CHANGES IN MASS AND NUTRIENTS DURING DECOMPOSITION OF *LEUCAENA LEUCOCEPHALA* AND *CYMBOPOGON CITRATUS* AND THE EFFECT OF SUBSTRATE QUALITY, WEATHER VARIABLES AND SOIL VARIABLES ON MASS LOSS DURING DECOMPOSITION IN A SEMI-ARID ECOSYSTEM, MADURAI, INDIA

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ILANGOVAN, M. & PALIWAL, K. 1996. Changes in mass and nutrients during decomposition of *Leucaena leucocephala* and *Cymbopogon citratus* and the effect of substrate quality, weather variables and soil variables on mass loss during decomposition in a semi-arid ecosystem, Madurai, India. The study of leaf litter decomposition in a semi-arid ecosystem, Madurai, using litterbags showed a reduction in the dry mass of *Leucaena leucocephala* by 70% and *Cymbopogon citratus* by 63% after one year of exposure. Initial chemical characteristics differed. Linear decay function and exponential decay function provided satisfactory fits to litter data. Different elements (C, N, P, K, Na, Mg, Mn, Cu, Zn, Pb) have different patterns of release over time and the gains and losses of mineral elements from litter over the time intervals are compared. Variations in leaf litter over the time intervals are compared. Variations in leaf litter disappearance are related to substrate quality, environmental and soil variables. The analysis indicated that C, K, Na, Mg for substrate quality; relative humidity for environmental variables; and soil temperature for soil variables were strongly correlated.

Key words: Decompostion - leaf litter - element release - semi-arid ecosystem - soil variables - substrate quality - weather variables

ILANGOVAN, M. & PALIWAL, K. 1996. Perubahan di dalam jisim dan nutrien semasa penguraian *Leucaena leucocephala* dan *Cymbopogon citratus* dan kesan kualiti substrat, pembolehubah cuaca dan pembolehubah tanih ke atas kehilangan jisim semasa penguraian di dalam ekosistem semigersang, Madurai, India. Kajian penguraian sarap daun di dalam ekosistem semigersang, Madurai, menggunakan begsarap menunjukkan pengurangan di dalam jisim kering *Leucaena leucocephala* sebanyak 70% dan *Cymbopogon citratus* sebanyak 63% selepas pendedahan selama setahun. Ciri-ciri kimia di peringkat awal adalah berbeza. Fungsi pereputan linear dan fungsi pereputan eksponen memberikan kesesuaian yang memuaskan kepada data sarap. Elemen-elemen yang berbeza (C, N, P, K, Na, Mg, Mn, Cu, Zn, Pb) mempunyai pola-pola pembebasan mengikut masa yang berbeza dan penerimaan dan kehilangan elemen-elemen mineral daripada sarap mengikut selang masa telah dibuat perbandingan. Perubahan-perubahan di dalam kehilangan sarap daun adalah berkaitan dengan kualiti substrat, pembolehubah-pembolehubah persekitaran dan tanih. Analisis menunjukkan bahawa C, K, Na, Mg, bagi kualiti substrat; kelembapan relatif bagi pembolehubah persekitaran; dan suhu tanih bagi pembolehubah tanih adalah berhubungkait rapat.

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Introduction

Disappearance dynamics play an important role in soil nutrient status in terms of nutrient cycling and maintenance of organic matter levels. In estimating decomposition rate, the assumption is made that the mass of the litter decreases according to a negative exponential decay curve, although there are frequent exceptions. Negative exponential decay models of Olson (1963) have been used in temperate decomposition studies but in comparatively few studies of tropical decomposition processes (Anderson *et al.* 1983).

The rates of disappearance and nutrient release depend much on the substrate quality, environmental factors, and other soil factors. Only a few of the published studies provide data on changes in absolute amounts of micro-elements in decomposing leaf litter (Bockheim *et al.* 1991). The macro-climatic variables are important regulators of decomposition processes but some studies showed that variables, rainfall and temperatures (La Caro 1974), and temperature and humidity (Pillers & Stuart 1993) do not affect the decomposition rate of leaf litter. In contrast, Maheswaran and Gunatilleke (1988) reported that rainfall affected the decomposition rate. Golley (1983) reported that litter decomposition is rapid due to the prevailing high humidity. Although these climatic variables have been related to decomposition studies for many ecosystems, very few studies are known for the semi-arid ecosystem. Furthermore, Jansson and Berg (1985) found that only a few attempts have been made to correlate field data of litter decomposition to soil temperature and moisture conditions.

The objectives of this study were to (i) measure decomposition of *Leucaena leucocephala* and *Cymbopogon citratus* leaf litter (ii) study changes in macro- and micro-element release, and (iii) establish relationships for mass loss rates with various abiotic variables in a semi-arid ecosystem of Madurai, India.

Materials and methods

Study area

The study was conducted at a plantation of *Leucaena leucocephala*, approximately 5 ha in size, and on grazing land, approximately 15 ha in size, in a semi-arid region of Madurai (latitude 9°55' N, longitude 78°10'E, elevation 132.5 m a.s.l.), India. The grazing land is located at the Biomass Research Centre, Madurai Kamaraj University, approximately 13 km west of Madurai, while the 7-y-old *Leucaena leucocephala* stand is located approximately 2 km north of the Biomass Research Centre, at the Botanical Garden, Madurai Kamaraj University, Madurai.

The study areas are in the Indian monsoon region, with a semi-arid ecoclimate. The average annual rainfall at the study sites was 575 mm. Mean high 38 °C (May) and mean low 20 °C (February) air temperatures were recorded. The climatic data (Figure 1) were obtained from the meteorological station, Madurai Kamaraj University, Madurai. Some physico-chemical characteristics of the study sites soil are summarized in Table 1 and Figure 2.

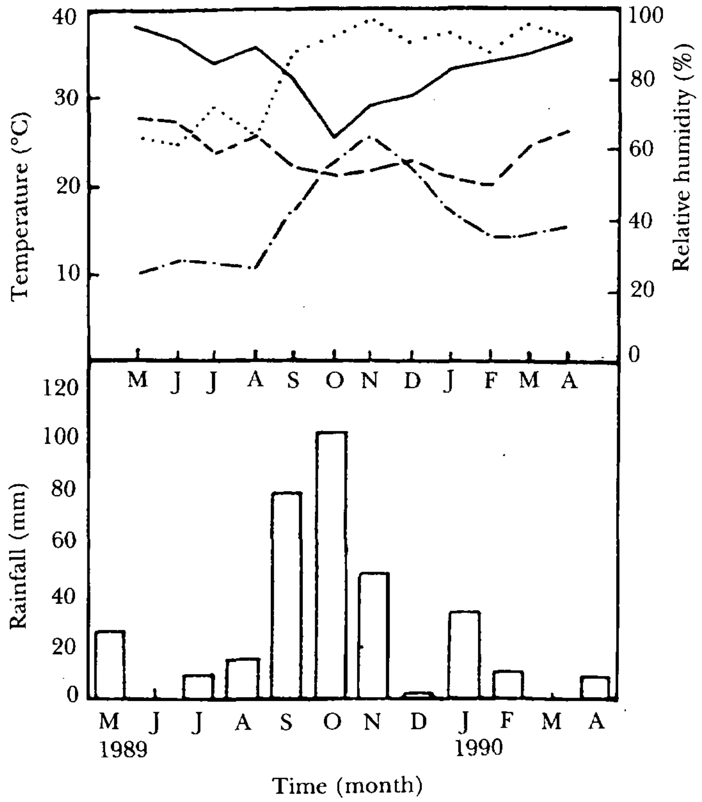

Figure 1. Weather conditions at the semi-arid ecosystem, Madurai, India. .... high humidity; – · – low humidity; —— high temperature; — — low temperature

Table 1. Summary of selected soil characteristics of sites

	Leucaena stand	Grazing land
Type	Laterite loamy sand	Sandy loam
Color	Reddish brown	Dark red
Bulk density (g cm^{-3})	1.81	1.60
EC (mmhos cm^{-1})	0.31	0.21
WHC (%)	46.20	43.80
pH	7.65	7.82
C (%)	0.290	0.410
N (%)	0.085	0.101
P (%)	0.014	0.013
K (%)	0.021	0.009
Na (%)	0.021	0.016
Mg (%)	0.024	0.032
Mn (%)	0.0041	0.0052
Zn (%)	0.0024	0.0003

Note: EC = electrical conductivity, WHC = water holding capacity. Soil measurements were made at a 30 cm depth.

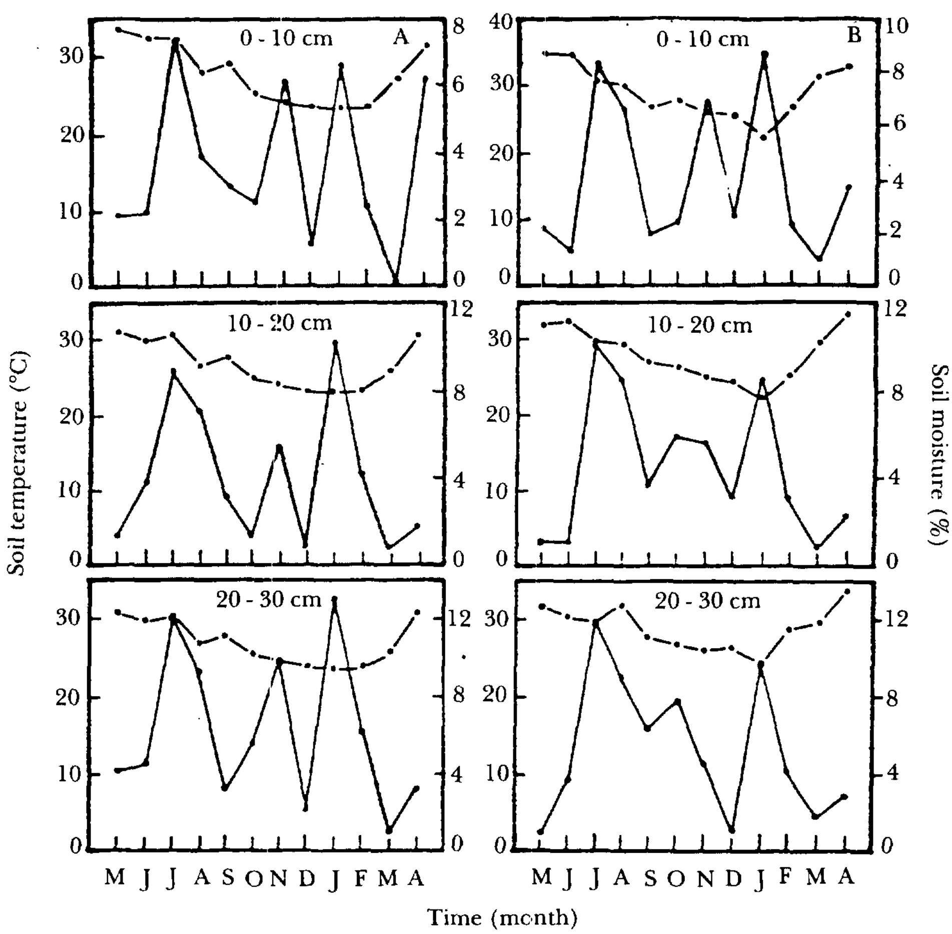

Figure 2. Mean monthly gravimetric soil water content (o— o) and soil temperature (●— ●) at three depths for the period, May 1989 - April 1990. A, *Leucaena leucocephala* stand; B, grazing land

The tree stand of *Leucaena leucocephala* plantation is exclusively composed of *Leucaena leucocephala*. There is no shrub layer or herbaceous cover in this stand. The grazing land had been grazed by cattle for several years until 1980, when 15 ha area was fenced. The vegetation of the grazing land comprises grasses and only scattered trees. *Cymbopogon citratus* and *Heteropogon contortus* are the dominant grasses of the grazing land. The other species are *Aristida adscensionis, Chrysopogon fulvus, Crotalaria angulata, Indigofera aspalathoides* and *Tephrosia purpurea.* The woody species are *Azadirachta indica* and *Hardwickia binata.* The dominant grasses made up 90% of the density of the total plant community, whereas the density of the other grasses was found to be very low.

Litter collection, field incubations and sampling of litterbags

A bulk sample of leaf litters from the plantation site was collected by suspending large tarpaulins beneath the trees during the peak period of litterfall (February - March). Each sample was sorted to remove other litter components, thoroughly mixed and air-dried. In the grazing land standing dead grasses of *Cymbopogon citratus* (upright, attached shoots) were clipped and litter (detached, but unfragmented grasses) were collected randomly from the study site, air-dried and mixed thoroughly.

The litter decomposition studies were carried out using a litterbag technique (Bocock *et al.* 1960). Litterbags measuring 20 × 20 cm (0.04 m^2), with a flexible nylon mesh size of about 1 mm, were prepared. Litterbags were loosely packed with 10 g of air-dried *Leucaena leucocephala* and *Cymbopogon citratus* leaf litters into each of 180 bags per species. Five additional samples of each species were oven-dried at 80 °C and weighed at the commencement of the experiment, to serve as the initial sample standard (i.e. 0% leaf decay). Samples were placed at 1 m intervals in the field on 7 April 1989 in a randomized block design within the study site. Ten bags per species were collected at 15-day intervals until 4 October 1989 and the last six collections were made at monthly intervals so that the final (eighteenth) collection occurred exactly one year after commencement of the experiment. The litterbags were transported directly to the laboratory and cleaned of ingrown roots, if any, brushed free of foreign materials and oven-dried at 80°C in a paper bag to constant weight. This temperature was chosen to attain optimal drying with minimal heat degradation. After drying the bags were weighed individually and then pooled to one sample for each sampling date, litter type and each set before chemical analyses were carried out.

Data analysis and calculations

For each composite litter sample, the remaining amount of each element was calculated by the equation

$$\text{Remaining amount of element (per cent of initial)} = (C/C_0) \times (DM/DM_0) \times 100$$

where C is the concentration of element in leaf litter at the time of sampling, C_0 is the concentration at the beginning of the study, DM is the mass of dry matter at the time of sampling, and DM_0 is the mass of dry matter at the beginning of the study. The percentage of organic matter remaining was calculated from the mean weight per species through time.

The final mass (M_2) and the initial mass prior to decomposition (M_1) were used to determine the per cent mass loss for each bag using the equation

$$\frac{(M_1 - M_2) \times 100\ M_1}{M_1}$$

Data were fitted to two models (Olson 1963):

i. linear mass loss

$$W_t/W_o = -kt \quad \text{or} \quad W_t = W_o - kt$$

ii. exponential mass loss

$$\text{In } (W_t/W_o) = -kt \text{ or } W_t/W_o = \exp(-kt)$$

where t is time (years), W_o is original mass (grams), W_t is mass remaining at time t, and k is instantaneous mass loss rate.

Soil sampling

A temperature probe was installed in hand-augured hole in each plot at three depths (0-10, 10-20, 20-30 cm). Three depths only were investigated because the soil below 30 cm in most plots was too compact to sample through. Weekly spot values of soil temperatures were read and summarised to obtain mean monthly temperatures. The time of sampling at each site was the same each week. Temperatures were read using a digital temperature indicator instrument (CT 804, Century, India).

Soils were sampled (0-10, 10-20, 20-30 cm depths) at five locations at each of the experimental sites. Soil samples were dried at 105 °C for 48 h and water content was determined gravimetrically and expressed as a percentage of dry soil mass.

Chemical analyses

Composite litterbag samples were ground in a laboratory mill equipped with a filter allowing particles of less than 1 mm diameter to pass. Soil samples were air-dried and sieved (<2 mm) before chemical analyses and all the chemical analyses were in triplicate.

Nitrogen and phosphorus were determined autoanalytically (Gradko International Limited, U.K.). K, Na, Mg, Mn, Cu, Zn, and Pb were determined by flame atomic absorption spectrophotometry using appropriate element lamps (Perkin Elmer 5000, U.S.A.). A 1% LaCl-solution was added to prevent interference against acid standards (Pawluk 1967) during K, and Mg analyses. Carbon content was determined by the modified Walkley-Black (partial oxidation) method (Anderson & Ingram 1989) using sucrose as standard. Absorbance was read at 600 nm in a spectrophotometer (LKB, Biochrom, Ultrospec II, England).

Statistical analyses

Simple and multiple linear regressions relating the dependent variable (relative decomposition rate) to the independent variables (substrate quality, weather factors and soil factors), with square correlation co-efficient (r^2) and its F statistics were calculated.

All statistical analyses were conducted using the SPSS (SPSS/PC+™ Update for V3.0 and V3.1 1989) statistical packages. Zar (1974) was used as a technical reference.

Results

Litter decomposition

Mean percentages of mass remaining for *Leucaena leucocephala* and *Cymbopogon citratus* are plotted in Figure 3. *Leucaena leucocephala* experienced a rapid phase of decomposition during the initial period of exposure. After an initial 45% loss of mass of *Leucaena leucocephala* during the first 3 months, the rate of decomposition decreased with only 25% loss for the next 12 months, whereas for *Cymbopogon citratus* only 19% of the initial amounts had been released during the 3 months and an additional 44% were lost over the rest of the decomposition period.

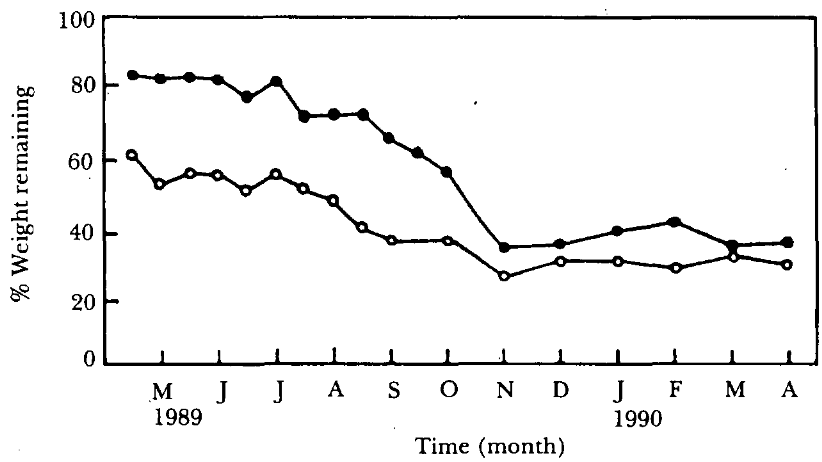

Figure 3. Percentage of original mass remaining through time. Note the time scale after October when rates was observed only at monthly intervals. (O - O), *Leucaena leucocephala*; (● - ●), *Cymbopogon citratus*

Leucaena leucocephala, due to its high N content (Table 2), disappeared at faster rates. The t_{50} or time for 50% of the mass to be lost were 0.58 and 0.69 year respectively for *Leucaena leucocephala* and *Cymbopogon citratus.* The estimated times for 50, 95, and 99% of initial mass lost and decomposition constants (k) are shown in Table 3.

Table 2. Chemical characteristics of the two litters

Constituent (%)	*Leucaena leucocephala*	*Cymbopogon citratus*
Carbon	64.491 (0.245)	59.192 (0.434)
Nitrogen	2.592 (0.059)	1.114 (0.057)
Phosphorus	0.112 (0.017)	0.069 (0.003)
Potassium	0.298 (0.001)	1.004 (0.007)
Sodium	0.116 (0.002)	0.142 (0.001)
Magnesium	0.638 (0.000)	0.176 (0.003)
Manganese	0.0034 (0.0001)	0.0008 (0.0000)
Copper	0.0018 (0.0003)	0.0014 (0.0001)
Zinc	0.2080 (0.0003)	0.0584 (0.0001)
Lead	0.0024 (0.0007)	0.0040 (0.0001)

Note: Values are means with standard deviations in parentheses.
Significant (α = 0.05) differences in litter chemistry, except Cu, among species were found (Student-Newman-Keuls test).

Table 3. Decomposition constants (k), time to 50, 95, and 99% decay for leaf litter

	Leucaena leucocephala	*Cymbopogon citratus*
Decomposition constant[a]	1.191	1.002
Time to 50% decay[b]	0.582	0.692
95% decay[c]	2.520	2.994
99% decay[d]	3.868	4.596

Note: [a] Calculated as $X = X_o e^{-kt}$, [b] Calculated as $0.693/k$, [c] Calculated as $3.0/k$,
[d] Calculated as $4.605/k$.

The per cent weight losses for both species were significantly related to time. A linear-decay model and exponential decay model (Table 4) fit the mass-loss data equally well.

Table 4. Regression statistics for the percentage of original mass remaining based on linear and exponential decay model

	Models of fit	Equation	r^2
Leucaena leucocephala	Linear fit	58.253 - 0.096t	0.814
	Exponential fit	$59.859\ e^{-0.002t}$	0.815
Cymbopogon citratus	Linear fit	89.050 - 0.170t	0.876
	Exponential fit	$95.106\ e^{-0.003t}$	0.852

Note: t - time in days. Regressions are significant at $p<0.0005$, F - test

Element dynamics

Absolute amounts of carbon in decomposing leaf litter declined over the 1- year period (Figure 4) and the loss takes place according to a negative exponential model ($p<0.0005$, for both species) (Table 5). In the initial stage of decomposition, the total amount of nitrogen in the litter decreased in each litter type (Figure 4). The percentage of original nitrogen mass or absolute amount of nitrogen (in % of initial) in decomposing leaves of *Leucaena leucocephala* and *Cymbopogon citratus*, in general, followed roughly the two phases, namely leaching and release. No net nitrogen immobilization took place in this study. The levels of P showed considerable fluctuations and exhibited initial leaching patterns in both species. The absolute amounts of K and Na decreased in all species. In the *Cymbopogon citratus* leaf litter K decreased with an approximately > 85% loss over the initial period, and with approximately 10% losses over the rest of the period. The absolute amount of Mg in *Leucaena leucocephala* declined over the study period, whereas in *Cymbopogon citratus* leaf litter the absolute amount first decreased, then increased and was then released gradually. The absolute amount of Mn increased over the 1-year period in *Cymbopogon citratus* leaf litter whereas the amount of Mn decreased for *Leucaena leucocephala*. After an initial increase in absolute amount Zn and Cu declined in the *Cymbopogon citratus* species. The absolute amounts of Zn and Cu decreased in *Leucaena leucocephala*. In decomposing *Leucaena leucocephala* and *Cymbopogon citratus* leaf litter, Pb increased over three months, did not change appreciably over the next incubation period, then was rapidly released (Figure 4).

Relationship between decomposition rates and abiotic variables

Mass remaining of each species at each collection interval during decomposition was linearly regressed against their litter quality parameters. There was a strong correlation between the mass remaining and the absolute amount of a carbon ($p<0.0005$) for both the litter types (Table 6). The percentage of *Leucaena leucocephala* mass remaining was significantly ($r = 0.782$, $p<0.0005$) related to the absolute amount of nitrogen but *Cymbopogon citratus* showed an overall lack of correlation ($r = 0.390$, $p<0.25$). Both the litter types failed to show significant correlation with the absolute amount of P. Decreases in K, Na, and Mg in decomposing *Leucaena leucocephala* and *Cymbopogon citratus* were best described by the linear function. There was no significant correlation between the mass remaining of both the litters and Mn and Pb. The absolute amount of Zn in decomposing *Cymbopogon citratus* leaf litter decreased approximately linearly as a function of mass loss; however, *Leucaena leucocephala* showed no correlation with Zn and Cu. The analysis (Table 6) indicated that carbon, potassium, sodium and magnesium gave the strongest correlations.

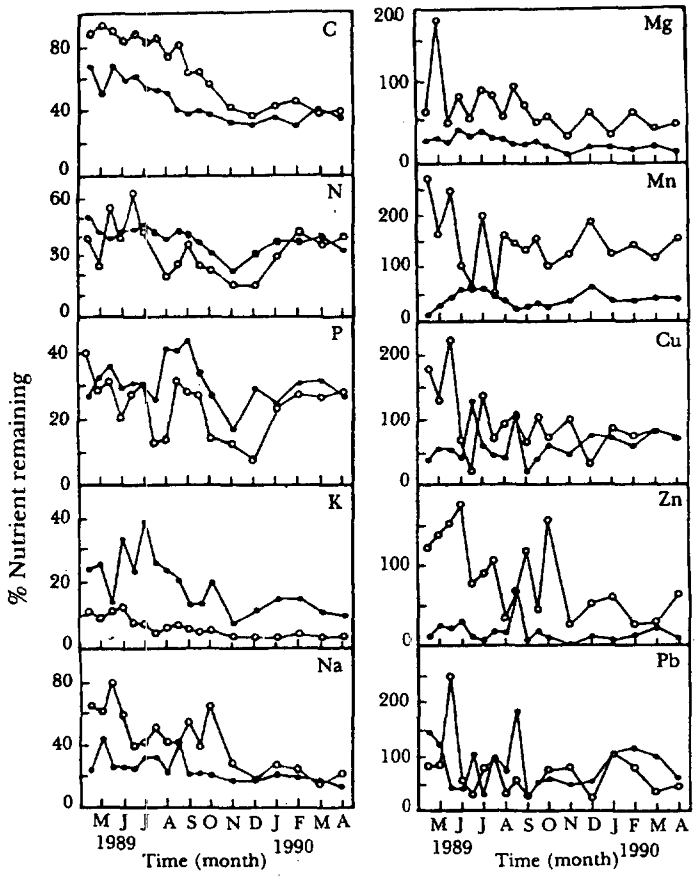

Figure 4. Changes in absolute amounts of elements with time in decomposing *Leucaena leucocephala* (O - O) and *Cymbopogon citratus* (● - ●) leaf litters. Time 0, not shown on graphs, is equal to 100%. Note that the Y-axis scales for the ten figures are not the same.

Table 5. Regression statistics for the percentage of carbon remaining in decomposing leaves based on exponential model

	Equation	r^2
Leucaena leucocephala	62.660 $e^{-0.002X}$	0.700
Cymbopogon citratus	103.550 $e^{-0.003X}$	0.867

Note: Regressions are significant at $p<0.0005$, F - test.

Table 6. Simple linear regression statistics of percentage of litter mass remaining and various litter quality (%) parameters

	Slope	Intercept	r^2
	Leucaena leucocephala		
Carbon	0.839	4.372	0.914
Nitrogen	1.322	-7.429	0.581
Phosphorus	0.411	30.107	0.058ns
Potassium	1.020	23.220	0.599
Sodium	0.783	23.250	0.307*
Magnesium	1.217	14.708	0.724
Manganese	0.065	40.061	0.007ns
Zinc	0.169	39.671	0.050ns
Copper	-0.046	45.746	0.012ns
Lead	0.026	40.668	0.010ns
	Cymbopogon citratus		
Carbon	0.869	4.685	0.962
Nitrogen	0.583	43.101	0.117ns
Phosphorus	0.938	39.359	0.181ns
Potassium	5.787	24.087	0.776
Sodium	0.832	26.161	0.638
Magnesium	0.300	42.741	0.281*
Manganese	0.079	50.438	0.055ns
Zinc	0.253	40.370	0.415**
Copper	0.182	44.542	0.215ns
Lead	0.110	54.027	0.085ns

Note: Regressions are significant at p<0.0005 except *(p<0.025), **(p<0.005), and ns(not significant; p>0.05), *F*-test.

Total rainfall in each month was not statistically correlated with mass loss (no regression equation is presented). However, the percentage weight remaining per month and the cumulative rainfall were negatively significantly related (p<0.0005) for both species (Table 7). Simple linear regression equations were developed for the relationship between mean air high temperature, mean air low temperature and average over high and low air temperatures and percentage of mass remaining for each litter type. All correlations are not significant except for mean air low temperature and mass remaining of *Leucaena leucocephala* (p<0.025) (Table 7). There was a significant negative correlation with the mass remaining of *Leucaena leucocephala* and *Cymbopogon citratus* and relative humidity. A linear combination of cumulative rainfall, mean monthly average of low and high air temperatures and mean monthly average of low and high relative humidities showed a significant (p<0.0005) relation with the percentage of mass remaining of *Leucaena leucocephala* and *Cymbopogon citratus* (Table 8).

Simple linear equations with soil temperature (Table 9) and multiple linear equations with the combination of soil temperature and soil moisture (Table 10) can be used for predicting annual percentage of mass loss from *Leucaena leucocephala* and *Cymbopogon citratus* leaf litters. Soil moisture showed a poor relationship with observed mass loss rates (Table 9).

Table 7. Simple linear regression statistics of percentage litter mass remaining and some meterological parameters

	Leucaena leucocephala		
Mean air high temperature (°C)	1.379	- 6.594	0.216ns
Mean air low temperature (°C)	2.697	- 23.804	0.424*
Average over high & low temperatures (°C)	2.163	- 21.841	0.325ns
Mean high relative humidity (%)	-0.730	99.748	0.839
Mean low relative humidity (%)	-0.607	63.444	0.508**
Average over high & low humidy (%)	-0.761	85.925	0.755
Cumulative precipitation (mm)	-0.079	54.699	0.906
	Cymbopogon citratus		
Mean air high temperature (°C)	2.089	-13.982	0.148ns
Mean air low temperature (°C)	4.013	-38.336	0.279ns
Average over high & low temperatures (°C)	3.218	-35.435	0.213ns
Mean high relative humidity (%)	-1.303	163.455	0.790
Mean low relative humidity (%)	-1.018	96.069	0.425*
Average over high & low humidy (%)	-1.323	136.677	0.679***
Cumulative precipitation (mm)	-0.149	84.453	0.947

Note: Regressions are significant at $p<0.0005$ except *($p<0.025$), **($p<0.01$), ***($p<0.005$), and ns(not significant; $p>0.05$), F - test. All correlations are negative except those for air temperature.

Table 8. Multiple regression equation of percentage of litter mass remaining against some meteorological parameters for leaf litter decomposed

	Equation	r^2
Leucaena leucocephala	$68.573 - 0.037T - 0.274H - 0.059P$	0.939
Cymbopogon citratus	$142.554 - 1.137T - 0.509H - 0.122P$	0.960

Note: Regressions are significant at $p<0.0005$, F - test. T, average of high and low air temperatures (°C); H, average of high and low relative humidity (%). P, cumulative precipitation (mm).

Discussion

A rapid loss of mass is almost universally observed in the first few weeks of leaf litter decomposition (e.g. Anderson 1973a, Harmon *et al.* 1990, Parsons *et al.* 1990, Sandhu *et al.* 1990, Berg & Ekbohm 1991, Reddy 1992 and many others). The regression statistics of mass remaining based on two models, linear-decay model and exponential-decay model, reveal that both the models were almost identical in this study. Vossbrinck *et al.* (1979), and Hart *et al.* (1992) also found that linear and exponentially models fit equally well. The initial rapid loss is by both physical leaching and microbial metabolism of water-soluble material (Ilangovan 1993). The data in Table 3 support the proposition of Olson (1963) that tropical litter has k values (year^{-1}) varying between 1 and 4, meaning that 95% of the initial biomass would disappear in 0.7-3 years.

Table 9. Simple linear regression statistics of percentage of litter mass remaining and soil parameters

	Slope	Intercept	r^2
	Leucaena leucocephala		
Soil temperature (°C) at			
0 - 10 cm	0.239	-25.331	0.570
10 - 20 cm	2.948	-38.086	0.528***
20 - 30 cm	3.117	-42.787	0.518***
Average over three depths	2.809	-35.263	0.546
Soil water content (%) at			
0 - 10 cm	0.287	41.884	0.004ns
10 - 20 cm	0.672	40.316	0.028ns
20 - 30 cm	0.527	40.425	0.021ns
Average over three depths	0.036	42.693	0.000ns
	Cymbopogon citratus		
Soil temperature (°C) at			
0 - 10 cm	4.098	-60.599	0.440**
10 - 20 cm	4.467	-66.303	0.392*
20 - 30 cm	3.136	-29.827	0.143ns
Average over three depths	4.446	-68.289	0.353*
Soil water content (%) at			
0 - 10 cm	-0.134	62.442	0.000ns
10 - 20 cm	0.223	61.055	0.001ns
20 - 30 cm	1.149	56.500	0.040ns
Average over three depths	0.583	59.504	0.008ns

Note: Regressions are significant at p<0.0005 except *(p<0.01), **(p<0.005), ***(p<0.001); ns(not significant); (p>0.05); *F* - test.

Table 10. Multiple regression equation of per cent litter mass remaining against soil parameters

Leucaena leucocephala	-40.211 + 2.867*ST* + 0.787*SW*	0.582**
Cymbopogon citratus	-87.483 + 4.906*ST* + 1.443*SW*	0.391*

Note: Regressions are significant at *(p<0.025) and **(p<0.0025), *F*-test. *ST*, average over three soil depths of soil temperature (°C); *SW*, average over three depths of soil water content (%).

As expected, during decomposition, changes in the concentration of carbon both linearly and exponentially were similar to changes in mass. When microorganisms decompose organic matter they use carbon compounds as energy sources. Thus, as decomposition proceeds, carbon content declines.

In the present study, most of the release of nutrients were during the initial period. The amount of nitrogen lost during the initial month of decomposition is probably mainly by leaching. For a relatively nitrogen-rich litter (e.g. >0.5% N) the potential difference in the length of the immobilization phase is relatively small

(Bosatta & Staaf 1982). *Leucaena leucocephala,* a nitrogen-fixing legume, has high element concentrations as an energy source for microorganisms and thus *Leucaena leucocephala* litter decomposes and releases nitrogen quickly. In some tropical forest N disappears at the same rate as biomass (Bernhard Reversat 1972, Anderson & Swift 1983). The loss of P during the initial period may be due to the presence of P in easily leachable forms. The relationship between mass remaining and absolute amount of P in this study was in agreement with the findings of Upadhyay *et al.* (1989) and Upadhyay (1993). Elements such as Na, K, and Mg, which are not structural parts of the litter, or only partly so, are susceptible to initial leaching losses (Staaf 1980). Upadhyay (1993) also reported a significant relationship between sodium amount and weight remaining. There are relatively rapid losses of both K and Mg from litter in most instances (e.g. Attiwill 1968, Berg & Staaf 1980, Staaf 1980, Anderson *et al.* 1983, Bockheim *et al.* 1991, Entry *et al.* 1991) as evident in this study. A decline in Mn appears to occur in decomposing leaves of *Leucaena leucocephala,* but it fails to show any relationship. Similar observations were also reported by Bockheim and Leide (1986), Rustad and Cronan (1988), and Bockheim *et al.* (1991). There was a net gain in Mn in *Cymbopogon citratus.* Increase in Mn, Cu, and Zn is also reported elsewhere (Cragg *et al.* 1977, Staff 1980, Entry *et al.* 1991).

The significant relationship between relative humidity and mass loss suggests that humidity could favor an increase in the activity of micro-decomposers and macro-arthropods. A linear combination of climatic variables is a reasonable predictor of the rate of decomposition and explains a markedly greater amount of variability in weight loss than either air temperature, humidity or rainfall alone. The data in Table 9 show that there is a significant correlation between percentage weight remaining and the soil temperature. The findings of Witkamp (1963, 1966), Anderson (1973b) and Moore (1986) corroborate this.

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