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Leaf litter decomposition of *Piper aduncum, Gliricidia sepium* and *Imperata cylindrica* in the humid lowlands of Papua New Guinea

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Abstract

No information is available on the decomposition and nutrient release pattern of *Piper aduncum* and *Imperata cylindrica* despite their importance in shifting cultivation systems of Papua New Guinea and other tropical regions. We conducted a litter bag study (24 weeks) on a Typic Eutropepts in the humid lowlands to assess the rate of decomposition of *Piper aduncum, Imperata cylindrica* and *Gliricidia sepium* leaves under sweet potato (*Ipomoea batatas*). Decomposition rates of piper leaf litter were fastest followed closely by gliricidia, and both lost 50% of the leaf biomass within 10 weeks. Imperata leaf litter decomposed much slower and half-life values exceeded the period of observation. The decomposition patterns were best explained by the lignin plus polyphenol over N ratio which was lowest for piper (4.3) and highest for imperata (24.7). Gliricidia leaf litter released 79 kg N ha^{-1}, whereas 18 kg N ha^{-1} was immobilised in the imperata litter. The mineralization of P was similar for the three species, but piper litter released large amounts of K. The decomposition and nutrient release patterns had significant effects on the soil. The soil contained significantly more water in the previous imperata plots at 13 weeks due to the relative slow decomposition of the leaves. Soil N levels were significantly reduced in the previous imperata plots due to immobilisation of N. Levels of exchangeable K were significantly increased in the previous piper plots due to the large addition of K. It can be concluded that piper leaf litter is a significant and easily decomposable source of K which is an important nutrient for sweet potato. Gliricidia leaf litter contained much N, whereas imperata leaf litter releases relatively little nutrients and keeps the soil more moist. Gliricidia fallow is more attractive than an imperata fallow for it improves the soil fertility and produces fuelwood as additional saleable products.

Introduction

The key component of a shifting cultivation system is the recycling of nutrients through the addition of above and below ground biomass of the fallow vegetation. Fallows in the tropics mean large biomass accumulations and such fallows can be natural, enriched or improved (Sanchez, 1999). Natural fallows consists of indigenous secondary vegetation which grows after a cropping period, whereas improved fallows are deliberately planted species which are usually N_2-fixing (Sanchez, 1999). The amount of nutrients recycled in a fallow system depends on the quality and quantity of the fallow biomass, but the rate of decomposition and nutrient release of the biomass is, however, determined by its chemical composition and the climatic conditions (Cadisch and Giller, 1997).

Shifting agriculture is widely practised in the humid lowlands of Papua New Guinea where each year approximately 200 000 ha of forest, secondary fallow or grassland are cleared for village-based food and cash crop production (Freyne and McAlpine, 1987). Two types of secondary fallow vegetation are common in the humid lowlands: *Piper aduncum* (L.) and *Imperata cylindrica* (hereafter referred to as piper and imperata, respectively). Piper is a shrub indigenous

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to tropical America and it was introduced into Papua New Guinea in the 1930s (Rogers and Hartemink, 2000). Piper has invaded aggressively in the lowlands of the Morobe and Madang Province where it forms locally monospecific stands (Kidd, 1997) and its invasion of secondary forests can be degenerative (Rogers and Hartemink, 2000). Farmers favour piper on short-fallowed land because it can be easily cut and is suitable as firewood, and many farmers claim that piper fallows makes the soil fertile and dry (Hartemink, 1999). Imperata grasslands in the Papua New Guinea lowlands are man-made and have resulted from annual bushfires, which hampers regrowth of woody vegetation.

The shifting agricultural system in parts of the Morobe lowlands consists of a short fallow period ($<$ 3–5 yr) alternated with a cropping period of about 1 year. At the end of the fallow period, piper is usually coppiced at 0.2–0.5 m above the ground, and the vegetation debris is left to dry for some weeks whereafter the woody parts are removed and are mostly used for firewood. Burning the slashed vegetation is uncommon due to the prevailing wet conditions, which hampers drying. Taro (*Colocasia esculenta*) or maize (*Zea mays*) are commonly firstly planted after a fallow period and these are gradually interplanted with sweet potato (*Ipomoea batatas*), which is the major staple food in the lowlands (Bourke, 1985), and bananas (*Musa* sp.) and sugar cane (*Saccharum* sp.). After 1 year, the piper has sprouted forming large branches, the bananas have grown large and the cropping site reverts back to bush. No information is available on the amount of nutrients cycled in these short fallow shifting cultivation systems.

In the large body of literature on decomposition, a considerable number of studies have been conducted under laboratory conditions (Handayanto et al., 1997; Lupwayi and Haque, 1998; Palm and Sanchez, 1991; Tian et al., 1992b) or under field conditions with no crop after the fallow (Budelman, 1988; Handayanto et al., 1994; Mwiinga et al., 1994; Oglesby and Fownes 1992). Although such information is essential to quantify maximum rates of decomposition, the absence of a crop is unrealistic as most farmers would plant shortly after the fallow vegetation is slashed. To our knowledge, no decomposition fieldstudy has been conducted with sweet potato as the first crop after a fallow. Sweet potato has a complete soil cover within 6–10 weeks after planting, which may affect the decomposition of fallow vegetation debris.

In October 1996, we started an experiment aiming to investigate the effects of piper and imperata fallows in comparison to an improved fallow with *Gliricidia sepium* (hereafter referred to as gliricidia) in the humid lowlands of the Morobe Province of Papua New Guinea. We planted plots with piper, imperata and gliricidia, which were slashed after 1 year and planted with sweet potato. Litter bags were installed in the plots with the planting of sweet potato to assess leaf decomposition and nutrient dynamics. The main objectives of our experiments were to quantify (i) the chemical contents and decomposition rates of the fallow vegetation leaves, (ii) nutrient release pattern during decomposition, and (iii) the effects of decomposition on some selected soil chemical and physical soil properties.

Materials and methods

Experimental site

The experiment was conducted near Hobu village (6° 34′ S, 147° 02′ E) which is 25 km N of the city of Lae in the Morobe Province. The site is located at an altitude of 405 m a.s.l. at the footslopes of the Saruwaged mountain range. Rainfall records were only available since the start of the experiment (November 1996) and the daily rainfall pattern during the litter bag study is depicted in Figure 1. The end of 1997 was a relatively dry period caused by the El Niño/Southern Oscillation climatic event that hit the Pacific severely in 1997/98. March 1998 was a wet month with 725 mm of rain. Temperatures were not available for the experimental site but average daily temperatures at the University of Technology, which is situated about 15 km to the S of Hobu, are 26.3 °C. The climate classifies as Af (Köppen).

The Hobu experimental site is located on an uplifted alluvial terrace with a slope of less than 2%. Soils are derived from a mixture of alluvial and colluvial deposits dominated by sedimentary rocks and coarse to medium grained, basic, igneous rocks. The soils are layered with water-worn gravelly and stony horizons below 0.2 m depth; effective rooting depth is over 0.7 m. Air-dried and sieved ($<$ 2 mm) soil had the following properties in the top 0.12 m: pH H_2O (1:5 w/v) = 6.2, organic C (dry combustion) = 55 g kg^{-1}, available P (Olsen) = 9 mg kg^{-1}, CEC (NH_4OAc, pH7) = 400 mmol$_c$ kg^{-1}, exchangeable Ca = 248 mmol$_c$ kg^{-1}, exchangeable Mg = 78 mmol$_c$ kg^{-1}, exchangeable K = 16.9 mmol$_c$ kg^{-1}, clay = 480 g kg^{-1} and sand

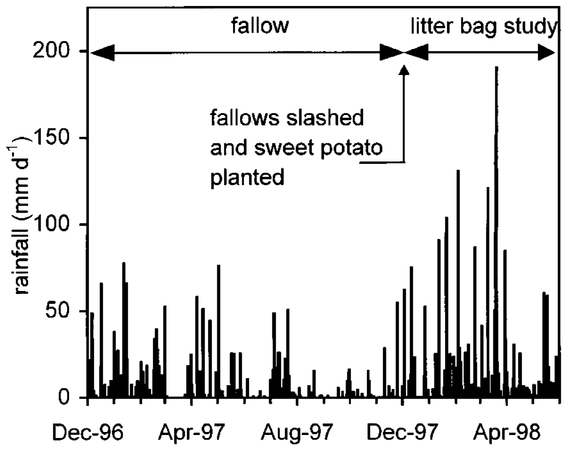

Figure 1. Daily rainfall between December 1996 and June 1998 at the experimental site in the Morobe province of Papua New Guinea.

= 360 g kg^{-1}, bulk density = 0.82 Mg m^{-3}. The soils are classified as mixed, isohyperthermic, Typic Eutropepts (USDA Soil Taxonomy) or Eutric Cambisols (World Reference Base). Further details on soil chemical and physical properties can be found in Hartemink et al. (2000). Inceptisols cover about 60% of Papua New Guinea and are the most intensively used soils (Freyne and McAlpine, 1987).

Litter bag experiment

The litter bag study took place in an existing fallow experiment which was undertaken to investigate the effects of natural and improved fallows on sweet potato yields. In short, the experiment consisted of replicated plots (n = 4) planted with piper, imperata and gliricidia (27th November 1996) which were cut at ground level one year after growth (20–24th November 1997). Woody parts were removed from the piper and gliricidia plots and all plots were planted with sweet potato one week after the vegetation was slashed. Directly after the planting of sweet potato, litter bags were installed. No inorganic fertiliser was applied.

Leaves for the litter bags were hand-picked from piper and gliricidia trees in the experiment prior to the cutting, and included a mixture of new and old leaves. For imperata, about 2 kg of leaves was cut at ground-level in each plot prior to the slashing. Leaves were washed with distilled water and ovendried at 70 °C for 72h. Although ovendrying may affect mass loss rates (Taylor, 1998), in nearly all studies conducted on litter decomposition leaves were ovendried (e.g. Mafongoya et al., 1998; Mwiinga et al., 1994; Palm and Sanchez, 1991) and in order to allow comparison with other studies we also dried the leaves before they were put in the litter bags. Ovendrying also increases the homogeneity of the leaves.

Litter bags of 0.20 × 0.20 m were constructed from nylon mosquitowire with a mesh size of 1 mm (Mwiinga et al. 1994; Palm and Sanchez, 1990). For each of the three species, 40 bags with 20 g ovendried leaf material were filled. Litter bags were randomly placed in the 16 plots (4 plots per species) 2 days after sweet potato was planted (29 November 1997). The bags were slightly covered with leaf litter to allow maximum influence of meso and macrofauna. Litter bags were sampled at 9, 16, 24, 29, 38, 51, 65, 86, 108 and 169 days, with one litter bag randomly selected from each plot and transported to the laboratory. So, for each sampling time, there were four bags (replicates) per treatment. Undecomposed litter was carefully separated from the litter bags and roots and soil particles were removed. The cleaned samples were put in paper bags and ovendried at 70 °C for 72 h to determine leaf litter mass remaining. Samples were ground (mesh 0.2 mm) before being sent for nutrient analysis at the laboratories of the School of Land and Food of the University of Queensland.

As the mulch applied to each treatment was the leaf material produced in the previous fallow, the quantity of mulch in each treatment varied. Imperata produced the largest leaf biomass (14.9 Mg ha^{-1} dry weight) while piper and gliricidia plots received 4.2 and 5.2 Mg ha^{-1} leaf mulch, respectively. Both the quantity and quality of the mulch may have affected the growth of the sweet potato crop. Vine yield at harvest was much lower in the previous imperata plots (20.7 Mg ha^{-1} fresh weight) than in the previous piper and gliricidia plots which both yielded over 30 Mg vines ha^{-1}.

Leaf litter analysis

A sample of the leaves which were used to fill the litter bags was analysed for lignin, polyphenol and nutrients. Lignin was determined by the procedure of Van Soest and Wine (1968), and polyphenol by that of Dalzell and Kerven (1998), using purified *Leucaena pallida* condensed tannin as standard. Leaf litter samples were analysed for nutrients, whereby one subsample was digested in 5:1 nitric:perchloric acids and analysed for P, K, Ca, Mg and S using ICP AES (Spectro Model P). A second subsample was analysed for C and N using a Leco CNS-2000 dry combustion analyser.

Soil sampling and analysis

Soil samples for chemical analysis were taken before the fallows were slashed (19th November 1997) and after one season with sweet potato (15th May 1998). Soil samples (0–0.15 m depth) were collected with an Edelman auger (diameter 0.05 m) at 12 random locations in a plot, mixed in a 20 L bucket and a subsample of about 1 kg was taken. Airdried samples were ground and sieved (2 mm) and were sent for analysis to the National Analytical Chemistry Laboratories in Port Moresby. The procedures for soil analysis were as follows: pH H_2O (1:5 w/v); organic C and total N by Leco CNS-2000 dry combustion; available P by Olsen; exchangeable cations and CEC by 1 *M* ammonium acetate percolation (pH 7.0); particle size analysis by hydrometer.

Bulk density of the soil was measured on 19th November 1997 before the fallows were slashed and 6th May 1998. In each plot, the 0–0.05 and 0.10–0.15 m soil horizons were sampled using two 100 mL cores per depth and measurements were duplicated in each plot. Cores were ovendried at 105 °C for at least 72 h. Gravimetric values were multiplied with the bulk density to obtain volumetric water contents. The average bulk density of the two sampling depths was taken for each plot.

Data analysis

Several models were tested, but it was found that the single exponential model provided the best fit for the decomposition pattern of the leaves. The single exponential model was fitted to the data:

$$Y = e^{-k \times t}$$

whereby Y is the proportion initial mass remaining at time t, and k is the decomposition factor. To calculate the k values the formula was rewritten as

$$\ln Y = -k \times t$$

hence the slope of the line, calculated by linear regression, is the k value. Although the coefficients of determination were over 87%, it was found that the single exponential equation did not provide the best fit of the piper and gliricidia data over the complete time of observation (i.e. 169 days). Therefore, k values were also calculated for the first 51 days and the first 108 days.

Analysis of variance was run on the decomposition data, whereby time and treatment (i.e. species) were treated as main effects. Volumetric soil moisture data were subjected to ANOVA and standard error of the difference in means were calculated. A simple *t*-test was performed to analyse statistical differences in the soil chemical data. All statistical analysis was conducted with Statistix 2.0 software.

Table 1. Chemical characteristics of *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica* leaves (g kg^{-1} ± 1 SD)

	Piper aduncum	*Gliricidia sepium*	*Imperata cylindrica*
C	404±15.3	438±9.8	426±4.7
N	15.6±2.0	25.2±2.0	3.9±0.4
P	1.9±0.4	1.4±0.1	0.8±0.2
K	28.2±1.4	12.6±1.8	4.5±1.1
Ca	18.7±1.7	27.7±6.3	3.0±0.7
Mg	5.4±1.2	5.5±1.6	2.6±0.5
S	1.0±0.1	1.6±0.2	0.3±0.1
Lignin (L)	61.3±14.4	149.8±23.8	93.5±8.3
Polyphenol (PP)	4.2±0.2	26.2±13.5	2.4±0.4
C/N	26±2	18±1	110±11
(L + PP)/N	4.3±1.2	7.0±1.2	24.7±4.2

Results

Chemical composition and decomposition pattern

Gliricidia leaves had the highest N content, which were on average seven times higher than imperata leaves (Table 1). The C:N ratios of imperata leaves were high because of the low N contents of the leaves. Piper leaves had intermediate N levels, but P and K concentrations were highest in piper leaves. Piper leaves were lowest in lignin and contained also much lower polyphenol contents than gliricidia leaves. Imperata leaves had the lowest polyphenol contents. The ratio lignin (L) plus polyphenol (PP) over N concentrations was lowest for the piper leaves despite its much lower leaf N concentration when compared to gliricidia leaves.

The decomposition pattern of piper, gliricidia and imperata leaves is depicted in Figure 2, whereby the mass remaining is expressed as percentage of the initial ovendry weight of the leaves. During the first 4 weeks of the decomposition, there was little difference between piper and gliricidia, which both lost about 30% of the initial mass. Thereafter, piper leaves de-

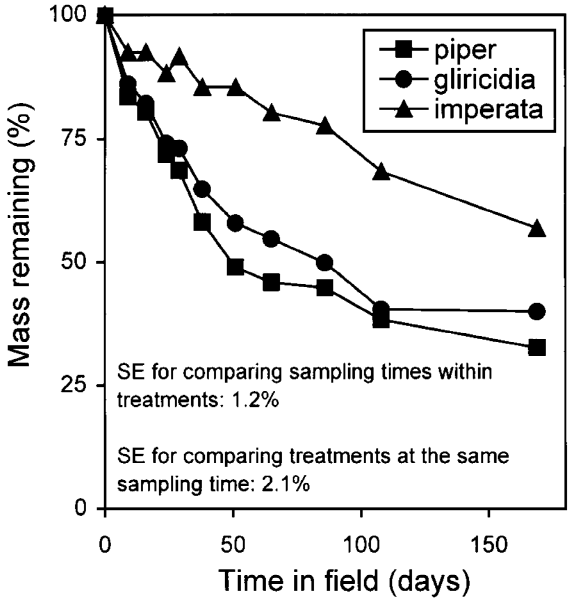

Figure 2. Decomposition pattern of *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica* in the humid lowlands of Papua New Guinea.

composed more readily. Gliricidia leaves decomposed slightly slower despite its higher N contents than piper, but gliricidia leaves had relatively high polyphenol levels. Rates of decomposition of piper and gliricidia leaves decreased five weeks after the bags were installed in the field and decomposition had virtually stopped after 15 weeks. Imperata leaves decomposed slowest and at the end of the experiment (24 weeks), more than 55% of the imperata leaf mass had not decomposed. Thus, the time taken for decomposition of half the biomass was 7 weeks for piper, 12 weeks for gliricidia and greater than 24 weeks for imperata.

Decomposition constants k were calculated for different periods (i.e. 51, 108 and 169 days). The three k factors differed significantly ($P<0.001$) if k was calculated based on the data of the first 51 days (Table 2). When k was calculated for 108 or 169 days, no statistical difference was found between piper and gliricidia, but both were significantly higher than the calculated k values for imperata leaf litter decomposition.

Nutrient change and release

Changes in major nutrient concentrations in the leaf litter is depicted in Figure 3. For most nutrients, changes appeared to be irregular over the first 51 days, perhaps reflecting variable rates of colonisation of individual litter bags by soil biota. There was a rapid initial loss of K, but concentrations of other nutrients (Ca, Mg) tended to be maintained or slightly increased over the period of measurement. Soil contamination of the samples was judged to be low, as C concentrations were maintained or increased compared to the initial concentrations in the plant material, but both Al en Fe concentrations increased with time.

While nutrient concentrations in the mulch may have remained relatively stable, these nutrients were released as the quantity of biomass declined (Table 3).

Table 2. Decomposition constants (k y^{-1}) calculated for different periods (t). Values were calculated with single exponential model ($Y = e^{-k \times t}$), coefficient of determination (r^2) indicates goodness of fit

	t=51 days		t=108 days		t=169 days	
	k	r^2	k	r^2	k	r^2
Piper aduncum	9.73	0.990	2.94	0.922	1.43	0.875
Gliricidia sepium	7.44	0.987	2.64	0.972	1.21	0.879
Imperata cylindrica	2.08	0.812	1.01	0.949	0.69	0.978
SED[a]	0.890		0.277		0.133	

[a] SED standard error of the difference in means (6 d.f.).

Table 3. Major nutrients in the leaf litter biomass at the beginning of the decomposition experiment and after 51, 108 and 169 days (kg ha^{-1})

Nutrient	Time (days)	Fallow species			SED[a]
		Piper aduncum	*Gliricidia sepium*	*Imperata cylindrica*	
N	0	67	130	59	9.5
	51	39	86	49	6.9
	108	35	61	78	8.6
	169	29	51	77	6.6
	Total released	38	79	−18	9.5
P	0	8	7	12	2.0
	51	3	5	8	1.9
	108	2	3	6	1.0
	169	2	3	6	0.4
	Total released	6	4	6	2.2
K	0	119	65	67	8.1
	51	7	9	27	8.5
	108	3	4	10	3.1
	169	4	6	10	1.1
	Total released	115	59	57	8.5

[a] SED standard error of the difference in means (6 d.f.).

Table 4. Volumetric soil moisture contents[a] (m^3m^{-3}) at the end of 1 year fallow with *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica* and after 13 and 24 wks with sweet potato

Sampling time (wks)[b]	Sweet potato after 1 year of fallow with: *Piper aduncum*	*Gliricidia sepium*	*Imperata cylindrica*	SED[c]
0	0.29	0.36	0.32	0.019
13	0.43	0.45	0.47	0.010
24	0.40	0.40	0.42	0.011

[a] Values are the mean of 8 samples taken at 0–0.05 and 0.10–0.15 m depth.
[b] Weeks after fallow vegetation was slashed and sweet potato was planted.
[c] Standard error of the difference in means (12 d.f.).

At the start of the experiment, gliricidia litter contained about twice as much N than that of piper or imperata. Total amounts of N, P and K on a kg ha^{-1} basis, declined steadily, but there were differences between these three nutrients. More than half of the N in the piper and gliricidia leaf litter was mineralised during the 24 weeks, but the imperata leaf litter showed a net gain in N, indicating that soil N was being immobilised by the decomposition organisms. Phosphorus contents were similar for the three litters but piper leaf litter contained significantly more K than the leaf litter of gliricidia and imperata ($P<0.001$). No significant differences were found in the P release of the three leaf litters and about half of all P in the leaf litter was released after 24 weeks. The amount of K released by the piper was about two times higher than for gliricidia and imperata, which both released similar amounts. Nearly all K was released within the 24 week period.

Effects on soil properties

Volumetric soil moisture content was measured a few days before the 1-year old fallows were slashed, and 13 and 24 weeks thereafter (Table 4). Moisture contents prior to the slashing of the fallows were significantly lower under piper than under gliricidia despite the fact that gliricidia had produced nearly 10 Mg ha DM ha^{-1} more above ground biomass than piper. The difference between the soil moisture contents of piper and imperata was not significant ($P>0.05$). Twelve weeks after the fallows were slashed, volumetric moisture contents under imperata was significantly higher, but at 24 weeks, after a comparatively dry period, there was no significant difference in volumetric soil moisture contents.

The effect of the different fallow mulches on soil chemical properties is shown in Table 5. In all soils, it was found that the CEC declined and the base saturation had increased during the period of the litter bag experiment. In the piper plots, pH and available P were significantly increased and also exchangeable K levels were increased. Total nitrogen levels was significantly decreased in the previous imperata plots (see Table 3).

Discussion

Large differences were found in the chemical composition, decomposition pattern and the effects on soil chemical and physical properties of piper, gliricidia and imperata leaf litter. No information is available in the literature on the chemical composition and decomposition of imperata and piper, but relatively much is known about *Gliricidia sepium* from research in various parts of the tropics (Table 6). Compared to published analytical results on gliricidia leaves, our data (Table 1) are on average about 10–15 mg N kg^{-1} lower. However, low N contents of gliricidia leaves was also reported by Cadisch et al. (1998) and Mafongoya et al. (1998). Such differences in the N concentration of leaves of *Gliricidia sepium*, is possibly related to differences in germplasm, the time of sampling and the environmental conditions under which the trees are grown. The lignin as well as the polyphenol contents of the gliricidia leaves in our study were on average above those reported in the literature, but again a wide range of values have been reported (Table 6).

Polyphenols appear to influence rates of decomposition as they bind to N in the leaves forming compounds resistant to decomposition (Fox et al., 1990; Palm and Sanchez, 1990). The mineralization of N is controlled more by soluble polyphenols (PP) than by lignin (L) or N content (Oglesby and Fownes, 1992). Palm and Sanchez (1990) were among the first to combine these three parameters for the prediction of decomposition rate, using the ratio L+PP/N. This ratio has been found to be a useful indicator in successive decomposition studies. We found that the piper decomposed fastest followed closely by gliricidia, but imperata litter decomposed considerably slower. Lignin contents in imperata leaves were in between piper and gliricidia and although numerous workers have suggested that the initial lignin content is a reasonable predictor of the rate of decomposition (Wieder and Lang, 1982), our data suggest that lignin

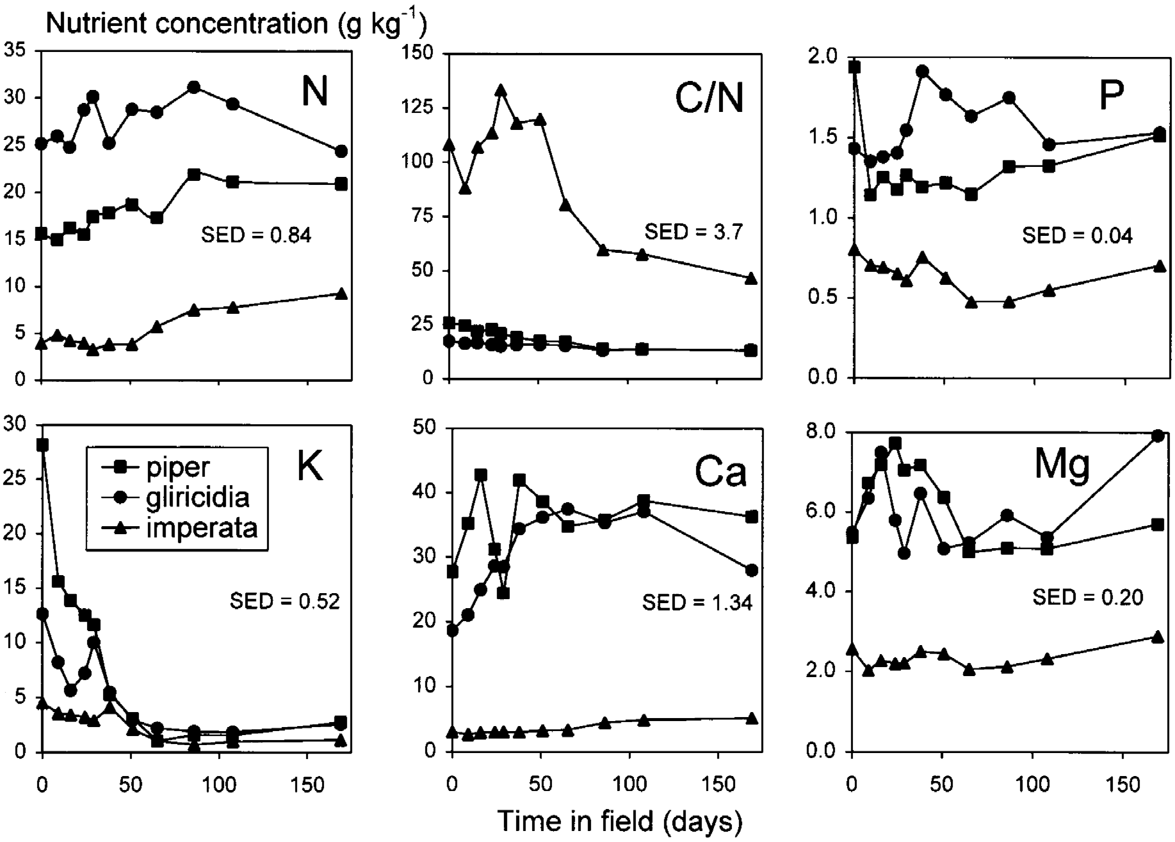

Figure 3. Changes in nutrient concentration during decomposition of *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica* leaves. SED is standard error of the difference in means, (96d.f.)

content alone is insufficient. Decomposition rates of the imperata can not be explained by the polyphenol content because it was lowest of the three species. The slow decomposition is mainly caused by the very high C/N and (L+PP/N) ratio of the imperata leaves. Gliricidia had the highest N levels and lowest C/N ratio but because of its high polyphenol content which is common in legumes (Oglesby and Fownes, 1992; Palm and Sanchez, 1990), it decomposed slightly slower than piper. Therefore, the rate of decomposition for these three species in the prevailing environmental conditions is best predicted by the L+PP/N ratio.

An additional factor that may influence the rate of decomposition is the total mulch biomass. The thickness of the layer of imperata mulch may have slowed its colonisation by soil biota, and allowed the micro-environment within the layer to differ to a greater extent from that in the soil, possibly impeding some degradational activities of the biota.

The pattern of steadily declining decomposition rates of piper and gliricidia suggests that first the soluble and easily degraded compounds are utilised and the remaining biomass is increasingly resistant to degradation. It appeared that 40–50% of the substrate was relatively labile, while the remainder was relatively durable. While the decomposition of imperata appeared near linear throughout the experiment, this could be said also for the other species over the period in which the first 45% of biomass decayed. Besides the chemical composition and its changes over time, decomposition may also be influenced by environmental changes relating to the growth of the sweet potato crop. The vines grew more vigorously in piper and gliricidia plots than in imperata. Thus, the cooling effects of crop transpiration and any effects of shading, for example on the light-labile polyphenols, were greater for piper and gliricidia treatments. In addition, in the second half of the litter bag study there was less rainfall (see Figure 1) which may have retarded the decomposition.

Considerable amounts of nutrients were released from the leaf litter. About 79 kg N ha^{-1} were mineral-

Table 5. Soil chemical properties at the end of 1 year fallow with *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica* and after one season (26 wks) with sweet potato. Sampling depth 0–0.15 m

	Sampling time wks^a	pH H_2O 1:5 w/v	Organic C g kg^{-1}	Total N g kg^{-1}	Olsen P mg kg^{-1}	CEC pH7 mmol$_c$ kg^{-1}	Exchangeable cations mmol$_c$ kg^{-1}			Base saturation %
							Ca	Mg	K	
Piper	0	5.5	71.0	7.2	5.2	440	219	62	8.4	67
aduncum	26	5.7	74.7	6.5	8.0	344	227	62	13.4	89
	Difference	$P<0.05$	n.s.	n.s.	$P<0.01$	$P<0.01$	n.s.	n.s.	$P<0.05$	$P<0.05$
Gliricidia	0	5.9	82.2	7.7	4.5	416	220	68	7.9	71
sepium	26	5.7	85.2	7.0	5.3	355	241	62	9.7	89
	Difference	n.s.	n.s.	n.s.	n.s.	$P<0.01$	n.s.	n.s.	n.s.	$P<0.01$
Imperata	0	5.7	76.8	7.5	4.6	449	239	65	11.6	71
cylindrica	26	5.8	76.2	6.4	9.7	350	235	59	12.7	88
	Difference	n.s.	n.s.	$P<0.05$	n.s.	$P<0.01$	n.s.	n.s.	n.s.	$P<0.05$

[a] Weeks after fallow vegetation was slashed and sweet potato was planted
(n.s. = not significant: $P>0.05$).

ised from the gliricidia litter and 115 kg K ha^{-1} from the piper litter. The rapid initial loss of K, particularly from the piper leaf litter, is commonly found in litter bag studies (Budelman, 1988; Palm and Sanchez, 1990; Tian et al., 1992a). It may have been slightly increased by ovendrying of the litter samples, as cell disruption makes K more accessible to leaching. However, rapid loss of K is expected from dead plant material, as this element is not chemically bound to the substrate. The divalent cations were bound more strongly by the cation exchange properties of the organic substrates, and released only in proportion to the biomass lost. Nitrogen-rich compounds proteins and nucleic acids) would tend to be relatively labile, but the N is quickly immobilised by the microflora unless it is in excess of their needs. Hence, the increase in N concentration of the material in the piper and imperata litter bags (Figure 3), as these organisms have a higher N concentration than the substrate. Likewise, the microflora immobilise some P, so it is difficult to assess how much of the stability in P concentration (Figure 3) is due to its resistance to degradation, and how much is due to immobilisation. It should be noted that constant concentration does not indicate that the nutrient is not being released, but that it is released in proportion to the biomass loss (Table 3).

Significant differences were detected in soil chemical properties (Table 5) despite the relative short period (24 weeks) between the soil sampling. A significant decrease in total N in the imperata plots was found which is likely due to the immobilisation of soil N in the leaf litter as the litter contained more N at the end than at the beginning of the experiment (Table 3). The exchangeable K levels in the piper plots increased because of the large release of the of K decomposed in the piper leaf litter, and despite the high K demand of the sweet potato crop. Decomposition of the roots of fallow species may also have contributed to changes in soil chemical properties. The pH increase in the previous piper plots might be related to the large addition of K. The addition of crop residues with high concentration of excess cations is known to minimise soil acidification (Tang and Yu, 1999). Likewise, the lower soil pH under piper at the end of the fallow period may be attributable to the large extraction of K by piper during the fallow, and its replacement merely restored the pH to a value similar to the other treatments.

The leaf litter also had some significant effects on soil physical properties. It was found that the volumetric moisture contents at the start of the experiment was much lower under piper which confirms the claim of many farmers that piper make the soil dry in comparison to other fallow species (Hartemink, 1999). In the mid-season, moisture contents in the previous imperata plots were significantly higher compared to the piper plots because of the largely undecomposed mulch layer and the reduced growth of sweet potato causing less transpiration. This higher soil moisture is, however, not an advantage as sweet potato is very sensitive to excess soil moisture (Bourke, 1989; Hahn and Hozyo, 1984), and yields are generally depressed

Table 6. Chemical properties of *Gliricidia sepium* leaves as reported in the literature, and found in this study

	Location	Value (g kg^{-1})	Reference
N	Nigeria, humid lowlands, Oxic Paleustalf	50.4	Tian et al. (1992)
	Ethiopia, highlands, Alfisol?	39.5	Anthofer et al. (1997)
	Peru, humid lowlands, Typic Paleudult	37.4	Palm and Sanchez (1991)
	Hawaii, humid lowlands, Typic Gibbsihumox	34.3	Oglesby and Fownes (1993)
	Sri Lanka, dry zone, Ultisols	29.2	Seneviratne et al. (1998)
	Indonesia, humid lowlands, Ultisols?	24.7–45.7	Cadisch et al. (1998)
	Papua New Guinea, humid lowlands, Typic Eutropepts	25.2	This study
	Zimbabwe, highlands, ustic Alfisol	18	Mafongoya et al. (1998)
Lignin	Papua New Guinea, humid lowlands, Typic Eutropepts	149.8	This study
	Ethiopia, highlands, Alfisol?	113.2	Anthofer et al. (1997)
	Zimbabwe, highlands, ustic Alfisol	111	Mafongoya et al. (1998)
	Nigeria, humid lowlands, Oxic Paleustalf	86	Tian et al. (1992)
	Hawaii, humid lowlands, Typic Gibbsihumox	86	Oglesby and Fownes (1993)
	Peru, humid lowlands, Typic Paleudult	78	Palm and Sanchez (1991)
	Sri Lanka, dry zone, Ultisols	61.7	Seneviratne et al. (1998)
	Indonesia, humid lowlands, Ultisols?	90–110	Cadisch et al. (1998)
Polyphenol	Papua New Guinea, humid lowlands, Typic Eutropepts	26.2	This study
	Zimbabwe, highlands, Ustic Alfisol	23	Mafongoya et al. (1998)
	Nigeria, humid lowlands, Oxic Paleustalf	21.2	Tian et al. (1992)
	Hawaii, humid lowlands, Typic Gibbsihumox	20.7	Oglesby and Fownes (1993)
	Sri Lanka, dry zone, Ultisols	18.6	Seneviratne et al. (1998)
	Indonesia, humid lowlands, Ultisols?	18.0–25.9	Cadisch et al. (1998)
	Peru, humid lowlands, Typic Paleudult	10.2	Palm and Sanchez (1991)

in seasons with high rainfall in the humid lowlands of Papua New Guinea (Hartemink et al., 2000b).

It can be concluded that piper leaf litter is a significant and easily decomposable source of K which is an important nutrient for sweet potato. Gliricidia leaf litter contained much N of which about two thirds is mineralised during the first season of sweet potato after the fallow. Imperata leaf litter decomposes very slowly, releases relatively little nutrients and immobilises N, and it keeps the soil more moist. Gliricidia fallows are more attractive than imperata fallows for they improve the soil fertility and produce additional saleable products in the form of firewood (Grist et al., 1998).

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