Nutrient Dynamics and Litter Decomposition in *Leucaena leucocephala* (Lam.) De Wit Plantation in the Nigerian Derived Savanna

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Abstract

Nutrient contents and rate of litter decomposition were investigated in *Leucaena leucocephala* plantation in the University of Agriculture, Abeokuta, Ogun State, Nigeria. Litter bag technique was used to study the pattern and rate of litter decomposition and nutrient release of *Leucaena leucocephala*. Fifty grams of oven-dried leaf litter of the species was weighed into 0.2 mm mesh litter bag, 35 cm × 25 cm in size, these bags were closed at all ends. Eighteen litter bags were used for the studies. The litter bags were numbered and placed on the field (above ground) on 26th April 2005. Three bags were retrieved randomly from the field at 20-day intervals for 120 days. The nutrient concentration in *L. leucocephala* followed the trend N > P > Mg > Ca > K > Na for leaf litter and seed components. Nutrient concentration in twigs and pods ranked N > Mg > P > Ca > K > Na. Among all the litter components, leaf litter contributed more nutrients, especially nitrogen, than other litter components. High potassium concentration during the dry season was due to lack of rainfall to leach out the element. Lower magnesium content in leaf litter was due to chlorophyll decay. High N-flux reflected the quantity and quality of nitrogen in the soil. Mass loss was significantly correlated with calcium ($P < 0.05$). At 120 days, 80% of the litter had decomposed; this implies that decomposition rate was at 0.6% per day. A net immobilization of all the nutrient elements at 20 days was due to lack of rainfall to leach out the nutrients. High rate of decomposition at the early stage was due to less moisture content in the soil and high temperature. Litter decomposed more during the wet season than the dry season.

Introduction

Energy flow and nutrient cycling are essential for the functioning of an ecosystem. Litterfall is a fundamental process in nutrient cycling and it is the main means of transfer of organic matter and mineral elements from vegetation to the soil surface (Vitousek & Sanford, 1986; Regina *et al*., 1999). The analysis of litter quality and quantity and its rate of decomposition is highly important for the understanding of energy flow, primary productivity and nutrient cycling in forest ecosystems. Quantification of the nutrient flux associated with litterfall is important to the understanding of ecosystems dynamics.

The maintenance of natural systems or soil fertility in tropical forest ecosystems is achieved by high and rapid circulation of nutrients through the fall and decomposition of litter. The decomposed litter is also the basis of many food chains in tropical forests and is a principal source of energy for the saprobiota of the forest floor and soil, where the trophic chain of detritus predominates (Spain, 1984; Ola-Adams & Egunjobi, 1992; Oliveira & Lacerola, 1993; Regina *et al*., 1999).

Decomposition is a key process in the control of nutrient cycling and formation of soil organic matter (Berg & McClaugherty, 2002). Decomposition of leaf litter is also an integral and significant part of biochemical (i.e. intra system) nutrient cycling and food webs; this refers to both the physical and chemical breakdown of litter and the mineralization of nutrients (Boulton & Boon, 1991; Terrell *et al.*, 2001). Decomposition of plant material is an important component in the study of forest ecosystem because of its critical role in nutrient cycling. Plant production depends on the recycling of nutrients within the system; recycling depends on the decomposition of organic matter and release of the nutrients it contains (Temel, 2003). The study, therefore, focuses on the amount of nutrient contents in litter and the rate of decomposition in leaf litter of *L. leucocephala.*

Materials and methods

Study site

The study area is *Leucaena leucocephala* plantation, University of Agriculture, Abeokuta. The site is on latitude 7° and 7° 58' N and on longitude 3° 2' and 20° 37' E, and it is 600 m above sea level. The general topography of the site is undulating while local topography is upper mid-slope. Soil is under laid by the pre-cambian metamorphic rocks of the basement complex with bed rock consisting predominantly of granite gneisses, bounded biotite, horn blende gneisses, quartzite and quartz schists. The soil is a fertile sandy loam, very dark in colour at the top surface and greyish brown in the subsoil with occasional areas of loamy soil.

The area has a tropical climate with a bimodal distribution of rainfall. It lies within the humid lowland region (Keay, 1953) with two distinct seasons. The wet season lasts from April to October while the dry season extends from November to March. The mean annual rainfall is 1113.1 mm. The bimodal distribution of rainfall has its peaks in July and September and a break in August. The mean monthly temperature varies from 22.74 °C in August to 36.32 °C in March. The relative humidity is high ranging from 75.52% in February to 88.15% in July (Aiboni, 2001).

Nutrient analysis

For the determination of cations, dry ashing of plant tissue techniques, as described by Wilde *et al.* (1972), were used. Quantities of Na and K were determined by flame photometry; Ca and Mg by atomic absorption spectrophotometry; P by colorimetry, and nitrogen by the Kjeldahl distillation method. (Brenner, 1965; Isaac & Kerber, 1972). Concentrations were read on an autoanalyser (Brenner, 1965).

Decomposition studies

A leaf litter decomposition experiment was carried out for 16 weeks (112 days) period from April 26 to August 24, 2005. Leaf litter of *L. leucocephala* was used to determine decomposition because this plant organ represents substantial proportion (50–80%) of the total above ground litter production in terms of biomass, and represents a major nutrient input because of its relatively high nutrient concentration (Moughalu *et al*., 1994) and, more so, leaves decompose faster than twigs and leaf petioles.

Litter bag technique (Anderson & Swift, 1983; Swift & Anderson, 1989) was used to study the pattern and rate of litter decomposition and nutrient release of *L. leucocephala*. Fifty grams of oven-dried leaf litter of *L. leucocephala* was weighed into a 0.2-mm mesh litter bag, 35 cm × 25 cm in size; these bags were closed at all ends. The mesh size was chosen to prevent the inflow of excess litter material into the weighted sample. Eighteen litter bags were used for the studies. The litter bags were numbered and placed on the field (above ground) on 26th April 2005.

Three bags were retrieved randomly from the field at 20-day intervals for 120 days. The bags were carefully removed and put into the polyethylene bag and taken to the laboratory. The contents were emptied and extraneous materials, such as soil, visible animals and fine roots were removed. The remaining sample was oven-dried at 100 °C to a constant weight to determine the final weight of the remaining sample and ground for chemical analysis. The ground samples were analysed for P, Mg, Na, Ca, K, N and carbon.

A single exponential equation, according to Olson (1963) and Oohara & Yoshida (1971), was used to calculate decomposition constant (k), and rates of loss of nutrient as follows:

$$\frac{x_1}{x_0} = e^{-kt}$$

where x_0 = the original weight of litter
x_1 = the final weight of litter
e = the base of natural logarithm
k = decomposition constant

t = the time.

The final weight represents the mass remaining after decay, and, hence, from this the percent of initial mass remaining was calculated. The percent of initial mass remaining was plotted against time (days).

Results

Nutrient composition of litter

In all the litter components, the relative ranking of nutrient concentrations were in the order N > P > Mg > Ca > K > Na for leaf litter and seed components, and N > Mg > P > Ca > K > Na twig and pod components. The flower component appeared to have an order different from the above mentioned categories, i.e. K > N > P > Mg > Ca > Na. Sodium concentration in all the components appeared to follow the same trend, i.e. all the components were low in Na concentration. However, N was in higher quantities in all the components.

Leaf litter had the highest concentration of Ca, Mg and P. The highest concentration of phosphorus was recorded for leaf, seed and pod during the raining season and for twig and flower in the dry season, Potassium was high in seed and flower in the dry season. Seed component tended to be high in nitrogen and phosphorus. There was a noticeable increase in N, P and K in the flower component between November and February – a period of little or no rainfall.

There was little variation in the monthly concentrations of the nutrient element in leaf litter and other litter components. Potassium was evidently high during the dry month in almost all the litter components. Mean monthly rainfall was positively correlated ($P < 0.05$), with all the elements but significantly high with Ca in leaf litter and twig (Table1). Maximum temperature showed significant positive relationship with Mg and Na ($P < 0.01$), but negatively correlated with P. However, it significantly correlated with nitrogen ($P > 0.05$). In the twig, maximum temperature was significantly correlated with Mg and Na ($P < 0.05$) and negatively correlated with phosphorus (Table1).

The nutrient with the greatest proportion for all the litter components (Table 2) is nitrogen followed by phosphorus, magnesium, calcium, potassium, and sodium content was the least. Leaf litter contributed the highest amount of nutrient element followed by twig, and the least was flower; leaf litter accounted for 61% of the nutrient, returned to the forest floor (Table 2). Litter components returned the nutrient to the soil in the order N > P > Mg > Ca > K > Na. Leaf litter returned more of N, P, Mg, Ca and K. However, seed returned more P than flowers and pods. Twigs returned more of Mg and Ca after leaf litter. A similar result was observed in Ca. Quantitatively, all the litter components tend to contribute more nutrient elements to the forest soil during the wet season than the dry season.

Litter decomposition

Loss in weight in decomposing leaf litter of *Leucaena* with days was rapid (Fig. 1). At 60 days, 50% of the initial weight of leaf litter had decomposed. Between 100 and 120 days, only 1% of the remaining weight decomposed. At 120 days, 80% of the original weight had decomposed (Table 3). This implied that 0.3 g or 0.6 % of the leaf litter decomposed daily. Mass loss was negatively correlated with P, Na and K, but significantly correlated with Ca ($P < 0.05$). However, it partially correlated with N and Mg (Table 4).

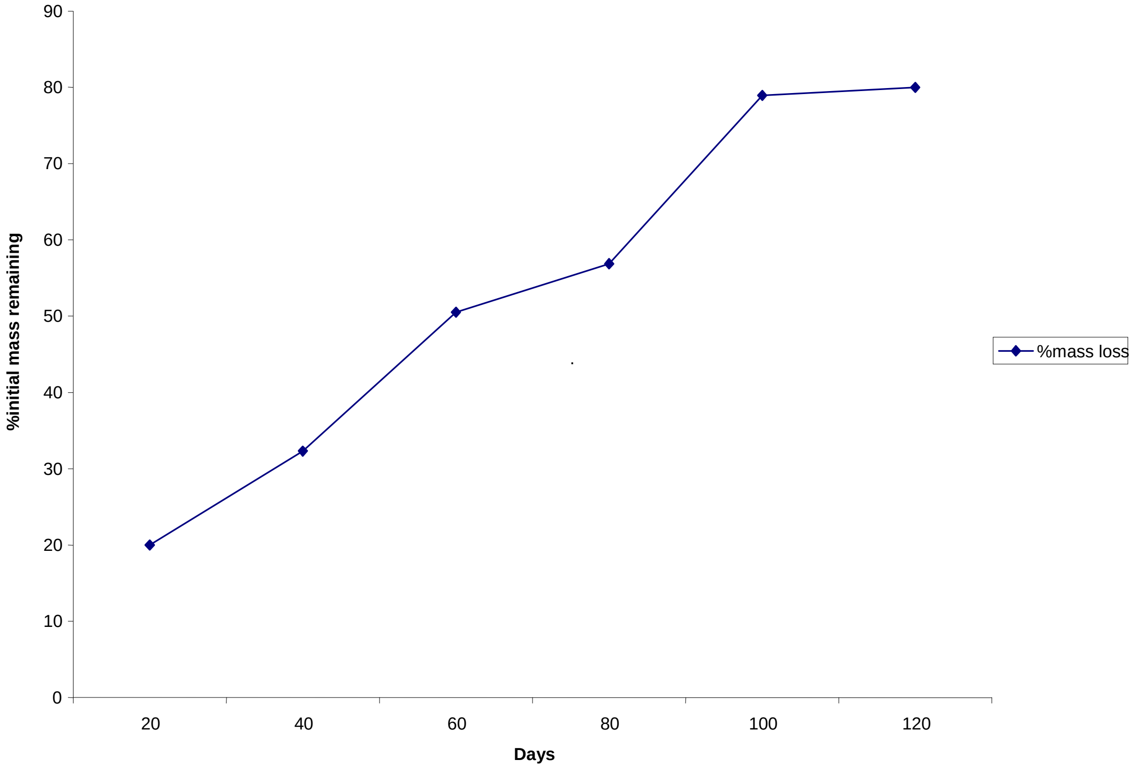

Fig. 1. Dynamics of %mass loss in leaf litter decomposition

Generally, the loss in weight of decomposing leaf litter was linear and increased with days. The various mineral elements showed different pattern of decomposition. There was a noticeable increase in all the nutrient elements during decomposition. Phosphorus content decreased greatly within 40 days (Table 5), followed by a slow rate of decomposition. A noticeable increase was observed at 120 days for all the nutrient elements. Organic carbon remaining was higher than other nutrient elements at the end of the study. Nitrogen and organic carbon contents followed the same trend, with a gradual decrease up till the 60th day, followed by a sudden increase in the 80th day.

Ca remaining after 20 days was lowest compared with other elements. A very rapid rate of decomposition was observed within the 40 days for Ca, followed by a gradual increase in the Ca remaining. Potassium witnessed a diffuse pattern of mineralization. The nutrient element did not show any particular trend with increasing days. The trend of nutrient immobilization at 120 days was in the order OC > N > Mg > P > Ca > K > Na.

TABLE 3

Pattern of Leaf litter decomposition

Days	*Decomposition*	*R_1/g*	*R_2/g*	*R_3/g*	*Mean/g*	*% Mass remain*	*% Mass loss*	*Mass loss*
20	D1	41.49	39.52	39.02	40.01	80.02	19.98	9.99

40	D2	35.72	32.21	33.58	33.84	67.68	32.32	16.16
60	D3	24.24	25.24	24.76	24.74	49.48	50.52	25.16
80	D4	21.84	20.78	22.05	21.56	43.12	56.88	28.44
100	D5	10.27	10.77	10.54	10.52	21.04	78.96	38.48
120	D6	10.57	9.84	10.05	10.01	20.02	79.98	39.99

R1, R2, R3 – Replicates.

TABLE 4

Correlations between mass loss in decomposition against nutrient content

	P	*Na*	*K*	*Ca*	*Mg*	*N*
Mass loss	–.554	–.666	–.260	.864*	.077	.050

*$P < 0.05$

TABLE 5

Percentage nutrient remaining in leaf litter after decomposition

Days	*Decomposition*	*P%*	*Na%*	*K%*	*Ca%*	*Mg%*	*N%*
20	D1	1095.9	1571.77	1037.76	64.02	1883.67	1569.02
40	D2	82.39	1208.57	475.87	1.35	1154.62	1280.6
60	D3	53.78	795.21	533.46	360.21	908.45	800.41
80	D4	32.81	754.60	330.13	337.74	977.09	740.22
100	D5	11.46	323.11	98.62	147.70	388.81	346.74
120	D6	89.57	328.90	258.07	174.57	482.08	453.39

Discussion

The concentration of plant nutrients in all the litter components of *Leucaena* litter followed this general trend: N > P > Mg > Ca > K > Na. However, leaf litter and seed component maintain that order, while twig and pod follow the order N > Mg > P > Ca > K > Na, and flower comes in a separate order, i.e. K > N > P > Mg > Ca > Na. This suggests that P and K are concentrated in the reproductive structure (Reinaldo & Philip, 1995). Variation in concentrations of nutrient elements reflected the seasonal trend in the amount of litter fall and the concentration of elements in the litter as observed by Muoghalu *et al*. (1993). Potassium, P and Mg had their maximum concentrations in the dry season although Klinge & Rodrigues (1968) recorded a high concentration of P and K in litter in the wet season. The maximum concentration of these elements was in the dry season. High potassium content could be due to lack of rainfall during these months. Potassium is easily leached from leaves and litter by rain water (Egunjobi, 1971; Egunjobi & Fasehun, 1972; Muoghalu *et al.*, 1993). Lower content of highly mobile nitrogen might be due to leaching with rain water, and lower Mg content in leaf litter possibly reflected the chlorophyll decay which confirms findings by Kava'ova & Acek (2003).

High calcium concentration in the litter components suggests that Ca is very active and immobile in the litter vascular system, and is believed to be recycled by means of litter decomposition (Kava'ova & Acek (2003), and the Ca flux in the site may be due to quantity and quality of Ca in the soil. More nitrogen is returned through litter fall than any other element in this study, which was similarly observed by other studies (Muoghalu *et al*., 1993; Hermansah *et al*., 2002). Generally, tropical forests have higher concentration of nitrogen than comparable temperate forests due to higher concentra-tion of this element in leaf litter. It may be assumed that, because *Leucaena* is a leguminous plant, it is potentially capable of symbiotic fixation of atmospheric nitrogen, and supplies high levels of this element at this site. The higher concen-tration of N and P was comparable with the results obtained by Burghouts *et al*. (1993) and Hermansah *et al*. (2002).

A significant positive correlation between mean monthly rainfall and P, K, Mg, Ca and N in leaf litter and twig could be associated with leaching of these elements from litter and their differential retranslocation. Fluxes of nitrogen associated with leaf fall are an important component of the internal N cycle of a forest ecosystem. Reich *et al*. (1992) and Aerts (1996) suggest that they are determined largely by the physiological and anatomical characters of the main tree species. The concentration of plant nutrients in litterfall is important because it influences both the rate of decomposition and the amount of nutrient released to the soil during such decomposition. Therefore, the quality of litterfall, particularly N, was probably affected by the concentration of N in the soil and also due to the nature of the tree which is a leguminous plant capable of fixing nitrogen.

The nutrient flux within the study site had nitrogen with highest flux and this may be presumably due to the tree species, a leguminous plant. Lower quantity of potassium may be due to leaching during the rainy season and also the greater number of days associated with wet season (Reinaldo & Philip, 1995). The amount of nutrient flux corresponded with the dry weight of litter produced. Nwoboshi (1981) made a com-parison of the nutrient contents in the foliage and the litter, and suggested that not all the elements taken up by the foliar component of the shoot returned to the forest floor through litter fall.

Decomposition essentially results in a change of state of a resource under the influence of a number of biological and abiotic factors. Mass loss of resource has been regarded as the simplest expression of state of change. Leaf litter decomposition is an important aspect in mineral cycling as it determines the rate at which nutrients in the litter become available for recycling as well as store of inorganic elements still remaining in the litter component. Decomposition rate in this study was increasing with days. This could mean that different species have different rates of decomposition as reported by Muoghalu *et al*. (1994) and Temel (2003).

High rate of decomposition recorded at the early stage and around July and August may be attributed to less moisture content in the soil, leading to high aeration, causing the aerobic organism to be active. Frioretto *et al.* (1998) suggested that microbial activity could be limited by litter moisture content. This is in support of the hypothesis that climate set the general limits of the litter decomposition process through physiological constraints on the activity of organisms. The general conclusion is that physical climate determines rates of decay (Courteaux *et al*., 1995; Temel, 2003). The result showed a small percentage of original weight remaining; this may suggest that there was always litter remaining before new litter fall, a situation that favours erosion control in plantations.

Slow decomposition rate recorded at 120 days may indicate period of low rainfall. However, decomposition still occurs in dry season. High rate of decomposition recorded in April could be attributed to high temperature and moisture. High tempera-tures tend to increase microbial activity, which, in turn, leads to increased decom-position. It has been found that species with high nitrogen content decompose more rapidly than species low in nitrogen (Muoghalu *et al*., 1994; Hobbie, 1996; Vanlauwe *et al*., 1997). Slow rate of decomposition recorded between 100 and 120 days of the study was associated with period of low rainfall and low temperature. This further suggests that decomposition occurs faster during the rainy season than dry season.

Percentage mass remaining was lower; this was expected because of the initial substrate quality of *Leucaena*. Studies had suggested that nitrogen exerts great influence in the early stage of decomposition because it affects the physiological adaptation of decomposition organisms (Salamanca *et al*., 1995; Hobbie, 1996; Temel, 2003). Concentration of soluble and recalcitrant compounds influenced the rate of decomposition because different fractions of chemical compound present in leaf litter occur at different rates and are influenced by changes in microclimate. Hence the effect of time on the level of residue remaining at sampling.

A noticeable increase in all the nutrient concentration at the early stages of decomposition may be due to (1) the activity of microorganism who fed, died and decomposed on the litter, thus, increasing the nutrient content, and (2) period of low rainfall where leaching away of the nutrient was affected. Leaching is a biotic process whereby soluble matter is removed from the resource by the action of water. This is in accordance with the observation by Frioretto *et al.* (1998) that microbial activity can be limited by litter moisture content. However, where there is high concentration of aerobic organism, nutrient release through decomposition will still continue because these organisms are active when there is high aeration.

The result indicated higher rate of P, K and Na release. Similar trend has been observed by Singh (1980) and Adejuyigbe (2000) in the humid tropical forest. This rapid release could be attributed to the rapid loss of water soluble compounds. Potassium and phosphorus are usually constituents of metabolites enzymes system of the plant sap. Calcium and Mg are constituents of the structural make-up, such as the cell wall.

Early immobilization of N and P and subsequent decrease in concentration following mass loss have been found in other studies (Sharma & Ambasht, 1987; Palm & Sanchez, 1990; Lisanework & Michelsen, 1994). The nutrient accumulation could also be from falling litter, herbivore frass, precipitation, through fall, stem flow, the soil substrate, and from in growth of fungal hyphae (Swift *et al*., 1979). High rate of nitrogen release from the leaf litter of *Leucaena* could be attributed to the influence of soil microarthropods. The sudden increase in nutrient remains at the end of the studies for nitrogen could indicate that soil N was being immobilized by the decomposing organism (Alfred & O'sullivan, 2001). This suggests that mineralization of nitrogen was in two patterns: (1) Initial net mobilization followed by net mineralization in later stages and (2) Net mineralization with time.

Net accumulation for P and K could be attributed to the effect of environmental factors. Generally, the net accumulation of nutrient remaining at the end of the study may also suggest that some microorganisms acting on the resource, fed, died and decomposed on the litter, thus, increasing the nutrient quality. Sodium accumulation at the early stage of decomposition could be attributed to sodium input from rain, dust and to some lag in the release from litter (Muoghalu *et al.,* 1994).

In decomposing litter, the chemical component may be regarded in a certain sequence, reflecting a succession of micro-organisms with different saprotrophic abilities (McClaugherty & Berg, 1987; Temel, 2003). This means that the heterogenous group of microorganisms that invades the litter initially decomposes the water soluble in the non-matrixed part of the cellulose and hemicellulose (as energy sources), and finally the complex of interwoven holocellulose and lignin is attacked by cellulolytic and lignolytic fungi. Frankland (1992), Adejuyigbe (2000) and Cox *et al*. (2001) attributed litter decomposition and release of N, P, K, Ca and Mg to the influence of microarthropods and earthworms. Decomposition is important because plant production depends on the recycling of nutrients within the system; recycling depends on the decomposition of organic matter and release of the nutrient it contains. It has long been recognized that soil fauna affects decomposition mainly through the combination of substrates, and influencing microbial activity (Tian *et al*., 1998).

The results agree with other authors' conclusion that litter decomposition rate is more related to litter quality than to environmental conditions (Facelli & Pickett, 1991; De Santo *et al*., 1993; Muoghalu *et al*., 1994; Scott & Binkley, 1997; Temel, 2003). C/N ratio followed the same trend with nitrogen. However, C/N ratio could not satisfactorily describe the effect of litter quality on decomposition (Thorburn *et al*., 2001).

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