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Leaf Litter Decomposition and Nutrient Release in a Rubber Plantation in Southwest Nigeria

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Abstract

Decomposition and nutrient release pattern of tropical agroecosystems such as those of rubber (Hevea brasiliensis) *are rarely studied compared to those of the temperate regions. This study describes the weight loss and nutrient release pattern from decomposing litter of a rubber plantation of different age stands (40-, 15-, and 5-year-old). Decomposition rates of 15-year-old leaf litter were fastest followed closely by the 40-yearold. In the 15-year-old plot, a significant reduction in mass (c. 70%) was observed within the first six months ($p<0.05$). Weight loss (95%) was completed by the by the 9th month in the 15-year-old stand while it was 10th and 11th month respectively in the 40-year-old and 5-year-old plots respectively. The pattern of weight loss exhibited an initial rapid decay phase (especially in the rainy season) followed by slow decay rate. Pattern of change in the concentration of N, P, and K was approximately linear to mass loss. The largest decay coefficients were observed in the 15-year-old rubber plot (0.338). The mineralization of P was similar for the three stands, but 15-year-old litter released large amounts of K. Levels of exchangeable K were significantly increased in 15-year-old litter. It can be concluded that 15-year-old litter is easily decomposable. There is therefore the need to be felled and replant old rubber plots and supplement nutrient in the 5-year-old plot with external inputs in order to improve nutrient cycling and promote sustainable production*

Key words: *Agroecosystem, decomposition, leaf litter, nutrient release, Hevea brasiliensis.*

Introduction

Litterfall and litter decomposition are crucial to the processes of energy flow and nutrient cycling in all terrestrial ecosystems. They can therefore be linked together functionally in ecosystem context (Cromack and Monk, 1975) because they account for a substantial portion of the internal nutrient cycling in the terrestrial ecosystems (Ewel, 1976; Montagnini, 1990; Hartemink and O'Sullivan, 2001; Starr *et al.*, 2005). Leaf breakdown (decomposition) and subsequent release of nutrient to the soil is considered a pivotal process in the metabolism of terrestrial ecosystems (NRC 2001; Hochella, 2002; Sparks, 2004), providing important information on the functioning of such ecosystems in respect of energy flow and nutrient cycling (Webster & Benfield , 1986; Wallace *et al.*, 1997).

Nutrient release of the biomass is determined by several physical, chemical and biological factors (Cadisch & Giller, 1997). On a global or broad regional scale, temperature and precipitation are largely responsible for determining the rate and extent of decomposition (Swift *et al*., 1979). At a local scale, the rate of decomposition and quantity of nutrient cycled through the decomposition mechanism are influenced primarily by (i) the quality of resources being decomposed (McClaugherty *et al.*, 1985; Finzi *et al.*,2001), (ii) physiochemical properties (i.e. temperature and moisture regime, pH, oxygen) that affect decomposer organisms in situ (Swift *et al*., 1979, Berg *et al*., 1993), and (iii) the length of time the resource is in contact with soil microenvironment (Lockaby and Walbridge, 1998). The relative importance of these factors appears to shift in response to spatial, temporal, and site-specific variations (Swamy and Proctor, 1994; Hartemink and O'Sullivan, 2001).

The assimilation of the mass of fallen leaves of plants is a critical function of both large and small soil organisms, which range in size from macrofauna (such as moles, earthworms, and millipedes), through intermediate mesofauna (such as arthropods e.g. mites and collembola i.e. springtails), to microfauna (such as nematodes and single-celled protozoan)(Gessner *et al*., 1999; Hochella, 2002; Sparks 2004). Mesofauna are largely detritivores and they are significant role players in nutrient cycling. In concert with various chemical changes, these soil organisms cause transformations in litter quality (e.g., increases in nitrogen and phosphorus concentrations) that influence decomposition dynamics (Webster & Benfield, 1986; Gessner *et al*., 1999).

Litter is a central nutrient resource in tropical forest ecosystems where soils are highly weathered and nutrient-poor. It also initiates the nutrient cycles by providing input to decomposer food chain (Martius *et al*., 2004). The relative value of leaf litter as a source of nutrient however, is dependent on its decomposition rate, which in turn controls the release of the tissue-held mineral ions. Decomposition rates are an indicator of the functionality of the biogenic below-ground ecosystem processes of nutrient cycling that include litter decomposition and nutrient supply and in which soil organism play a central role (Tain *et al*., 1997; Lavelle *et al*., 2001; Tian and Badejo, 2001). There is the need to understand the litter decomposition processes in terrestrial ecosystems including monospecific tree crop plantation such as rubber for an improved recycling of soil nutrients and to maintain the nutrient balance of the agriculturally managed soils so that they are less dependent on external inputs.

Leaf age is an important factor affecting concentrations of nutrients in foliage because of mobile nutrients such as N tends to decline with age (Snowdon *et al*., 2005). Seasonal fluctuations in nutrient concentrations in leaves also occur. In plantation trees, the foliar concentrations of nutrients are often used as an aid for assessing the presence of nutrient deficiencies or the need for fertilizer applications. In view of these variations, concentration of nutrients in the youngest fully expanded leaves can be used to diagnose nutrient status and study leaf litter decomposition. The commonly used method to study litter decomposition is to place senescent or litterfall in mesh bags (litterbags) in contact with the litter layer and then to record changes in biomass and nutrient content. Measurements over time on component of intact litter layer can also be made (Snowdon *et al.*, 2005). Berg *et al.* (1993) have identified the litterbag method as a most useful procedure for understanding decomposition and nutrient dynamics of litter in forest ecosystem. The only shortcoming of this method according to Ewel (1976) and Sundarapandian and Swamy (1999) is that the decay rate measured by the method is underestimated because of the restriction of micro – fauna entry into the litterbags. A considerable number of decomposition studies have been conducted under laboratory conditions (Handayanto *et al.*, 1997; Lupwayi and Haque, 1998; Palm and Sanchez, 1991; Tian *et al.*, 1992) or under field conditions with no crop after the fallow (Budelman, 1988; Handayanto *et al.*, 1994; Mwiinga *et al.*, 1994; Oglesby and Fownes, 1992). Studies under field condition with tree crops such as rubber stands is essential to quantify maximum rates of decomposition and nutrient release in such agroecosystem. Field studies of decomposition such as these are surprisingly few in sub-Saharan countries like Nigeria.

The objectives of this study were (i) to quantify and compare mass loss of leaf litter representative from different rubber (*Hevea brasiliensis* Willd. Muell-Arg. Euphorbiaecae) age stands and (ii) to examine nutrient release from decomposing leaf litter representative from different rubber age stands. It was hypothesized that higher quality leaf litter (i.e. litter with narrow litter quality ratios such as C:N, C:P, N:P, and lignin) would decompose faster than low quality litter (i.e. litter with wider ratios).

Materials and methods

Experimental site

The experiment was conducted in the Remo Rubber Plantation located 2 km S of Ikenne (Latitude 6º 50' to 6º 54' N and Longitude 3º 40' to 3º 45' E) SW Nigeria. The plantation site is on an undulating land about 145 m above sea level, with and average annual temperature of 27ºC and an annual precipitation of 1,550mm with 125 rainy days per year. The mean annual relative humidity (r.h.) is 80 % at 1500 Greenwich Mean Time (GMT) and this could be attributed to the prevalence of moisture-laden tropical maritime air mass over the area for about nine months in the year. The soil of the area is classified as an ultisols due to the annual rainfall with base saturation often less than 50%. The texture of the surface soils is usually loamy and sandy, becoming heavier with clay at greater depths, frequently with gravel layers at 30-60cm. The Cation Exchange Capacity (CEC) varies from 1.3 Cmol/kg to 17.3 Cmol/kg in the topmost layer (Aweto, 1987) and the soil pH values ranges from 6.5 to 6.7 in the topsoil. However, a rapid decline in pH and aluminium toxicity occurs with depth and this can lead to a serious fall in productivity after only a few years of cultivation.

The plantation site was acquired, for commercial rubber production in the late 1950s by the Old Western Nigerian Development Corporation (WNDC) as one of the major tree crop plantations established by the government. Other tree crop plantations include those of cocoa, oil palm, teak, and *Gmelina* spread over suitable areas in the region. Most of these plantations are still in existence but producing far below capacity due to shift of government attention away from agriculture to crude oil production and export for foreign exchange. Land preparation in the plantation started in 1959 and the first nursery was established in 1960.

However, only about 1,111 hectares of the 2,500 hectares acquired for the plantation were planted with rubber, while the Ministry of Agriculture, the Institute of Agricultural Research and Training (IAR&T), and the International Institute for Tropical Agriculture (IITA) use the other areas for research purposes.

Presently, effective rubber trees cover about 500 ha of which 94% are old and have outlived their economic lives. Rubber clone is principally the GT1, which are planted in different blocks within the plantation. In 1991/1992 planting season, 15 hectares was devoted for the planting of the GT1 clone in the plantation and latter in the 2000/2001 season, efforts were made to replant another 15 hectares of the GT1 clone.

Leaf Litter Collection and Preparation

The litterbag study was undertaken in three different rubber age stands (40-, 15-, and 5-year-old). The decomposition rate of leaf litter was determined by measuring weight loss and nutrient variation of a known quantity of leaves using the litterbag method (Berg *et al.*, 1993; Aerts, 1997; Trofymow *et al.*, 2002, Hobbie and Gough, 2004). Two plots (each 8 m x 16 m) chosen randomly from the inner portion of each stand were established in the plantation. Each 8 m x 16 m plot which were 100m apart was divided into a grid of 2 m x 2 m sub-plots. With three rubber stands and three replicates per stand to distribute, nine sub-plots were randomly selected from the thirty-two total sub-plots. Assignment of rubber tree per sub-plot was also randomly selected.

Freshly fallen leaves from the three rubber age stands were collected, composited and air-dried. The dry weight equivalent were determined by oven drying the samples at 70 °C for 48 h. Five sub samples of the dried litter were retained for initial chemical analyses. Litterbags containing 5 g of dried litter were placed on the plantation floor within the sub-plots and tethered to an anchor. The litterbags were made of nylon bags of 10 x 10 cm with 1 –mm mesh openings on top and 0.1 –mm openings on the bottom. The mesh sizes are to allow access to the mesofauna (e.g. mites) and the microfauna (such as nematodes) into the litterbags. Smaller mesh sizes (e.g. 0.01mm) tend to exclude valuable soil fauna, which can aid decomposition of fallen leaf litter. In summary, 90 litterbags were investigated throughout the period of sampling (i.e.3 rubber stands x 2 plots x 3 replicates x 5 collections).

Litterbag Collection and Nutrient Analyses

A single litterbag was collected from each sub-plot after: 1, 3, 6, 9, and 12 months respectively from July 2005 to July 2006. This sampling regime was chosen in order to be able to compare mass loss over time at three month interval. After each collection, litterbags were gently cleaned by hand to remove extraneous materials attached (e.g. sand and soil particles and detritus), oven-dried at 60°C on the day of collection until weight stabilization. After drying, the litterbags were weighed and the mass loss percentage was determined. The fraction of litter decomposed was calculated as the difference between the mass of litter initially present in the litterbag and the mass of the remaining litter on a given time. Samples were milled in laboratory mill equipment, and were analyzed for total contents of N, P, lignin and other elements (such as Na^+, P, Ca^{2+}, K^+, and Mg^{2+}). A micro-Kjeldahl digestion method and Technicon Autoanalyzer was used to determine the total N. For phosphorous, the ascorbic acid method was used (Rezende *et al.*, 2001). Total organic matter was estimated as loss-on-ignition after incineration of known mass at 500°C for two hours. The carbon content was estimated as Wesemael (1993). The structural components (e.g. lignin and cellulose), were obtained by the acid detergent fibre method (van Soest, 1963), and for cations (Na^{+}, Ca^{2+}, K^{+}, and Mg^{2+}) using nitric acid digestion, followed by analysis with atomic absorption (Perkin-Elmer Corporation, Norwalk, CT, USA).

The remaining mass in the litterbags (%RM) and remaining amount of mineral and organic nutrients were calculated as percentage of initial amount (Wesemael, 1993). Decay constants (k) were obtained assuming simple negative exponential decay (Olson, 1963):

$$x = x_0 e^{-kt}$$

where x is the weight remaining at time t, x_0 is the original mass, e is the base of the natural logarithm and k, the decay rate coefficient (Olson, 1963), was fitted to the weight loss data. Half-lives ($t_{0.5}$) of decomposing litter (i.e. the theoretical time required for decomposition of 50% of the mass) were obtained following the model by Olson (1963). Nutrient content of decomposing leaf was derived as:

$$\%\ Nutrient\ remaining = \left(\frac{C}{C_o}\right) x \left(\frac{DM}{DM_o}\right) x\ 10^{2}$$

where C is the concentration of the element in litter in the time of sampling; C_o, the concentration of element in the initial litter kept for decomposition; DM, the mass of dry matter at the time of sampling and DM_o, the mass of dry matter kept for decomposition (Bockheim *et al.*, 1991).

Statistical Analyses

The differences in data was obtained by Tukey test with $p<0.05$ after application of one-way ANOVA. All statistical analyses were performed using SPSS for windows Version 11.0 (SPSS, 2003).

Results and Discussion

The soils used in this study are characterised by the quick and complete transformation of organic matter and the rapid removal by leaching of decomposition products, soluble salts, exchangeable bases, and silica (Lal, 1989). They do not differ significantly in their chemical and biological characteristics.

Table 1. Chemical properties in soil depth (0-20cm) under Rubber (*Hevea braziliensis*) plantation

Age	Org. C (%)	Tot. N (%)	C/N	P	Ca	Mg	K	Na
				←	mg/kg $ha^{-1}yr^{-1}$			→
40-year-old	38.6	2.3	16.9	6	82	31	24	32
15-year-old	54.3	4.8	11.3	10	60	26	22	28
5-year-old	40.5	4.2	9.6	5	105	50	49	36

Although, the initial nutrient levels of leaf litters do not differ significantly ($P < 0.05$) among the rubber age stands (Table 2). However, the initial nutrient contents of the leaf litter of younger trees i.e. the 15 and 5-year-old rubber stands are relatively higher than the 40-year-old rubber stand (Table 2). Litter from the different rubber age stands differed in initial concentration of lignin nutrients, C/N ratios, and N/P ratios. Initial C/N ratios ranged from 36 to 41.

Table 2. Initial Litter Chemistry

	Litter Nutrients (%)							LOI[1]	N/P	C/N[2]	Lignin/N
Age stand	N	P	Ca	Mg	K	Lignin[§]	Cellulose				
40-year-old	0.61	0.025	4.38	0.18	1.25	20	32	87	35	41	20.2
15-year-old	0.73	0.026	5.20	0.29	1.95	13	33	96	45	36	28.3
5-year-old	0.71	0.022	5.00	0.20	1.45	16	30	78	26	41	17.9

[§] *Lignin is acid detergent lignin (van Soest, 1963).*
[1]*Loss on ignition at 500°C (%)*
[2]*Carbon content = (LOIx10)/2 ((mg.g^{-1}dry matter) (Rezende et al., 2001)*

The lower the initial C/N ratios of litter, the more rapid were the decomposition process. C/N ratio in the bodies of microorganisms is not only less variable but also much lower. It falls between 5:1 and 10:1 and in the soil microbes must incorporate into their cells about eight part of carbon for every one part of nitrogen (i.e. assuming the microbes have an C/N ratio of 8:1) (Snowdon *et al.,* 2005).

Decomposition rate

Mean dry weight of the remaining litter in the different rubber stands during the decomposition period are presented in (Table 3). A significant mass loss ($p<0.05$) was observed in the first three to four months for all the rubber stands. In the 15-year-old plot, a significant reduction in mass (c. 70%) was observed within the first six months ($p<0.05$). Many workers (Aranguren *et al*., 1982; Kumar and Deepu, 1992; Kunhamu, 1994; Hegde, 1995, Carvalho, *et al*., 2005) had reported a fast rate of decomposition for the litter of tropical tree species. Half lives ($t_{0.5}$) and decomposition constant (k) were 9 month and 0.678 respectively for the 15-year-old stand and 10.5months, 0.447 and 11 months, 0.408 for the 40-and 5-year-old stands respectively (Table 3). The value of k indicates the relative rate of decomposition in a month. This suggest that 67.8% of 15-year-old age stand leaf litter, 44.7% of 40-year-old age stand leaf litter, and 40.8% of 5-year-old age stand leaf litter are decomposed in one year. These correspond to half-lives ranging from 9 months to 11 months. The modestly higher decay rates observed in the 15-year-old plot may be attributed to favourable site conditions and impact of soil biota.

Table 3. Annual rate of decomposition (k) and half-life ($t_{0.5}$) in months of the three rubber age stands

Age	k	$t_{0.5}$
40-year-old	0.447	10.5
15-year-old	0.678	9
5-year-old	0.408	11

,,
Soil temperature and moisture content have being linked to the rate of decomposition. At favourable condition such as increasing temperature, there is an exponential increase in decomposition. In the present study, constant high temperature and moisture content ensure the fast rate of decomposition.

Table 4. Mean dry weight (g) $\pm$SD (n=3) of litter remaining in 40, 15, and 5-year-old rubber stands.

Time (months) 40	15	5	F	P	
0	**5.0**	**5.0**	**5.0**		
1	3.65 ± 0.12^{a}	3.01 ± 0.15^{b}	3.71 ± 0.1^{a}	23	<0.01
3	3.02 ± 0.2^{c}	2.45 ± 0.19^{d}	3.35 ± 0.21^{c}	27.3	<0.01
6	2.62 ± 0.14^{e}	1.38 ± 0.12^{f}	2.82 ± 0.1^{e}	19.2	<0.01
9	2.25 ± 0.23^{g}	0.80 ± 0.02^{h}	2.42 ± 0.25^{g}	10.5	<0.01
12	1.09 ± 0.19^{i}	0.11 ± 0.05^{j}	1.16 ± 0.14^{i}	20.6	<0.01

Note: Same letter indicate samples which are not significantly different (P <0.01) within a row using Fisher's LSD

Soil acidity extremes (pH < 4 or > 9) may severely reduce decomposition rate (Snowdon *et al.*, 2005), however, for the study site soil pH was between 6.20 and 6.56, which is favourable to rapid decomposition of litter. Percentage of litter remaining at three monthly intervals in the study sites were presented in Fig. 1. The time taken for 95% decay was moderately faster in the 15-year-old rubber stand than the 40-year-old and 5-year-old plots. For instance, weight loss (95%) was completed by the by the 9th month in the 15-year-old stand while it was 10th and 11th month respectively in the 40-year-old and 5-year-old plots respectively.

Between the 6th and 9th month all leaves from the different rubber stands increase in weight and subsequently the rate of decomposition decreased rapidly. The litter from the 15-year-old stands decomposed faster than other stands, and thus releases nutrients faster. The lowest decomposition was found in the 5-year-old stand. Moreover, the residual litter mass declined exponentially with time in the three plots (r^2 values, 0.92 for 15-year-old, 0.88 for 40-year-old and 0.80 for 5-year-old plots respectively). This indicated a good fit of the model to the observed data.) (Biam *et al.*, 1990; Martius *et al.*, 2004). Percentage weight of litter remaining after the 12 months period was 8 % for the 15-year-old rubber stand, while that of the 40- and 5-year–old stands were 22 % and 23 % respectively The value of k in the model was estimated to be 0.447 for the 15-year-old stand, while k was 0.538 and 0.574 for the 40-, and 5-year-old stands respectively.

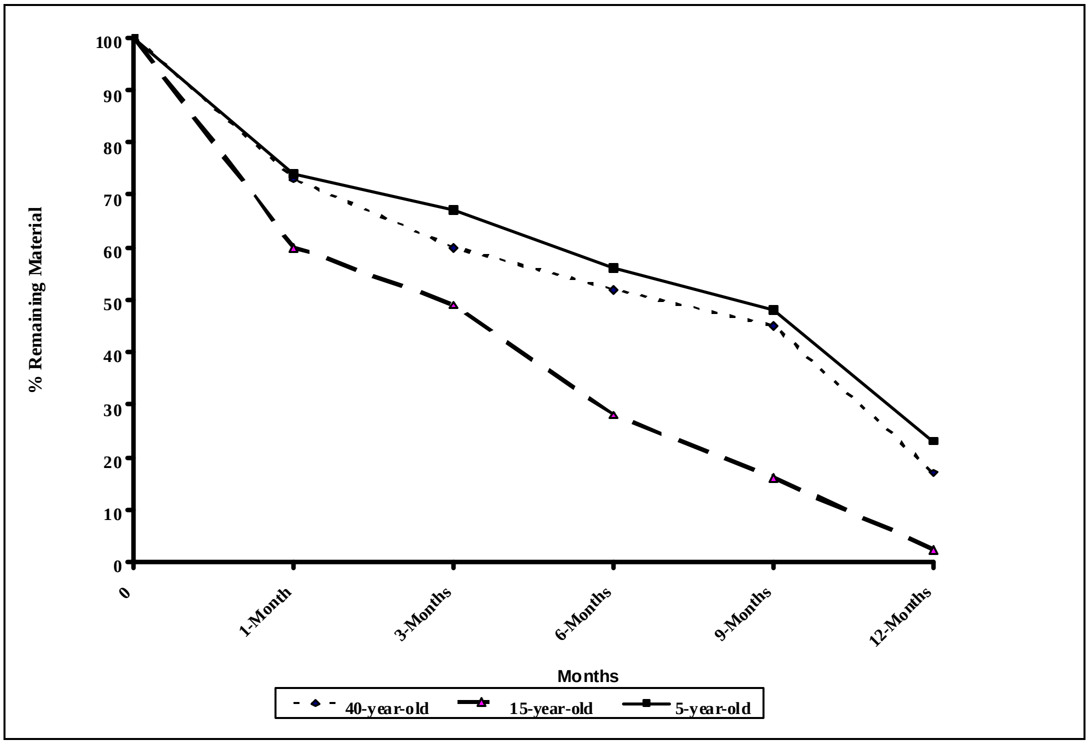

Fig 1: Weight loss of rubber (*Hevea brasiliensis Willd. Muell-Arg. Euphorbiaecae*) leaf litter under 40-, 15-, and 5-yearold plantation.

The decomposition pattern was in two phases with an initial rapid phase followed by a slower phase. In these phases could have occurred the loss of soluble and easily decomposable compounds, which characterizes the first phase of decomposition (Songwe *et al.*, 1995). Hegde (1995) suggested that this might have triggered the activity of soil fauna and soil microbes, which are responsible for the decomposition. Soon after there was a tendency to stabilization in mass loss as a result of the breakdown of more simple compounds as sugar, amino acids as well as lignocellulose material (Rezende *et al.*,2005). These compounds could have inhibited mass loss. In addition, the high leaching losses of water-soluble fractions from the decomposing materials during the rainy periods might have resulted in a heavy mass loss during the initial phase

The rapid rate of decomposition of rubber litter from July to November indicates its significant role in crop production. The organic recycling achieved by litter decomposition and its subsequent impact on sustaining crop productivity in rubber plantation with large quantity of leaf litter was thus reiterated. Faster initial decay rates may reflect easily decomposable tissue and readily mineralizable elements (Swift *et al*., 1979; Sundarapandian and Swamy, 1999). Residual tissues decompose less rapidly and therefore relatively slower rates in later stages may be attributed to accumulation of more resistant or stable constituents in residual litter mass (Sundarapandian and Swamy, 1999, Sreekala *et al*., 2001). There are reports that litter decomposed completely within 7 months in moist deciduous and moist evergreen forests in tropical environment and more or less one year in temperate deciduous forests (Ovington, 1962). Nevertheless, Singh *et al.* (1993) reported that only 3 to 5 months were required for complete decomposition of leaf litter of some important tree species in tropical deciduous forests. The implication of the foregoing is that nutrient cycling in tropical ecosystems not only varies regionally, but also locally in response to topo-edaphic conditions and variations in floristic composition of vegetation.

Decomposition rates of leaf litter from the different rubber age stands differ slightly (with the 15-year-old stand being higher) and this can be related to the initial nutrient composition of the leaves (Melillo *et al.,* 1982; Bubb *et al.,* 1998). Other authors have attributed variability to morphological characteristics of foliage (Songwe *et al.,* 1995). Other factors include the properties of the substrate (leaves), the availability of moisture and temperature and the N content of the leaves (Sreekala *et al*., 2001).

Net change in C remaining after 52 weeks (Table 5) exhibited a pattern nearly identical to percent mass remaining among the three rubber stands. Temporal patterns in C remaining through the study period also closely resemble those of mass loss. N content in the initial litter was lower than the organic C content for all stands because tree species tend to reallocate higher proportion of leaf N to perennial tissues before leaf fall, therefore making a more efficient use of N (Chapin, 1980). Moreover, decay of organic materials can be delayed if insufficient nitrogen to support microbial growth is neither present in the material undergoing decomposition nor available in the soil solution in the first six months. The net percentage of P remaining in the plantation site also exhibited a pattern similar to C. Initial loss of P in the leaf litters could be attributable to leaching. After 12 months, all the treatments (leaves from different age stands) showed a release of P, but this did not exceed the remaining amount of nutrient (Table 5).

Table 5: Percentage C, N and P remaining in the leaf litter at the rubber plantation after 52 weeks. Standard errors of the means are in parentheses.

Age	Carbon Remaining (%)	Nitrogen Remaining (%)	Phosphorous Remaining (%)
40-year-old	34.2A (8.3)	56.4A (4.7)	52.2A (6.1)
15-year-old	21.3B (3.6)	35.9B (1.5)	34.2B (4.5)
5-year-old	26.5C (1.1)	38.3C (0.7)	44.2C (2.8)

Means within each age stand with the same uppercase letter are not significantly different at alpha 0.05 level

Litter quality factor important to decomposition include composition of organic matter, C fractions (such as extractables, cellulose, hemicellulose, lignin), concentration of polyphenols (including tannins) and nutrient content (e.g. C: N, lignin: nitrogen ratio). Litter with high concentration of nutrient and lower concentration of lignin and polyphenols will decompose more rapidly and net mineralization begins earlier (Snowdon *et al*., 2005). Low values of C/N, lignin and polyphenols all contribute to high litter quality and high speed of decomposition (Table 6). Cellulose decrease in all treatments however, there were no significant differences. This decrease was approximately 50%, 46% and 42% for the 15-, 40-, and 5-year-old stands respectively. The C/N ratios of litter affects soil processes such as the rates of decomposition and net N mineralization of organic matter and the availability of nutrients to the soil (Handayanto *et al.,* 1997; Snowdon *et al*., 2005). The ratio of carbon to nitrogen (C/N) in organic residues in the soils is important for two reasons: (i) intense competition among microorganisms for available soil N occur when residues having high C/N ration are added to soils, and (ii) the C/N ratio in residues helps determine the rate of decay and the rate at which nitrogen is made available to plants (Pagioro and Thomaz, 1998; Issac and Nair, 2004; Snowdon *et al*., 2005).

Table 6. Litter Quality in relation to lignin content, polyphenols content and C/N ratios of the three rubber age stands

Age	Lignin %	Polyphenols %	C/N	Decomposition Constant (k)*	Litter Quality
40-year-old	18	2.5	44	0.135	Medium
15-year-old	8	1.4	15	0.230	High
5-year-old	11	3.2	29	0.164	Medium

** Note the larger the decomposition constant k, the faster the decomposition.*

Availability of nutrient from other soil pools also enhances decomposition rates if nutrient concentrations are low in the litter. The 15-year-old rubber stand thus have better litter quality than the other two stands going by the amount of nutrient returned.

Concentration of nutrients in decomposing litter

Release of nutrients during the decomposition showed that Ca^{2+}, N, and P tended to be immobilized, with rapid weight loss. The litters from the 15-year-old rubber stand lost only 34 % of P during the 12 months decomposition an indication that partial immobilization of P occurred. Concentrations of P in all rubber stands increased in the first 6 months, followed by a gradual decrease latter. Available P is completely retained in within the plant-soil-microbe system because P tend to accumulate over time in more refractory soil organic pool an “occluded” inorganic pool (Crews *et al*., 1995).This causes significant hydrologic loss of $PO^{3-}{}_4$ and dissolved organic P (DOP) (Hedin *et al*., 2003).

Calcium loss rate was also less than the weight loss for all the three rubber stands e.g. a 29 % decomposition loss of Ca^{2+} compared to a 50 % weight loss in the 15-year-old stands. There was no significant loss of calcium from the rubber stands during the study, as it remains consistent during the study. Evidence exists that litter and soil-inhibiting fungi can concentrate substantial amounts of calcium (Cromack and Monk, 1975). Although the initial K^+ levels differed among different age stands, the changes in concentration of these elements were similar for all three rubber stands. Percentage K^+ and Mg^{2+} loss rates were greater than weight loss for the 40 and 5-year-old rubber stands. K^+ loss during the first 6 months for the litter in the 15-year-old rubber stand was 56 %, while K^+ loss was 58 % for 40-year-old litter. Mg^{2+} loss was 48 % from 15-year-old litter and it was 53 % from 40-year-old litter. Major reduction in K^+ occurred in the first 6 months, followed by little change subsequently. Nutrient release from decomposing leaf litter is in the order of $K^+ > Mg^{2+} > Ca^{2+} > N > P$.

Conclusion

At the end of the 12 months (52 weeks), increases in weight loss followed by a decrease in the subsequent collections were found throughout the study. This is a common fact in studies using the litterbag technique (Olah, 1972; Swift *et al.,* 1979; Rezende *et al.,* 2001). The rate of decomposition of rubber litter in the different rubber stand varied significantly, but followed the same pattern of initial rapid decomposition. Favourable moisture and temperature regimes during this season (July-November) must have contributed towards the faster rate of decomposition. While litter decreases with time, total nutrient content can increase, decrease or fluctuate according to the balance of gains and losses of nutrients by decaying litter components. The result of the study revealed that after the sixth month, the decomposition process continued, though at a slow rate, gradually reached a maximum by the end of the year for the 15-year-old stand. This implied that even after one year of exposure not all the original material was decomposed. It is well known that consequent upon decomposition of any organic matter added to soil, the native soil organic matter also begins to decompose and in this process, more quantities of nutrients are liberated for use by the plant through priming action. The decomposition rates for rubber in this study lies in the upper part of those reported for temperate forests and in the lower parts of the range for tropical forests (Songwe *et al.,* 1995).

Comparison of decay rates and final per cent mass remaining among the tree stands in the study area revealed interesting patterns. Although the litterbags in the three stands were exposed to similar microenvironment and edaphic conditions, the 15-year-old stand decay significantly faster than the other stands. Pattern of change in the concentration of N, P, and K was approximately linear to mass loss. The largest decay coefficients were observed in the 15-year-old rubber plantation during the peak rainfall. This shows that the large litter stock accumulated during the dry season were rapidly decomposed in the following months. It also point to the effects of the heavy rainfall prevailing in these months on litter decomposition (including fast leaching and high humidity. The study also implicated that litter quality is a primary factor governing decomposition. Bargali *et al.* (1993) report that the older plantations (40 years old) of *Eucalyptus* cause a chemical and biological degradation to soils, and this collaborate the results of this study which revealed that the 40-year-old rubber plot decompose slowest and return lesser amount of nutrient to the soil. Base on this study, we can conclude that the 15-year-old rubber plot exhibited faster rate of decomposition indicating that the old trees that have passed their productive age need to be felled and replanted, while external inputs is needed in the 5-year-old plot to enhance nutrient cycling and promote sustainable production. However, considering the importance of trees in reducing global warming, The older trees can be used for rubber agroforestry purpose as practiced in the Amazonia and Indonesia until it can no longer produce latex. Rubber wood is also important for furniture making which can be a long-term store of carbon.

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References

Aber, J.D., and Melillo, J.M. (1991). *Terrestrial Ecosystems.* Saunders College Publ., Orlando, Florida.

Aerts, R. (1997).Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship. *Oikos*, 79:439-449.

Aranguren, J., Escalente, G. and Herrera, R. (1982). Nitrogen cycle of tropical perennial crops under shade trees: II Cacao. *PI. Soil*, 67: 259-269

Aweto, A.O. (1987). Physical and nutrient status of soils under rubber (*Hevea brasilensis*) of different ages in southwestern Nigeria. *Agricultural Systems*, 23:63-72.

Bargali, S.S., Singh, S.P. and Singh, R.P. (1993). Patterns of weight loss and nutrient release from decomposing leaf litter in and age series of *eucalyptus* plantation. *Soil Biology Biochemistry*.25: 1731-1738

Berg, B., Berg, M.P., Bottner, P., Box, E., Breymeyer, A., Calvo de Anta, R. (1993). Litter mass loss rates in pine forests of Europe and Eastern United States: some relationships with climates and litter quality. *Biogeochemistry*,.20: 127-159.

Biam, J. M., Parmelee, R. W. and Beare, M. H. (1990). Decay Rates, Nitrogen Fluxes, and Decomposer Communities of Single- and Mixed-Species Foliar Litter. *Ecology*, 71(5) 1976-1985

Bolan, N. S., Adriano, D. C. and de-la-Luz, M (2004). *Dynamics and environmental significance of dissolved organic matter in soil.* Third Australian New Zealand Soils Conference, 5–9 December 2004, University of Sydney, Australia.

Bockheim, J.G., Jepsen, E.A and Heisey, D.M. 1991. Nutrient dynamics in decomposing leaf litter of four tree species on a sandy soil in northwestern Wisconsin. *Can. J. For. Res.*, 21:803-812

Bubb, K. A., Xu, Z.H., Simpson, J.A., and Saffigna, P.G. (1998). Some nutrient dynamics associated with litterfall and litter decomposition in hoop pine plantations of southeast Queensland, Australia *Forest Ecology and Management*, 110: 343-352.

Budelman, A (1988). The decomposition of the leaf mulches of *Leucaena leucocephala, Gliricidia sepium* and *Flemingia macrophylla* under humid tropical conditions. *Agrofor. Sys*., 7: 33–45.

Cadisch G and Giller K E (eds) (1997). *Driven by nature – Plant Litter Quality and Decomposition*. CAB International, Wallingford.

Carvalho, P., Thomaz, S. M. and Bini, L. M. (2005).Effects of temperature on decomposition of a potential nuisance species: the submerged aquatic macrophyte *Egeria Najas* Planchon (Hydrocharitaceae). *Braz. J. Biol.*, 65 (1): 51-60.

Chapin, F.S. III (1980). The mineral nutrition of wild plants. *Ann. Rev. Syst*. 11, 233-60.

Crews, T.S., Kitayama, K., Fownes, J.H., Riley, R.H., Herbert, D.A., Mueller-Dumbios, D. and Vitousek, P.M. (1995). Changes in soil phosphorous fractions and ecosystem dynamics across a long chronosequence in Hawaii. *Ecology*, 76: 1407-1424.

Cromack, K. Jr. (1973). Litter production and decomposition in a mixed hardwood watershed and a white pine watershed at Cowetta Hydrologic Station, North Carolina. Dissertation, University of Georgia, Athens.

Cromack, K. Jr. and Monk, C.D. (1975). Litter production, decomposition and nutrient cycling in a mixed hardwood watershed and a white pine watershed. In: Gentry, J.B and Smith, R.R (eds.) *ERDA Symposium (Conf - 740513)*, 18: 609-624.

Ewel, J.J. (1976). Litterfall and leaf decomposition in tropical forest succession in Eastern Guatemala. *J. Ecol.* 64: 2930308

Ewel, J.J., and Hiremath, A.J. (1998). Nutrient use efficiency and the management of degraded lands. In: *Ecology today: An anthology of contemporary ecological research*. Gopal, B., *et al*. (eds.). Pp.199-215. International Scientific Publications, New Delhi, India.

Finzi, A. C., Allen, A.S., Delucia, E. H., Ellsworth, D.S., and Schlesinger, W.H. (2001). Forest Litter Production, Chemistry, and Decomposition Following Two Years of tree-Air CO_2 Enrichment. *Ecology*, 82 (2) 470–484.

Fogel, R., and K. Cromack. (1977). Effect of habitat and substrate quality on Douglas fir litter decomposition in western Oregon. *Can. J. Bot.*, 55: 1632–1640.

Gessner, M. O., Dobson, M., & Chauvet, E. (1999). A perspective on leaf litter breakdown in streams. *Oikos*, 85: 377-384.

Greenway, M. (1994). Litter accession and accumulation in a *Melaleuca quinquenervia* (Cav.) S.T. Blake wetland in southeastern Queensland. *Aust. J. Mar. Freshwater. Res.*, 45:1509–1519.

Handayanto, E., Cadisch, G and Giller, K. E. (1994). Nitrogen release from prunings of legume hedgerow trees in relation to quality of the prunings and incubation method. *Plant Soil*, 160: 237–248.

Handayanto, E., Giller, K. E. and Cadisch, G. (1997). Regulating N release from legume tree prunings by mixing residues of different quality. *Soil Biol. Biochem*., 29: 1417–1426.

Hansen, S., H.E. Jensen, N.E. Nielsen, and H. Svendsen. (1991). Simulation of nitrogen dynamics and biomass production in winter wheat using the Danish simulation model DAISY. *Fertilizer Research*, 27:245–259.

Hartemink, A. E. and O'Sullivan, J.N. (2001).Leaf litter decomposition of *Piper aduncum, Gliricidia sepium* and *Imperata cylindrica* in the humid lowlands of Papua New Guinea. *Plant and Soil*, 230: 115–124, 2001.

Hedin, L.D. Vitousek, P.M., Matson, P.A. (2003). Nutrient losses over Four Million Years of Tropical Forest Development. *Ecology,* 84 (9): 2231-2255.

Hegde, R. (1995). Nutrient content and decomposition of leaf litter of *Acacia mangium* Willd as affected by season and field conditions. M.Sc. (For.) Thesis, Kerala Agricultural University, Thrissur

Helmisaari, H. (1992). Nutrient translocation in *Pinus sylvestris* stands. *Forest Ecology and Management*. 31: 347-367.

Hieber, M., and Gessner, M. O. (2002). Contribution of stream detritivores, fungi, and bacteria to leaf breakdown based on biomass estimates. *Ecology*, 83, 1026-1038.

Hobbie, S.E. and Gough, L. (2004). Litter decomposition in moist acidic and non-acidic tundra with different glacial histories. *Oecologia*. 140: 113-124.

Hochella, MF Jr (2002) There's plenty of room at the bottom. *Geochimca et Cosmochimica Acta*, *66*: 735-743.

Hopkins B. (1966). Vegetation of the Olokemeji Forest Reserve, *Nigeria. J. Ecol.*, 54: 687–703.

Isaac, S. R and Nair, M. A. (2004). Decomposition of wild jack (*Artocarpus hirsutus* Lamk.) leaf litter under subcanopy and open conditions. *Journal of Tropical Agriculture,* 42 (1-2): 29-32.

Jenkinson, D.S., and J.H. Rayner. (1977). The turnover of soil organic matter in some of the Rothamsted classical experiments. *Soil Sci.,* 123: 298–305.

Johansson, M.B., Berg, B. and Meentemeyer, V. (1995). Litter mass loss rates in late stages of decomposition in a climatic transect of pine forests: long-term decomposition in Scots pine forest. *Canadian Journal of Botany,* 73:1509-1521.

Jones, J. B. and Warner, M. H. (1969). Analysis of plant-ash solutions by spark-emission spectroscopy. *Developments in Applied Spectroscopy*. p. 152-160.

King, J.S., H.L. Allen, P. Dougherty, and B.R. Strain. (1997). Decomposition of roots in loblolly pine: effects of nutrient and water availability and root size class on mass loss and nutrient dynamics. *Plant and Soil,* 195:171-184.

Kulshrestha, M and Gopal, B. (1982). Decomposition of freshwater wetland vegetation II. Aboveground organs of emergent macrophytes. In: B. Gopal, R.E. Turner, R.G. Wetzel and D.F. Whigham (eds*). Wetland: Ecology and management. Jaipur: National Envt. Ecology,* 282p.

Kumar, B.M. and Deepu, J.K. (1992). Litter production and decomposition dynamics in moist deciduous forests of the Western Ghats in Peninsular India. *For. Ecol. Mange., 50*: 181- 201.

Kunhamu, T.K. (1994). Nutrient content and decomposition of leaf biomass of selected woody tree species. M.Sc. (For.) thesis, Kerala Agricultural University, Thrissur.

Lal, R. (1989). Agroforestry systems and soil surface management of a tropical alfisol: II Water runoff, erosion and nutrient loss. *Agroforestry Systems,* 8: 97-111.

Lavelle, P., Barros, C., Blanchart, E., Brown, G., Desjardins, T., Mariana, L and Rossi, J. (2001). SOM management in the tropics: Why feeding the soil microfauna? In: Martius, C. *et al.* (eds.). *Management of Organic matter in tropical soils: Scope and Limitations.* Kluwer Academic Publishers, Dordrecht, The Netherlands. Pp. 53-61.

Lockaby, B.G. and Walbridge, M.R. (1998).Biogeochemistry. P.149-172. *In*: M.G. Messina and W.H. Conner (eds.). *Southern forested wetland ecology and management*. Lewis Publishers, Boca Raton. FL.

Lupwayi, N. Z. and Haque, I. (1998). Mineralization of N, P, K, Ca and Mg from Sesbania and Leucaena leaves varying in chemical composition. *Soil Biol. Biochem.*, 30: 337–343.

Martius, C., Höfer, H., Garcia, M.V.B., Römbke, J. and Hanagarth, W. (2004): Litterfall, litter stocks and decomposition rates in rainforest and agroforestry sites in central Amazonia. *Nutrient Cycling in Agroecosystems*, 68: 137–154, 2004. http://131.220.109.9/module/register/media/4b1d_LSP_Martius%20et%20al_2004.pdf Retrieved June 15 2005.

McClaugherty, C.A. Pastor, J., Aber, J.D. and Melillo, J.M. (1985). Forest litter in relation to soil nitrogen dynamic and litter quality. *Ecology*, 46: 266-275.

Melillo, J.M., Aber, J.D. and Muratore, J.F. (1982). Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology*, 63: 621–626.

Montagnini, F. 1(990). Ecology applied to agroforestry in the humid tropics. In: Goodland, R (ed.). *Race to save the tropics: ecology and Economic as a Sustainable Future*. Island Press, Washington DC. p. 49-58.

Montagnini, F., Gonzalez, E., Rheingans, L. and Porras, C. (1995). Mixed and pure forest plantation in the humid neotropics: a comparison of early growth, pest damage and establishment cost. *Comm. For. Rev*., 74*: 306*-314.

Mwiinga, R. D., Kwesiga, F. R. and Kamara, C. S. 1994. Decomposition of leaves of six multipurpose tree species in Chipata, Zambia. *For. Ecol. Manage.* 64: 209–216.

National Research Council (NRC) (2001). *Basic research opportunities in earth science.* National Academy Press, Washington, DC.

Nwoboshi, L.C. (1981). Nutrient cycling in a managed teak plantation ecosystem. II. Litterfall and macronutrient return to the forest floor. *Nig. Journal of Science*, 17: 23-28.

Nye, P.H. (1961). Organic matter and nutrient cycles under moist tropical forests. *Plant and Soil*, 13: 333-346.

Oglesby, K.A. and Fownes, J.H. (1992). Effects of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. *Plant and Soil,* 143: 127–132.

Olah, J., (1972). Leaching, colonization and stabilization during detritus formation. *Mem. Inst. Ital. Idrobiol., 29*: 105-127.

Olson, J.S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. *Ecology*, 44: 322-331.

Orimoyegun, S.O. and Kadeba, O. (1983). Potential of Obeche (*Triplochiton Scleroxylon* K. Schum) as a Leaf Vegetable. *Acta Hort. (ISHS), 123*:99-104 http://www.actahort.org/books/123/123_8.htm. Retrieved 11/06/06.

Ovington, J.D. (1962). Quantitative ecology and wood land ecosystem concept. *Adv. Ecol. Res*. 1: 103-192

Palm, C. A. and Sanchez, P. A. (1991). Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biol. Biochem*, 23: 83–88.

Rastetter, E.B., R.B. McKane, G.R. Shaver, J.M. Melillo, K.J. Nadelhoffer, J.E. Hobbie, and J.D. Aber. (1991). A general biogeochemical model describing the responses of the C and N cycles in terrestrial ecosystems to changes in carbon dioxide, climate, and nitrogen deposition. *Tree Phys.,* 9: 101–126.

Rezende, J. L. P., Garcia, Q .S. and Scotti, M. R. M. (2001). Laboratory decomposition of *Dalbergia nigra all. Ex. Benth and eucalyptus grandis W.hill ex*. Maiden leaves in forest and eucalypt plantation soils. *Acta Bot. Bras. 15*(3) Sao Paulo Sept./Dec. 2001. www.sciencedirect.acta/pubs/Rendezeetal/pdf. Retrieved 12/27/06

Singh, O., Sharma, D.C. and Rawat, J.K. (1993). Production and decomposition of leaf litter in sisal, teak, eucalyptus and poplar forests in Uttar Pradesh. *Indian For.,* 119: 112-120

Snowdon, P., Ryan, R and Raison, J (2005). Natural carbon accounting system: Review of C/N ration in vegetation, litter, and soil under Australian native forest and plantation. Technical Report. No. 45. http://www.greenhouse.gov.au/ncas Dept. of the Environment and Heritage. Australian Greenhouse Office. P. 1-60.

Soil Survey Staff (1975). Soil taxonomy; a basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, U.S. Department of Agriculture, *Agriculture Handbook* No. 436.

Soil Survey Staff. (1993). *Soil Survey Manual. USDA Handbook* No. 18. US Govt. Print. Office, Washington D.C. 437 pp.

Songwe, N.C. and Okali, D.U.U. and Fasheun, F.E. (1995). Litter decomposition and nutrient release in a tropical rainforest, Southern Bakundu Forest Reserve, Cameroon. *Journal of Tropical Ecology,* 11: 333-350.

Sparks, D.L. (2004) Grand challenges and opportunities in basic soil science research and the discipline of soil science. In 'Proceedings of the SuperSoil 2004. Retrieved from www.regional.org.au/au.asssi/supersoil2004/keynote/index.htm 12/27/06

Sposito, G. (1989). *The Chemistry of Soils.* Oxford University Press, New York.

SPSS. Statistical Package for Social Scientists (2003).Standard version 11. SPSS Inc. Chicago, Illinois.

Sreekala, N. V., Unnithan, Mercy George V. K. G., John, P. S. and Nair, R. V. (2001). Decomposition Dynamics of Cocoa Litter under Humid Tropical Conditions. *Journal of Tropical Agriculture,* 39: 190-192.

Starr, M., Saarsalmi, A., Hokkanen, T., Merilà, P. and Helmisaari, H.-S. (2005). Models of litterfall production for Scot pine (*Pinus sylvestris L.)* in Finland using stand, site and climate factors. *Forest, Ecology and Management*, 20: 215-225

Sundarapandian, S.M. and Swamy, P.S. (1999). Litter production and leaf-litter decomposition of selected tree species in tropical forests at Kodayar in the Western Ghats, India. *Forest Ecology and Management*, 123: 231-244.

Swamy H.R. and Proctor J. (1994). Litterfall and Nutrient Cycling in Four Rainforests in the Sringeri Area of the Indian Western Ghats. *Global Ecol. Biogeography,* 4(5): 155–165.

Swift, M.J., Heal, O.W. and Anderson, J.M. (1979). Decomposition in Terrestrial Ecosystems. Blackwell Scientific Publications: Oxford, U.K.

Tian, G., Kang, B. T. and Brussaard, L (1992). Effects of chemical composition on N, Ca and Mg release during incubation of leaves from selected agroforestry and fallow plant species. *Biogeochemistry,* 16: 103–119.

Tian, G., Brussaard, L., Kang, B. T. and Swift, M.J. (1997). Soil fauna-mediated decomposition of plant residues under constrained environment and residue quality conditions. In; Caddish, G and Giller, K.E. (eds.) *Drive by Nature*. CAB International, Wallingford UK. p.125-134.

Tian, G. and Badejo, M.A. (2001). Soil fauna and soil fertility. In: sustaining soil fertility in West Africa. *SSSA. Special Publ.,* 58:45-67

Trofymow, J.A., Moore, T.R., Titus, B., Prescott, C., Morrison, I., Siltanen, M., Smith, S., Fyles, J., Wein, R., Camire´, C., Duschene, L., Kozak, L., Kranabetter, M., Visser, S., (2002). Rates of litter decomposition over 6 years in Canadian forests: Influence of litter quality and climate. *Canadian Journal of Forest Research*, 32: 789–804.

Van Soest, P.J. (1963). Use of detergents in the analysis of fibrous feeds II. A rapid method for the determination of fibre and lignin. *Journal Association Official Agronomy Chemistry,* 46: *829*-835.

Wallace, J.B., Eggert, S.L, Meyer, J.L. and Webster, J. R. (1997). Multiple tropic levels for a forested stream linked to terrestrial litter inputs. *Science,* 277: 102-104.

Webster, J. R., and Benfield, E. F.(1986). Vascular plant breakdown in freshwater ecosystems. *Annual Review of Ecology and Systematics*, 17, 567-594.

Wesemael, B.V. (1993). Litter decomposition and nutrient distribution in humus profiles in some Mediterranean forests in southern Tuscany. *Forest Ecology and Management,* 57: 99-114.