation des écosystèmes des deux forêts.

Introduction

The most predominant farming system practised in Ghana has been slash-and-burn in which forest vegetation is destroyed before farms are established. In the decades before the 1970s, fallow periods were 4 to 10 years. Because of rapid population growth in recent years, this period has reduced and, in extreme cases, it is less than 3 years. This has impoverished the arable land to support agriculture. As such, many reconstituting forests (secondary) exist. Various land-use types such as traditional rice cultivation in lowland (Wakatsuki *et al.*, 2001), cocoa plantations, and mixed cropping in the lowland to upland fringe transitional area characterize the agro-ecological zone of Ghana, while secondary forest and fallow vegetation are in the upland areas of the inland valley watersheds.

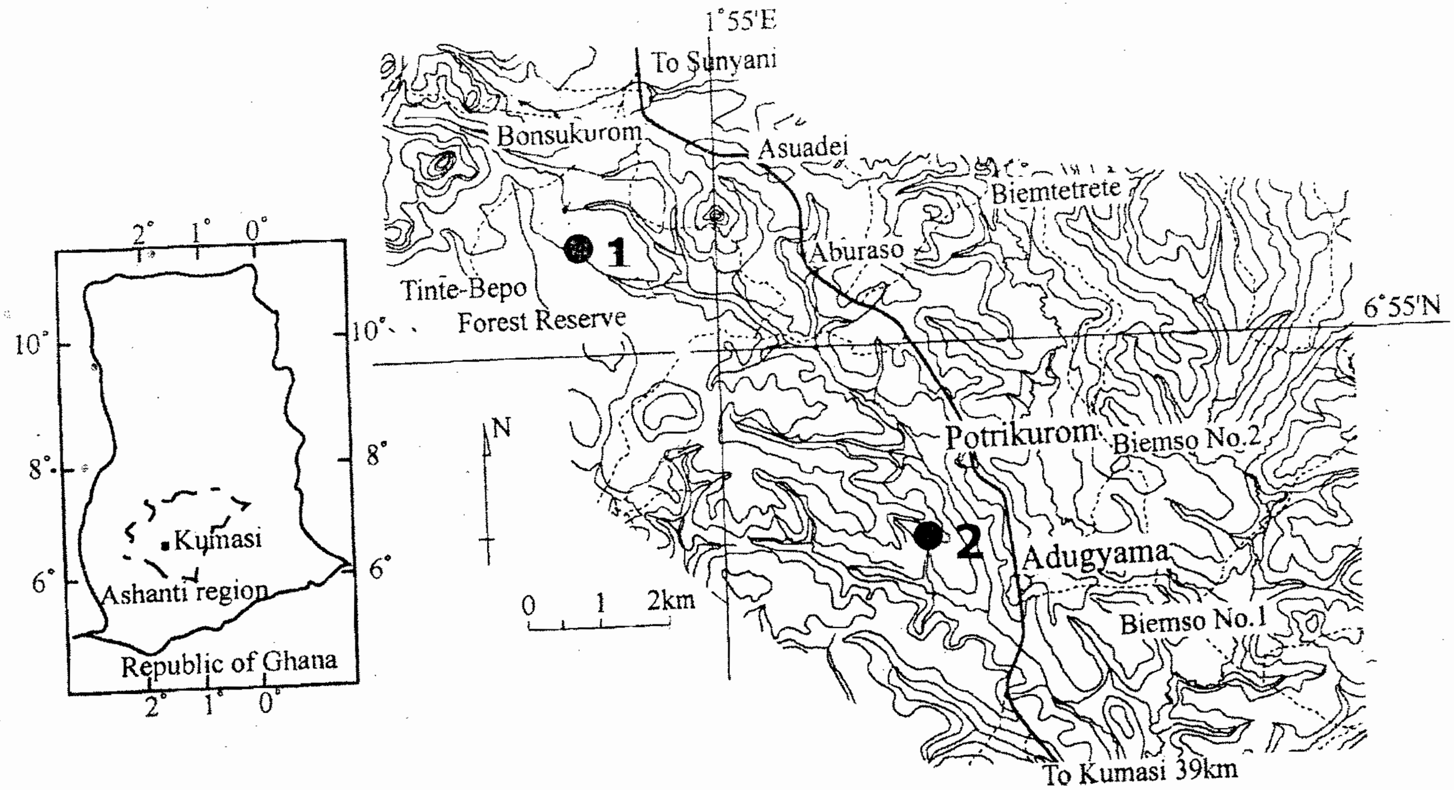
It is unusual to find fallow lands over 20 years old. If they exist, it is likely the "matured" secondary forest vegetation at different locations will differ in how they influence the soils for any cropping system. Each land use depends on material re-cycling through litter fall, decomposition, nutrient mineralization (Swift, Heal & Anderson, 1979), and the subsequent absorption of dissolved nutrients by plant species. Most nutrients are lost from the ecosystem through erosion and leaching (lateral and vertical) of the upland soil (Radulovich & Sollins, 1991).

During high water or floods, mineral nutrients (in suspension and dissolved) contained in sediments and organic material flow from up-slope sources and are recaptured in lowland areas (Frangi & Lugo, 1985). It is, therefore, necessary to investigate, assess and estimate nutrient status of decomposing leaf litter that is incorporated into the soil through mineralization.

Experimental

The study area

Two secondary forests, Akyaakrom and Dopiri both on the same latitudes (6° 33' N and 7° 03' N) and longitudes (1° 55 and 2° 06 W) but 7 km apart and in the same watershed, were selected for this study (Fig. 1). The Akyaakrom secondary forest (28 years old) covers 30 ha with mean elevation of 200 m above mean sea level and has a mean slope of 5°. The dominant tree species is *Griffornia simplicifolia* (Atoto). The Akyaakrom secondary forest is the result of fallow from a previously established cacoa farm plantation. Mixed food cropping system with traditional crops such as plantain, cocoyam, maize, yam and vegetables were planted together with *Theobroma cacao* (cocoa) trees. Except in gaps, food cropping was discontinued after the 4th year for the cocoa trees to take over the whole area. The cacoa plantation was abandoned after 15 years of existence and the resultant vegetation is the 28-year-old fallow.



● 1. Akyaakrom secondary forest. ● 2. Dopiri secondary forest.

Fig. 1. The location of Akyaakrom (AS) and Dopiri (DS) secondary forests in Dwinyama Watershed.

The Dopiri secondary forest (27 years old) covers 20 ha. Its mean elevation is 300 m above mean sea level and has a mean slope of 9°. The dominant tree species is *Albizia zygia* (Okro). The Dopiri secondary forest was put under only mixed food crop farms until soil fertility declined. The food crops grown in the forest were cassava, plantain, cocoyam, yam and variety of vegetables. Such cropping system and pattern continued until the area was abandoned and allowed to fallow for the past 27 years.

The forests consist of two layers. The dominant tree species occupy the upper layer (10-20 m) whilst the lower layer (1-5 m) consists of tree saplings in both forests. Shrubs, herbaceous plants, and litter materials occupy the ground layer. The soils in the Akyaakrom and Dopiri secondary forests belong to the ferric lixisol of Bekwai and Nzima series, respectively. The *p*H is slightly acidic, ranging from 5 to 7 (Wakatsuki *et al.*, 2001).

The two reconstituting secondary forests had been and still are under human disturbances of varying intensities. Timber tree species are harvested from Akyaakrom whilst firewood gathering and wild yam harvesting occur in Dopiri. The Akyaakrom forest is 11 km whilst the Dopiri forest is 4 km from human settlement (Fig. 1). The rainfall distribution patterns for the Akyaakrom and Dopiri secondary forests were recorded using the open-pan method set up in the field from September 1998 through to August 2000. Air and soil temperatures were recorded using wet and dry-bulb and soil thermometers, respectively. Relative humidity and soil moisture were recorded using humigraph and Theta meter probe (HHI), respectively, during the decomposition study period (September 1998 to August 1999).

Litter fall collection

Three plots each of size 25 m × 25 m were demarcated in each of the secondary forests. Within each plot, three litter traps were erected at random locations to collect falling litter from September 1997 to August 2000 (3 years); that is, nine litter traps were installed at each site. Each litter trap was as described by Owusu-Sekyere *et al.* (2003) to collect litter. The fallen litter in each trap was collected every 14 days and the leaf portion was sorted out from the total litter trapped. The collected leaf litters were oven-dried at 60 °C for 72 h and weighed to determine the quantity of leaf litter fall. During the 1st year (September 1997 to August 1998), the leaf litter collected was dried, stored in a cool dry place and used for further studies.

Field experiment on leaf litter decomposition

Two sets of observations were made on decomposition and changes in nutrients released from the fallen leaves. The leaf litter of *Griffornia simplicifolia* (Caesalpiniaceae) (AG) and mixed species in leaf litter fall (AM) in the Akyaakrom secondary forest, and of *Albizia zygia* (Mimosaceae) (DA) and mixed species in leaf litter fall (DM) in the Dopiri secondary forest were gathered into separate piles and were each subjected to decomposition study. The single species in leaf litter fall (AG and DA) represented more than 50 per cent of the total leaf litter trapped at its respective site. Each of the mixed species in leaf litter contained all trapped leaves at the respective sites in the proportion in which each was collected. The 1st year's (September 1997 to August 1998) leaf litter collected was used for the decomposition study.

Square decomposition boxes (Owusu-Sekyere *et al.*, 2003) were used, and 10 g of each treatment comprising leaf litter type were enclosed in the boxes and planted in the field at the end of September 1998. The treatments were AG, AM, DA and DM. Each treatment had 36 boxes (three replications for each treatment) during the study period. The ground was cleared of previously fallen litter so that the decomposition boxes could directly contact the forest soil. The decomposition boxes were randomly placed in each site. For each treatment, three boxes were sampled every 28 days beginning in October

1998. The sampled boxes and the contents were taken to the laboratory. The partially decomposed leaf litters were separated from the soil particles, plant roots and other materials, oven-dried at 60 °C for 72 h to prevent further decomposition, stored and used for nutrient analyses.

Sample and data analyses

The residual leaf litter samples for each treatment in the boxes collected periodically were pooled together, and milled using vibrating mixer mill (MRK-Retsch Mitamura Rikon Kogyo). The concentrations of nitrogen (N) were determined by dry combustion (Sumitomo Chemical, Sumigraph High sensitive N-C (90A) Analyzer); and phosphorus (P), calcium (Ca), and magnesium (Mg) by the Inductively Coupled Plasma Spectrometer (ICPS-2000, Shimadzu Co., Kyoto, Japan) after digesting in HNO_3 (wet oxidation in Teflon containers in the oven at 150 °C for 3 h). The Atomic Absorption Spectrometry (AAS, Hitachi 170-70, Japan) was used to determine potassium (K), and the Makkar & Goodchild (1996) method for total extractable phenols (TEPH). Nutrient release patterns and nutrient fluxes (kg ha^{-1} month^{-1}) from leaf litter types in the two forests were calculated from the differences in the residual nutrient contents at each month and annual fluxes were estimated. The data gathered were analyzed using the StatView and SAS software.

Results and discussion

Leaf litter fall

Fig. 2a shows monthly production of leaf litter and rainfall distribution patterns recorded within the 2-year study period (September 1998 to August 2000) in the Akyaakrom secondary forest (AS). During the 1st year (September 1998 to August 1999) and in the dry months (November-February), appreciable quantity of rainfall was recorded (19 %). Within the same period, leaf litter fall constituted 45 per cent of the annual total production. However, within 2 months before the

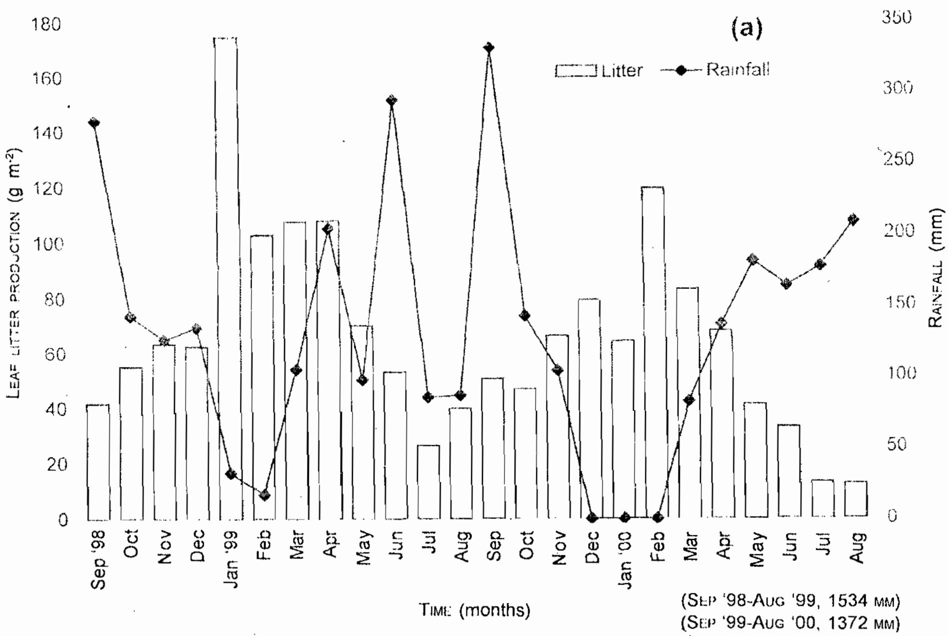


Fig. 2a. Monthly leaf litter production (g m^{-2}) and rainfall (mm) pattern in the Akyaakrom secondary forest (AS) in Dwinyama Watershed.

major rainy season (February and March) and after the minor rainy season (November and December), leaf litter falls were recorded as 210 and 126.1 g m^{-2}, representing 35 and 14 per cent, respectively, of the annual production. Leaf litter fall was highest in January (175 g m^{-2}) whilst rainfall was least in February (17.2 mm). For 4 months (January to April) within the 12 months' period, leaf litter fall were high and accounted for 54 per cent of the annual leaf fall whilst rainfall was 22 per cent in the same period.

In the 2nd year, September 1999 to August 2000, no rain fell in December (1999), January and February 2000 (0 mm) (Fig. 2a). The highest rainfall was recorded in September 1999 (331.8 mm). Within the driest months (December-February), leaf litter production was 39 per cent of the annual production. Similarly, leaf litter fall for 2 months after the minor rainy season (November and December 1999) and before the major rainy season (February and March 2000) contributed 22 and 30 per cent, respectively. Leaf litter fall was highest in February (119 g m^{-2}) and lowest in August (12.4 g m^{-2}). The 2 months marked the beginning of the major and minor rainy seasons, respectively.

The rainfall distribution and leaf litter fall production patterns as observed in AS were similar for the Dopiri secondary forest (DS) for the same study periods (Fig. 2b). Mean annual leaf litter turnover in AS and DS were comparable (7.9 and 7.7 t ha^{-1} $year^{-1}$, respectively) (Fig. 2a and 2b). The leaf litter fall production values for the secondary forests were higher than those reported by previous authors (Proctor *et al.*, 1983; John, 1973).

Leaf litter decomposition

The loss of leaf material of the leguminous tree species, *Griffornia simplicifolia* (AG) during decomposition was rapid in the Akyaakrom secondary forest. By the end of the 7th month,

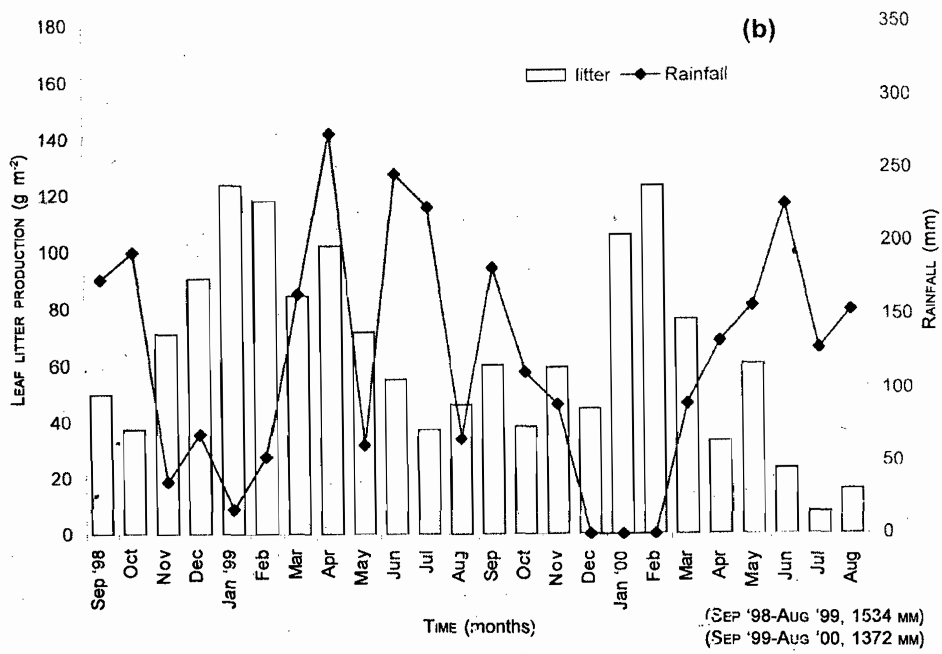


Fig. 2b. Monthly leaf litter production (g m^{-2}) and rainfall (mm) pattern in the Dopiri secondary forest (DS) in Dwinyama Watershed.

AG had lost more than 90 per cent of its dry weight. However, the decomposition rate of *Albizia zygia* (DA), also a legume, in the Dopiri secondary forest was slower and its decomposition trend was similar to that of the mixed species leaves (DM) during 9 months of exposure (Fig. 3). The decomposition rate of DM was accounted for by *A. zygia* leaf litter contributing to more than half of the total species leaf litter produced. The trends in decomposition of mixed species leaves in litter differed between Akyaakrom (AM) and Dopiri (DM) secondary forests for the 1st to 3rd months and 9th to 10th months (Fig. 3). Tanner (1981) suggested that the lower rate of decomposition in the upper mountains, as compared to lowland rain forests, was the result of lower temperatures, different leaf characteristics, and differences in water relations.

The monthly soil and air temperatures showed small variations in both forests. The variations ranged from 25 to 34 °C in Akyaakrom (Fig. 4a) where forest temperature values fluctuated between the rainy and the dry months (May-October and December-March, respectively). The highest soil moisture and RH were 65 and 83 per cent , respectively, recorded in August during decomposition. The lowest soil moisture and RH were 22 and 55 per cent, respectively, recorded in January which corresponded to the period of less rainfall (Fig. 2). There were wider variations in soil moisture and relative humidity within AS, more especially between the rainy (March to October) and dry (November to February) months (Fig. 4a).

The pattern of monthly temperature variations observed in AS was similar to that of DS but was relatively smaller (26 and 33 °C). However, the transition from rainy September to the beginning of dry October (start of dry months) (Fig. 2b) showed wider variations (27 and 33 °C, respectively) (Fig. 4b). The soil moisture and RH recorded in DS showed inconsistencies and fluctuated in the months of rainfall. During the

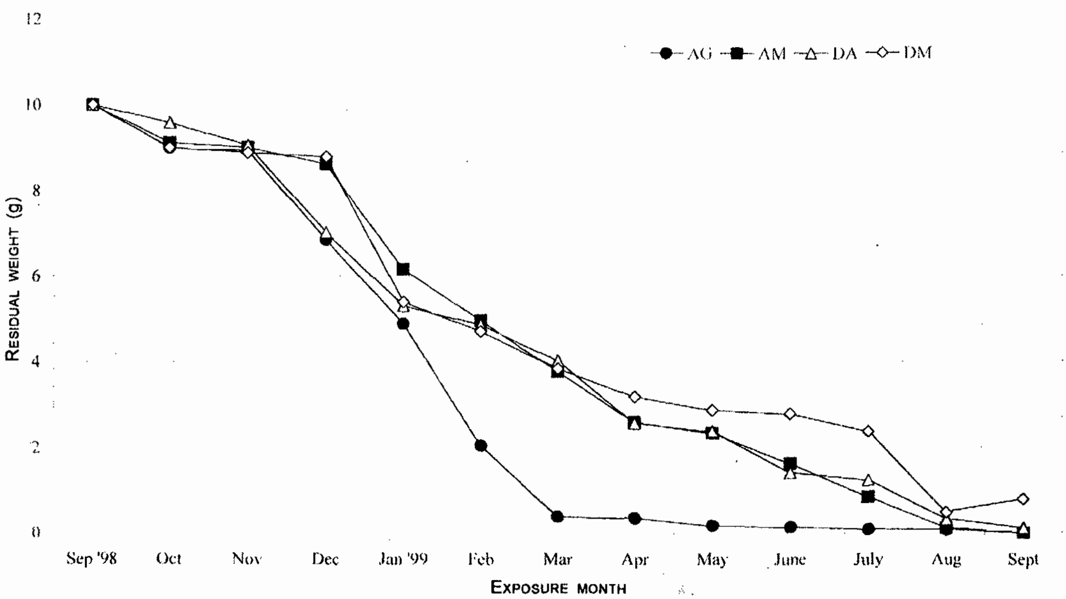


Fig. 3. Residual weights (g) of four types of decomposing leaf litter in two secondary forests. Initial weight of leaf litter was 10 g.

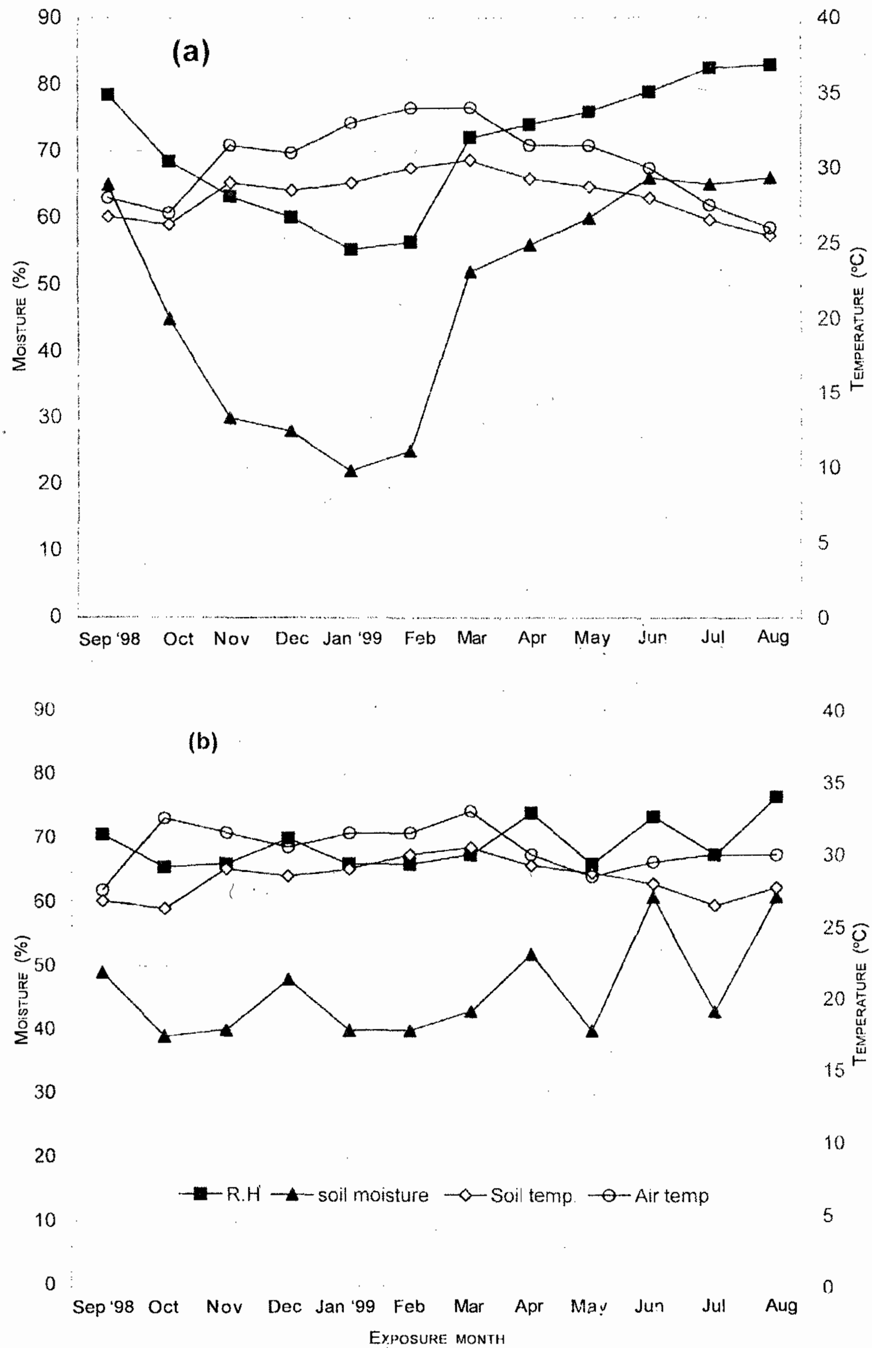


Fig. 4. Moisture (%) (soil and RH) and temperature (°C) (air and soil) in a) Akyaakrom (AS) and b) Dopiri (DS) secondary forests measured during the exposure months of decomposition (Sep 1998 to Aug 1999).

driest months (January and February), soil moisture was 40 per cent whilst RH was 66 per cent. The moisture values for DS were relatively higher as compared to those of AS.

The influence of environmental factors like temperature and moisture (air and soil) (Fig. 4) on the decomposition of the leaf litter types (Fig. 3) in the two forests was not clearly established. Tanner (1980) reported that decomposition may be related to physical environmental factors, mainly temperature and moisture. Prescott & Blevins (2000) reported that decomposition of pine needle litter is most affected by moisture. But Anderson & Swift (1983) suggested that it could be related to the influence of site. In this study, moisture and temperature fluctuations were small and, therefore, adequate for microbial activity throughout the decomposition period. The high temperatures (25-37 °C) and adequate moisture (>22 %) for both forests during the decomposition period provided favourable conditions for loss of leaf material and mineralization of nutrients from the leaf litter types.

In this study, the differences in the rate of decomposition can be fully explained by the differences in TEPH concentration in leaf litter types. The TEPH concentration of fresh leaf litter was highest in DM (28.0 %), DA (24.7 %), AG (17.8 %), and AM (16.8 g kg^{-1}) (Fig. 5). At 3 months exposure, the TEPH concentration in AG was considerably low, but it declined in DA and AM by 55 and 18 per cent , respectively (Fig. 5). Although TEPH concentration of DM at the 0th exposure month was high, it declined considerably by the 3rd exposure month (Fig. 5). The rapid decline of TEPH in AG caused the rapid decomposition of its leaf litter, while the slower decline of TEPH in AM, DM and DA delayed decomposition in their leaf litter (Fig. 3 and 5). However, trends in TEPH decline (Fig. 5) and leaf litter loss (Fig. 3) did not coincide with each other. Factors other than TEPH concentration might have contributed to the observed trends during decomposition of the leaf litter types in the secondary forests. The trend of decomposition was rather complex in studying immature forests.

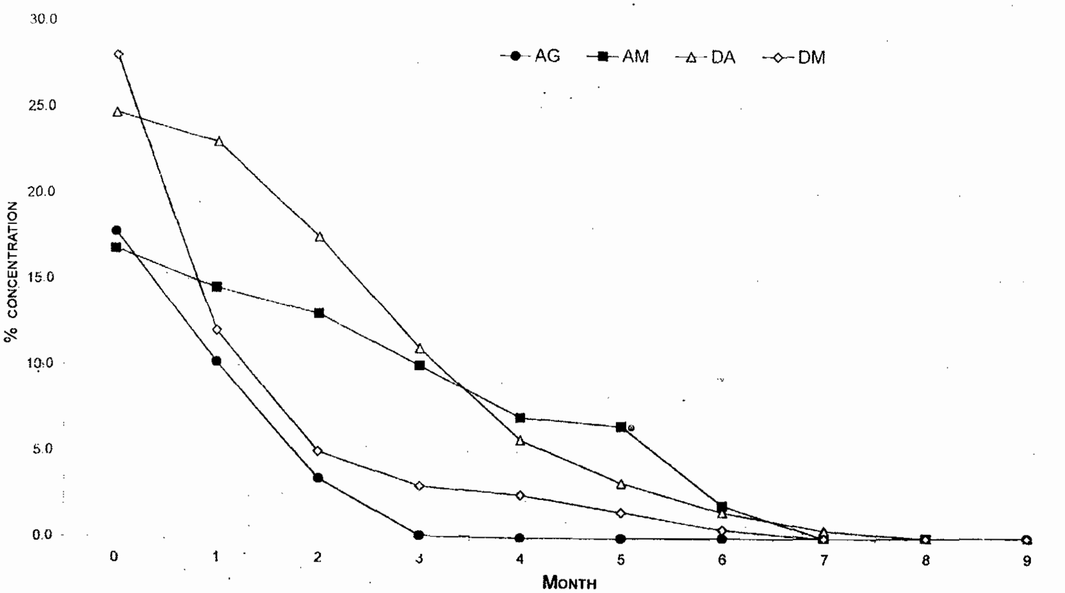


Fig. 5. Percentage (%) total extractable polyphenolic (TEPH) concentrations in residual leaf litter.

Nutrient release from leaf litter

Fig. 6 shows monthly changes in the total nutrient concentrations (g kg^{-1}) of N, P, K, Ca and Mg and nutrient quantities released from the decomposed leaf litter in the residual leaf litter from Akyaakrom (AM, AG) and Dopiri (DA, DM) secondary forests during the decomposition experiment. Generally, nutrient decreased gradually as the leaf litter decomposed. However, some variations were observed in the changing trends of nutrient concentrations; hence, the nutrient released among the leaf litter types in the early stage of decomposition. Nitrogen concentrations seemed to increase during decay.

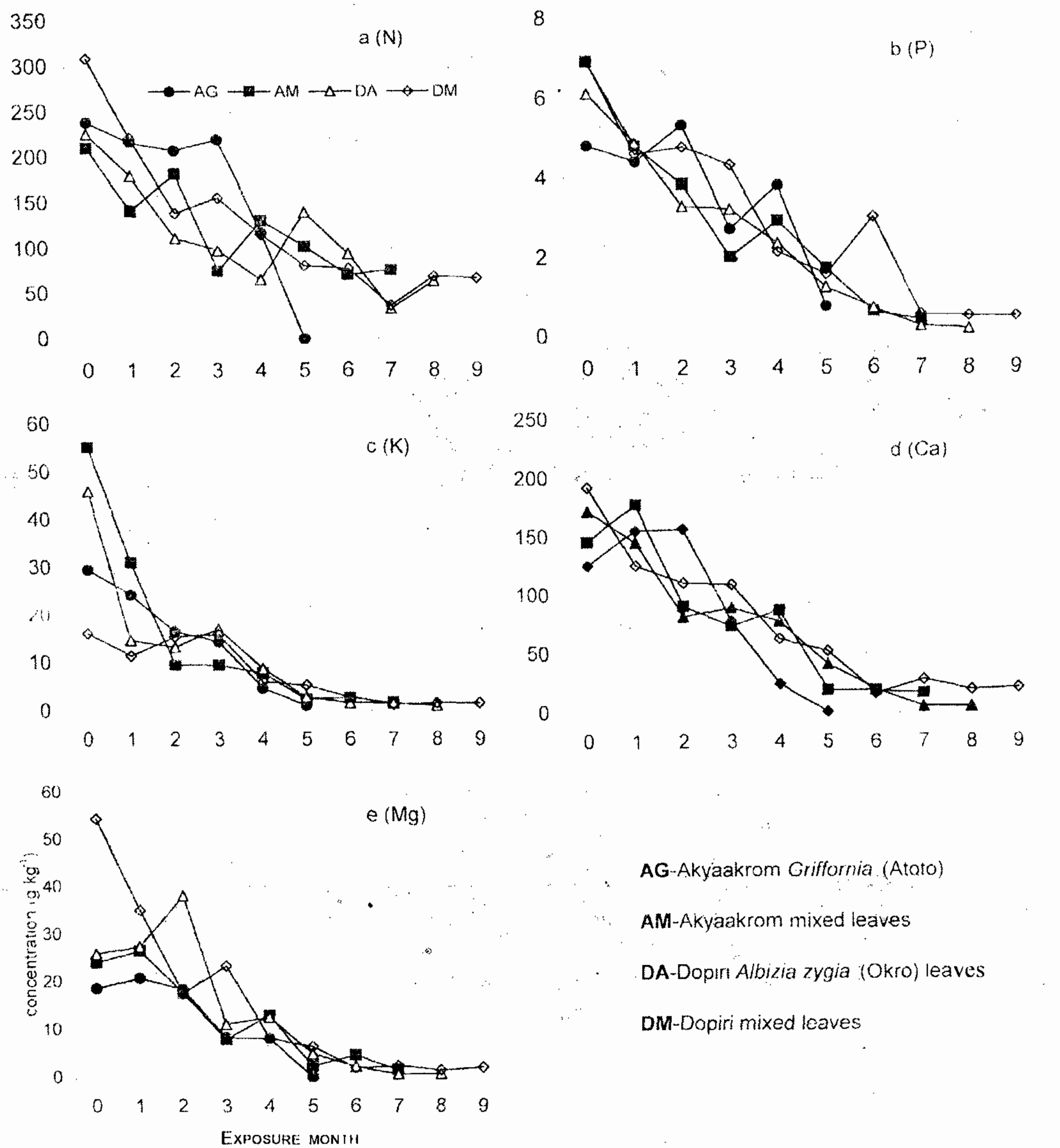


Fig. 6. Nutrient release patterns of decomposing leaf litter in secondary forests.

The progressive increase of N at the 2nd and 4th month exposure of AM (Fig. 6a) in the remaining leaf litter indicated that either N was immobilized and accumulated or that the litter acted as a sink. However, such temporal N increase was unclear for DM (Fig. 6a). Hence, the build-up of nitrogen in the leaf litter, and higher values were recorded as decomposition progressed (Maheswaran & Gunatilleke, 1988). O' Connell (1988), Songwe Okoli &Fasehun (1995), and Owusu-Sekyere *et al.* (2003) reported that N build-up initially in decomposing litter either translocates and accumulates or immobilizes N and P for the build-up of microbial tissues. This may have contributed to the accumulation of N in decomposing leaf litter.

In all leaf litter types, nutrients were gradually released as decomposition progressed. However, K of AM was released rapidly as in DA. Magnesium was also released rapidly in DM, while Ca of AG and AM, N of AG and AM, and P of AG increased temporarily during the early period of decomposition. During the release of K and Mg, leaf litter types with high initial concentrations tended to release those nutrients rapidly and *vice versa*. However, N of AG was released rapidly as leaf litter decomposition proceeded after the 3rd month (Fig. 3 and 6a). The decline in P concentration seemed slower and might be due to the concentration in fresh leaf litter in the forest trees (Fig. 6b). Concentrations of K in mixed species leaf litter AM showed a quick 73 per cent decrease at the 3rd month. However, K concentrations in *G. simplicifolia* (AG) and Dopiri mixed species leaf litter (DM) decreased very slowly or not at all Low K concentration in fresh leaf litter for AG and DM might be the reason for the slow decline in K concentration (Fig. 6c). As expected, Ca was released at a relatively slower rate than any other nutrient for all the leaf litter types (Fig. 6d). Similarly, Mg release was very slow as that of K (Fig. 6e and 6c).

Mitsch & Gosselink (1993) observed that hydroperiod (i.e., inundation frequency and distribution) is the single most important factor governing ecological processes in wet land and floodplain environments. Groffman *et al.* (1996) suggested that while adequate moisture is required for decomposer organisms to operate efficiently, excessive moisture or anaerobic conditions resulting from prolonged inundation may impede the activity of soil flora and fauna and as such decomposition. Brinson (1981) noted that decomposition is optimized at a point along soil moisture continuum. However, Lockaby & Walbridge (1998) reported that timing of litter input to the soil microenvironment may have a substantial influence on decomposition process. Leaf litter input was about average in September (Fig. 2a and 2b), moisture (air and soil) was enough, and temperatures (Fig. 4a and 4b) were adequate relative to the other months for efficient activity of the soil biota. Thus, material loss, mineralization and nutrient inputs to the soil environment would be better than if the experiments were conducted either in the comparatively drier or wetter months.

Nutrient flux from leaf litter in the two secondary forests

Based on the leaf litter fall, residual weights and nutrient released from AM and DM (Fig. 2, 3 and 6), monthly nutrient fluxes fron leaf litter from October 1998 to September 2000 were estimated for AS and DS forests (Fig. 7). Basically, the patterns of nutrient flux were similar to the patterns of leaf litter production at each site (Fig. 2a and 2b, 7a and 7b). The monthly fluctuations were influenced by monthly litter production. The period with high leaf litter production generally had high nutrient flux in both forests and *vice versa*. However, the patterns of nutrient fluxes were different between AS and DS (Fig. 7a and 7b).

In AS, monthly nitrogen flux was highest in April (24.0 kg ha^{-1}) in 1999 and in May (17.5 kg ha^{-1}) in 2000, and lowest in April (9.4 kg ha^{-1}) in 1999 and in March (9.1 kg ha^{-1}) in 2000. The temporal small N fluxes were the result of

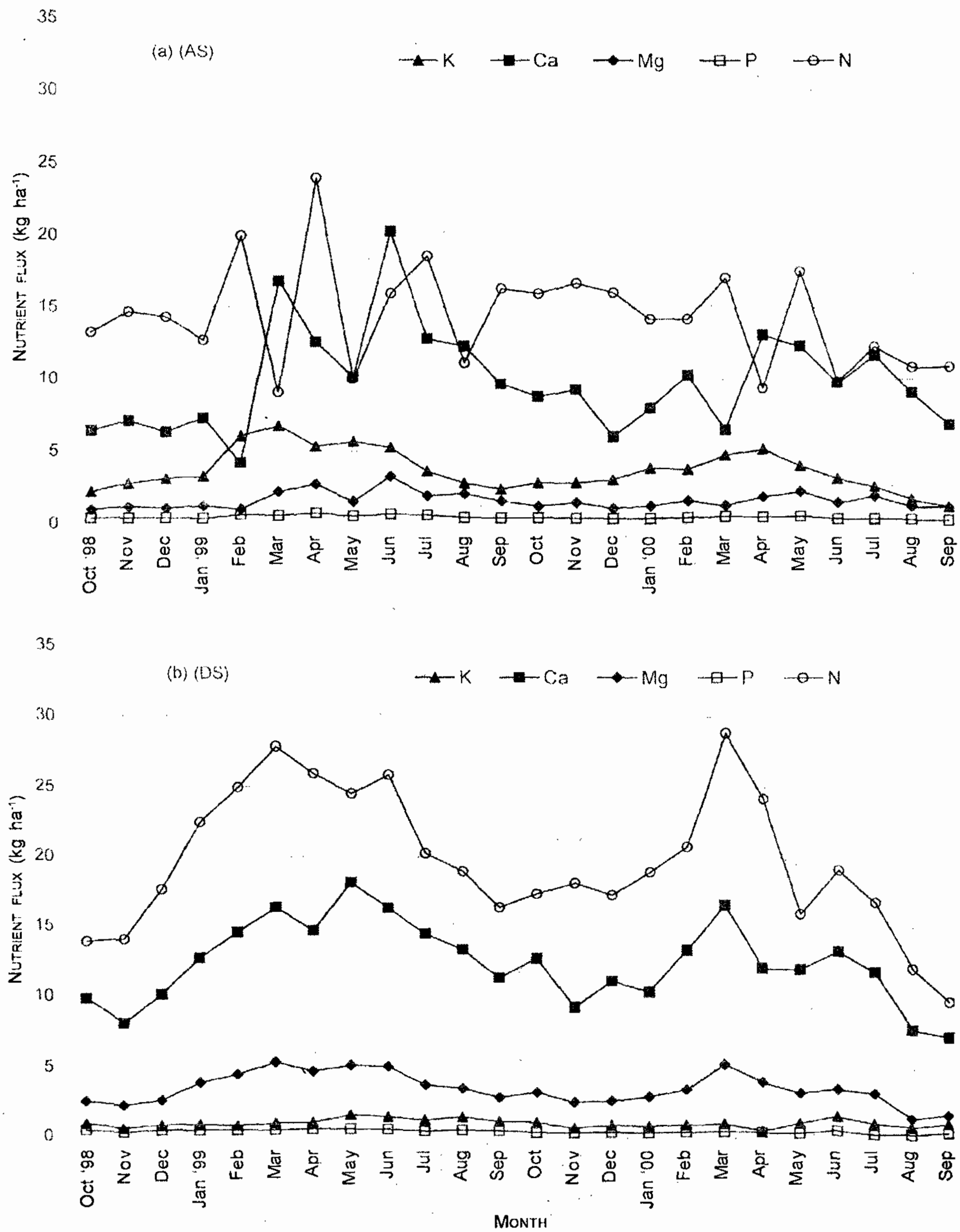


Fig. 7. Nutrient fluxes (kg ha^{-1}) from decomposed leaf litter in a) Akyaakrom (AS) and b) Dopiri (DS) secondary forests.

probably N accumulation in decomposing leaf litter at 2nd and 4th months of exposure (Fig. 5a). The high leaf litter production in January 1999 and February 2000 (Fig. 2a) caused apparent N starvation in March and May 1999, and in April and June 2000 which may affect plant growth in the AS ecosystem. Although such N starvation was also observed in DS (Fig. 7b) with monthly N flux dropping in May in 1999 and 2000, that was less distinctive than it did in AS. The monthly N fluxes in AS fluctuated more than those in DS did in the year (Fig 7a and 7b). The temporal N starvation and big fluctuation in N fluxes may indicate ecosystem degradation of the two secondary forests.

When denitrification was neglected, the mean annual N fluxes from the decomposed leaf litter to soil from October 1998 to September 2000 was estimated as 172 kg N ha^{-1} in AS (Fig. 7a). However, in AS, relatively high N flux was observed even in the dry season. The Dopiri secondary forest showed the highest mean N flux (i.e., 236 kg ha^{-1} y^{-1}) (Fig. 7b) which peaked in March in both years (27.9 kg ha^{-1}), and was the lowest in October 1998 (12.1 kg ha^{-1}) and September 2000 (9.7 kg ha^{-1}). Monthly N fluxes were high in the beginning of the major rainy season (March to April) and low in the minor rainy season (September to October). The ecological significance of the peak in N flux from March to May in the two secondary forests was the result that moisture was available for nutrient flux from decomposing litter into the soil during decomposition (Fig. 7 and 4).

The mean annual fluxes of Ca were 119 and 149 kg ha^{-1} in AS and DS, respectively (Fig. 7). The peak months of Ca flux were in June 1999 (20.3 kg ha^{-1}) and April 2000 (13.1 kg ha^{-1}) in AS, and in May 1999 (18.2 kg ha^{-1}) and March 2000 (16.6 kg ha^{-1}) in DS. In DS, the mean annual Mg flux was 42 kg ha^{-1}; the peak of 5.4 kg ha^{-1} was reached in March in both years, and the lowest was 2.2 kg ha^{-1} in November 1998 and 1.5 kg ha^{-1} in August 2000. The differences in amount and patterns of nutrient fluxes among the secondary forests were led by the differences in patterns of leaf litter production and nutrient release characteristics of leaf litter in each site.

In this study, the dominance of leguminous tree species in AS and DS that constituted the bulk of the leaf litter contributed to the relatively high N fluxes but lower Ca and P fluxes in the secondary forests than in the primary forest in the same watershed as observed by Owusu-Sekyere *et al.* (2003). The nutrient flux imbalance showed scarcities of Ca and P compared to N in the two secondary forests.

Conclusion

Information on the dynamics and cycling of nutrients in Africa's tropical forest ecosystems is scarce. Leaves decompose and release nutrients faster than other plant parts do. Therefore, the study of production of leaf litter through decomposition and mineralization to release of nutrients is important. The annual leaf litter fall recorded in this study was higher than values previously recorded in the tropics. The decomposition process was completed within a year. The litter comprising leaves of leguminous tree species decomposed and released nutrients faster than the other leaf litter types did. Nutrient release was prolonged in the litter of mixed species leaves from the Dopiri secondary forest. However, N accumulation instead of mineralization was recorded for all the litter types. The release of nutrients from the litter into the soil environment would lead to the understanding of nutrient accumulation and energy flow through the system.

The nutrient balances due to litter fall and nutrient fluxes clearly show relative scarcities of Ca and P compared to N-flux in the secondary forest types. Potassium in DS and Mg in AS were low in the secondary forests. The nutrient imbalances may relate to the degradation of soil and ecosystem of the two secondary forests. Studies on detailed characterization of forests in nutrient decomposition and nutrient fluxes require further investigation.

Acknowledgement

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