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Effect of Litter Quality and Inorganic-N on Decomposition and Nitrogen Release in Alley Cropping from Three Leguminous Agroforestry Tree Species

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Research Article

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ABSTRACT

The effects of litter quality and inorganic nitrogen (N) on rate of decomposition and N release pattern by three leguminous woody species were investigated under field conditions by the litterbag technique. The research was carried out in Zambia. The alley trees were *Leucaena leucocephala, Senna siamea* and *Flemingia macrophylla.* Maize was the companion crop. Dried leaf litters were placed inside litterbags and buried into the top 10-15 cm depth of soil. The four inorganic N levels were 0, 34, 68, and 112 kgNha^{-1}. Samples were drawn at intervals of 2, 4, 8, 12, and 16 weeks and were analysed to determine remaining dry matter weight, N, lignin, cellulose, polyphenol and carbon. Major findings were that *L. leucocephala* and *S. siamea* decomposed significantly faster than *F. macrophylla*. It was also observed that the level of inorganic N had a significant effect on decomposition rate. These results show that both the chemical composition of plant residues and level of inorganic fertiliser N applied increased the rate of plant residue decomposition.

Key words: Decomposition, Nitrogen release, Litterbag technique, Leguminous woody species, Alley cropping.

INTRODUCTION

Alley cropping or hedgerow intercropping is an agroforestry system where food crops are grown between rows of trees, preferably leguminous trees Handayato *et al* (1994). The trees are periodically pruned and utilised as green manures, particularly as source of N and mulching material, Mafongoya *et al* (1997). The objectives of agroforestry technologies such as alley cropping are to increase soil fertility, conserve moisture and in some cases suppress weeds (Kang *et al*., (1984). Ladd *et al*. (1981) reported that the main value of leaves from N-fixing agroforestry trees was the accumulation of soil organic matter from the litterfall, which eventually is made available to companion crops in the alley after mineralization. However, successful use of alley cropping for soil fertility improvement depends largely on the understanding of biological factors that affect decomposition and nutrient release from the resource material. The factors include the residue C: N ratio, polyphenol and lignin concentrations (Palm, 1988; Constantenides and Fowns, 1994; Tian *et al*. 1992; Handayanto *et al*., 1994; Mendonca and Stott, 2003; Semwal et al 2003; Dhanya *et al* 2013).

Results of various alley cropping experiments in the tropics have indicated that sustained food crop production is feasible using a combination of legume residues and judicious amounts of inorganic nutrient input. Kamara *et al*., 1994; Xu *et al*., 1993, working on N cycling in semi-arid tropics, established that the N supply by the hedgerow legumes was not sufficient to achieve optimum companion crop yield. In order to manage the N mineralised from organic residues for crop uptake, there is need to understand decomposition and N mineralisation patterns of the organic inputs in relation to their chemical composition. Studies by various researchers established that high lignin, high polyphenol content and high C:N ratios in leaves tended to slow down litter decomposition and nutrient release Upadhyaya *et al* 2012; Constantinides and Fawnes (1994), Handayanto *et al* (1994).

Multipurpose trees (MPTs) which are low in polyphenols, can provide a rapid flush of N during mineralisation, and may therefore be a good choice for use with annual crops such as maize which requires large amounts of N in a short period of time. Nitrogen release by plant litter with high contents of polyphenols, lignin and C: N ratios is slow so that decomposition occurs over a long period of time . The latter may be better choice for tree or perennial

production systems (Palm, 1988). Thus, in order to sustain production in hedgerow intercropping systems, a better understanding of the effects of litter quality on decomposition and N release is essential.

The objective of the study includes the determination of the influence of the chemical composition present in the plant leaves (N, lignin and polyphenol), added N-fertiliser and rate of N release by the leguminous tree species under investigation.

MATERIALS AND METHODS

Experimental site

This study was carried out at the SADC/ICRAF Zonal Agroforestry Research Project at Chalimbana Research Station in Lusaka, Zambia. The site is situated $28^0$29'56" E, $15^0$21'32" S, and its elevation is 1280 m above sea level (asl). Mean rainfall at the site is 520 mm and the mean minimum and mean maximum temperatures were 18^0C and 31^0C respectively. The soils have been classified as plinthic lixisols or in soil taxonomy as fine loamy, mixed iso-hyperthermic plinthic kandiustalf (Chirwa *et al*., 1994). Soil pH ($CaCl_2$) is 4.8. Chemical composition of major nutrients shows 1.3 mg kgN, 1.97 mg kg^{-1} P and 0.66 cmol K kg^{-1} soil. The experiment was superimposed on an alley cropping experiment established in 1987. The hedgerow species were *Leucaena leucocephala, Senna siamea* and *Flemingia macrophylla.* The companion crop has been Maize since establishment of the alleys. This experiment was conducted on those plots which had not received fertilizer treatments since establishment of the alley cropping experiment.

Management of plant residues

The prunings of *L. leucocephala, S. siamea* and *F. macrophylla* were sun-dried and incorporated into the soil at the rate of 5 tha^{-1} in the alleys of each species. Where a species could not yield a 5 tha^{-1} target, the shortfall was from litter banks of the same species and same age at the station so as to minimise source of error. Part of the dried litter, a total of 1200g for each species was confined in nylon litterbags each containing 20g to monitor decomposition and N release.

Experimental design and treatments

A split plot in a Randomised Complete Block Design (RCBD) replicated three times was used. Plant residues made up the main plot factor while N levels were the subplot factor. The experiment was carried out in the outer three rows of the hedgerows. Each of the three species in a block delineated an alley 4.5m wide and 10m long with 6 rows of maize in the main alley and 3 rows on either side of the hedgerows. The outer rows were divided into two, measuring 2.25m wide x 4.5m long to give four subplots of each species per block. Subplots received 0, 34, 68, and 112 $kgNha^{-1}$ plus 5 tha^{-1} dry prunings of the tested tree species. One third of the N fertilizer treatments was applied as D compound (10N:20P:10K) at planting. The balance was applied as urea (46%N) four weeks later. The 0 $kgNha^{-1}$ plots did not receive any fertilizer.

Litterbag contents

Decomposition and disappearance of the prunings were followed in the field by employing the litterbag method as described by Anderson and Ingram (1989). Nylon litterbags measuring 20cm x 20cm with a 4mm mesh were used for this study. A total of 180 litterbags were prepared each containing 20g dry prunings (equivalent to 5 tha^{-1}). Each of the three species had 60 litterbags. Five litterbags per type of pruning were randomly incorporated at a soil depth of 10-15cm in each of the four subplot treatments in a replicate. A sample of dry prunings from each species was retained for the determination of the initial N, lignin and polyphenol contents.

Leguminous tree species plant analysis

Harvested leaf samples were analysed for initial contents of N, lignin and polyphenols. Total N was analysed by Macro-Kjeldahl digestion, followed by distillation and titration (Anderson and Ingram 1993; Bradstreet 1965). Lignin and cellulose were determined by the Acid Detergent Fibre (ADF) method as outlined in Anderson and Ingram, (1993). The polyphenols were extracted in hot (80^0C) 50% aqueous methanol and determined calorimetrically with tannic acid as a standard (Anderson and Ingram 1993; Hagerman, 1988).

Decomposition and N- release

One litterbag, from each subplot was removed at 2, 4,8,12 and 16 weeks after incorporation into the soil and the samples used for mass loss determination and chemical analysis, as described in above.

Estimation of decomposition and N-release

An exponential decomposition constant (kD) was derived from the following decomposition equation (Budelman, 1988);

$Y=Y(0)\, e^{-kt}$ (1)

Where; Y(0) is the original amount of material (litter dry weight); Y is the amount of incorporated residue left undecomposed after a period of time (t) in weeks and k is the release constant. This decomposition rate equation was determined, *a priori*, to be the appropriate model to describe decomposition.

Sampling

Sampling was done at 2, 4,8,12 and 16 weeks after the incorporation of litterbags. At each sampling time (i.e., harvesting/lifting of buried litterbags), a total of 36 litterbags, one from each subplot treatment, were placed in separate plastic bags and transported to the laboratory. Soil and other contaminants were washed off using distilled water, and the roots were sorted by hand and discarded. The material was oven-dried at 80 0C for 48 hours before weighing. After drying the material was weighed and then ground in a Willey Mill to pass through a 1 mm sieve. Subsamples weighing 1 g were used to determine the ash-free dry weight by incineration in a muffle furnace at 500 0C for three hours. Ash-free dry weight was used to correct for contamination of undecomposed litter. The remaining samples were set aside for determination of N, lignin and polyphenol content.

Statistical analysis

Data was analysed using the MSTAT computer package. The Duncan's Multiple Range test was used to separate means where significant treatment effects were obtained from the analysis of variance.

RESULTS AND DISCUSSIONS

Initial chemical composition of the plant residues

The initial chemical composition of the litter from the three leguminous tree species used in this study are shown in Table 1. The differences in the contents of N, polyphenols and lignin contents among the three species provided a basis for determining factors influencing decomposition rates and nutrient release patterns.

Table 1: Initial chemical composition of litter from the three leguminous plants.

Component	*L. leucocephala*	*S. seamea*	*F. macrophylla*	Mean	SD±
% water	6.92	5.53	9.18	7.21	1.80
% Ash	7.22	5.28	5.82	6.11	1.46
% Carbon	62.03	68.70	57.61	62.78	5.57
% N	3.50	2.31	2.31	2.71	0.69
% Lignin	29.94	28.29	35.43	31.22	3.74
% Polyphenol	4.60	1.60	3.50	3.20	1.52
% cellulose	8.43	13.57	40.29	20.73	17.10
C: N	17.72	29.74	24.94	24.13	6.05
Lignin: N Ratio	8.55	12.25	15.33	12.04	3.39
Polyphenol: N ratio	1.31	0.69	1.51	1.17	0.43
Polyphenol+lignin: N	9.87	12.94	16.85	13.22	3.50

SD-Standard Deviation

Decomposition patterns of plant residues

Generally, there was a rapid loss of mass from the litterbags during the first two weeks among all the three species (Fig. 1), in the order *L. leucocephala* > *S. siamea* > *F. macrophylla*. By the end of the second week, *L. leucocephala* and *S. siamea* had lost about 60% of their original ash free dry weight, whereas only 35% of the original litter of *F. macrophylla* had been decomposed. After the second week, the rate of mass loss due to decomposition declined for all species. Even then, *L. leucocephala* continued to decompose faster compared to *S. siamea*. *F. macrophylla* on the other hand, showed a consistently slow decomposition throughout the incubation period as determined by mass loss (Table 2).

Decomposition rates obtained from this study ranging from 0.118 to 0.299 wk^{-1} (Table 4), fall within the range reported from Nigeria by Tian *et al*. (1992). Although, some of the variations in decomposition rates between sites was due to macroclimatic differences, analytical methodology differences can also be a source of error. Palm (1988), citing Meentemeyer (1978) suggested that the quality of the plant material controls the rate of decomposition in the tropics more than climatic factors. Plant residues with high initial N content have been known to show high correlations between N content, N release and biomass loss (Tien *et al*., 1992).

In this study, the three residue types had high N contents, well above the critical level of 2% (Table 1). Among the three species studied, *L. leucocephala* and *S. siamea* decomposed significantly faster than *F. macrophylla*. Also in this study, *L. leucocephala* and *S. siamea* had similar decomposition rates although they differed in C: N ratios and in contents of N and polyphenols. They however had similar lignin contents. *S. siamea*, on the other hand had similar N content as *F. macrophylla* but contained lower lignin and polyphenols.

From the foregoing discussion, it is possible to attribute slow decomposition of *F. macrophylla* to lignin as being the limiting factor, thus making it a better predictor. This observation is in conformity with Meentemeyer (1978) cited by Palm (1988), who observed that within a site, lignin content is a good predictor of decomposition rates. Also, Kalbitz *et al*, (2006) attributed the slow rate of decomposition of folia litter of certain trees to the presence of recalcitrant materials such as lignin. Although a lower polyphenol content for *S. siamea* resulted in faster decomposition and a higher content for *F. macrophylla* resulted in a slower rate, the situation was different for *L. leucocephala*. This multi-purpose tree had the highest polyphenol content yet decomposed faster than *F. macrophylla* with comparatively high polyphenol content also. This suggests that other chemical factors favoured the decomposition of *L. leucocephala* than polyphenols. Despite the high polyphenol content, *L. Leucocephala* had the highest N content, lignin similar to *S. siamea* and the lowest C: N ratio. The C: N ratio did not serve as good an indicator as lignin content because *F. macrophylla* with a lower C: N ratio decomposed significantly slower than *S. siamea* which had a higher C: N ratio. The lignin + polyphenol: N and lignin: N ratios served as good predicters. The higher the ratio, the less the decomposition rates. This suggests the level of decomposition of plant residues is a function of the integrated effects of chemical characteristics of the residue. In fact, going by the respective values of regression coefficients, the lignin + polyphenol: N ratio and may be lignin: N ratio, probably give a better indicator than just lignin content (Table 5). However, there is insufficient ancillary data on the chemical characteristics of the leaves to determine the relative importance of N, lignin and polyphenol content and other characteristics on decomposition in these studies (Palm, 1988).

The C: N ratio is a good indicator of whether net mineralisation or decomposition will occur during decomposition. Since all materials had C: N ratios less than 30:1, it can be assumed that mineralisation took place during litter decomposition. Materials with C: N ratios greater than 30; 1, can decompose just as rapidly as those with low C; N ratios provided adequate N is available in the soil. The decomposition rate constant equation for the materials studied were established during the investigations (Table 5). The positive correlation between the decomposition rate constants and rate of inorganic N fertiliser applied justifies the reason why companion crop yields (in this case maize) in alley cropping experiments where fertiliser N is added, are superior to those yields where no fertiliser has been added. Although decomposition rate increased with increasing amount of fertiliser N, no significant differences were observed between 68 and 112 kg N ha^{-1} rate (table 4). This implies that the 68 kg N ha^{-1} had the same effect as 112 kg N ha^{-1} on decomposition rates. This observation justifies the reason why the recommended N-fertiliser rate for hybrid maize companion crop in alley cropping at Chalimbana is 68 kg N ha^{-1}. N levels beyond this are not only uneconomical but tend to retard decomposition of incorporated leguminous plant residues probably due to luxury microbial biomass synthesis using inorganic N. Fertiliser N above this tends to be wasteful since it encourages luxury microbial N immobilisation at the expense of degradation of residue substrate (SADC/ICRAF, 1993).

The decomposition of leguminous leaves or litter in the tropics has received little attention (Palm, 1988). Values reported in the literature indicate fast but variable rates of decomposition ranging from 91% to 848% per year.In this study, the range was higher, from 614% to 1560% per year. The fact that there were significant differences between kD and inorganic N level in which the bags were incorporated, suggests the existence of the effect of N amendments on faunal activity on residues. This could be due to increased available inorganic N in the

soil which makes N not limiting for soil microorganisms which are responsible for degrading the residues. However Knapp *et al*., (1983) reported conflicting evidence where some studies found mixed results from the effect of N additions on straw decomposition. The varied results could be attributed to the effect of chemical composition, soil environmental factors and duration of incubation. If environmental conditions are optimal for maximum microbial activity, N and C will be utilised and microbial biomass can serve as both sink or source of soil nutrients or as a "driving force" in nutrient availability, where microbes promote the decomposition process. It is not only the microbial pool, but also the turnover rate that is important for nutrient availability. The kinetics of the system during this period is of agronomic interest in that they may be ultimately useful for residue management.

Fig 1: Decomposition of *L. leucocephala, S. siamea* and *F. macrophylla* over a period of 16 weeks

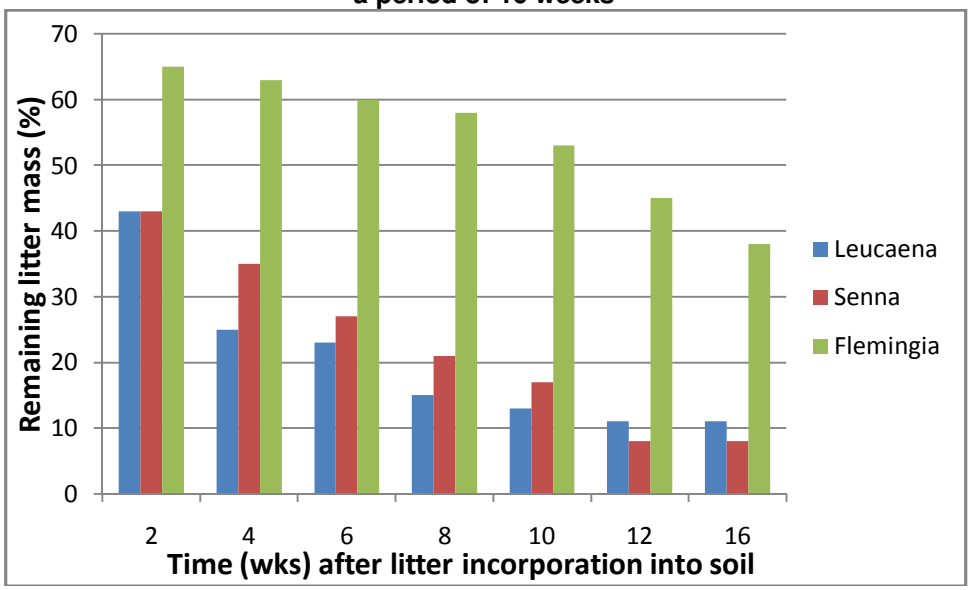


Table 2: The effect of leguminous tree species on remaining mass (g) during 16 weeks of incubation

Species	Incubation Time (weeks)				
	2	4	8	12	16
L. leucocephala	6.72b	4.40b	2.59c	1.79b	1.60b
S. siamea	7.01b	5.65b	3.42b	1.44b	1.24b
F. macrophylla	11.17a	10.64a	9.83a	7.68a	6.60a
Analysis of variance					
Species	**	**	**	*	**

§ means in the same column followed by the same letter are not significantly (P ≤ 0.05) different from each other by the Duncan's Multiple Range Test.

Fig 2: Effect of inorganic N on (kD) for *L. leucocephala, S. siamea* and *F.macrophylla.*

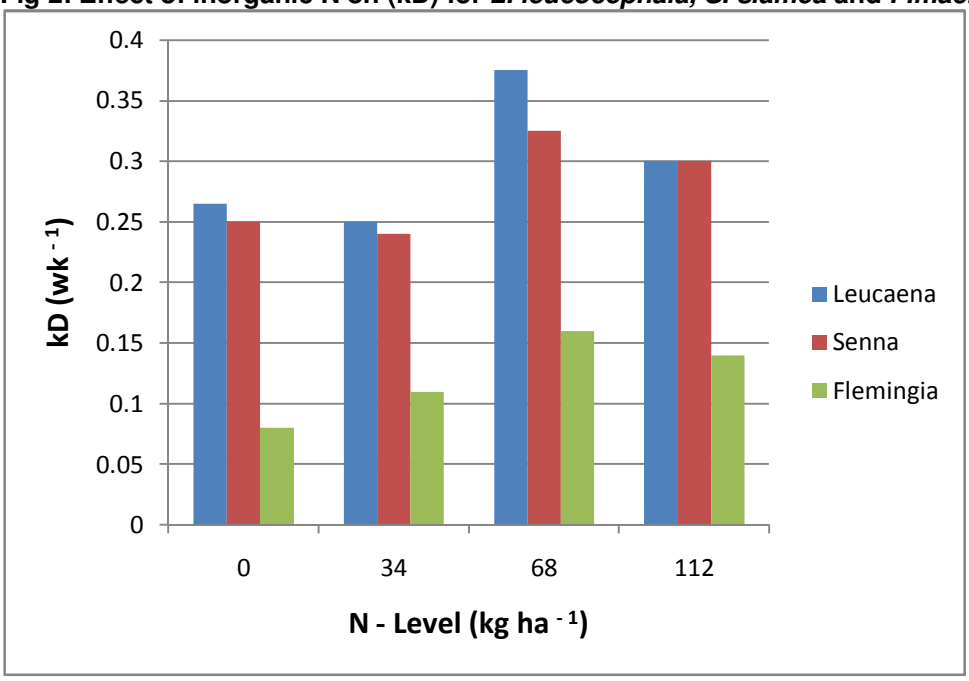


Table 3: The effect of species on decomposition rate constant (KD) at various sampling times

	Litter incubation time (weeks) in soil					
Species	**2**	**4**	**8**	**12**	**16**	**Mean**
			kD wk^{-1}			
L. leucocephala	1.45a§	0.37a	0.23a	0.23a	0.19a	0.30a
S. siamea	0.44a	0.28a	0.19ab	0.16a	0.12a	0.24a
F. macrophylla	0.23b	0.10c	0.08b	0.20a	0.14a	0.12b

§ Means in the same column followed by the same letter are not significantly (P ≤ 0.05) different from each other by the Duncan's Multiple Range Test.

Table 4: The effect of inorganic N on decomposition rate constant kD per week averaged over species

	Time (weeks)					
N kgha^{-1}	**2**	**4**	**8**	**12**	**16**	**Mean**
			(kD wk^{-1})			
0	0.36a§	0.19b	0.17a	0.14b	0.15a	0.20b
34	0.36a	0.24ab	0.19a	0.16b	0.14a	0.22b
68	0.36a	0.31a	0.14a	0.26a	0.18a	0.30a
112	0.42a	0.26ab	0.16a	0.20ab	0.14a	0.24ab

§ Means in the same column followed by the same letter are not significantly (P ≤ 0.05) different from each other by the Duncan's Multiple Range Test.

Table 5: The effects of selected parameters on decomposition rate constants (kD) of leguminous tree litters

Parameter	r^2†	F-value	p-level§	p,r¶
N content	0.0377	21.51	0.01	0.748
Lignin	-0.0253	21.51	0.01	-0.702
Polyphenols	-0.0309	21.52	0.01	-0.702
C: N	0.0644	21.51	0.01	-0.745
PP: N	-0.2208	21.52	0.05	-0.703
L + PP: N	-0.0463	21.52	0.05	-0.704
Inorganic N	0.0377	9.84	0.01	0.698
Constant (K)	2.4389			

† Regression coefficient §Probability level ¶ partial correlation
N Nitrogen C carbon PP polyphenol L Lignin

Nitrogen release pattern

Nitrogen release from the three leguminous plant litter partly followed the same pattern as decomposition for the first three weeks (Fig 3). Over 45 % of N in the litter was released during the first three weeks of incubation for all litter. Thereafter, the N content in the remaining undecomposed litter generally increased with time for all litter types (Fig. 3).

Nitrogen release rates varied with plant residues and N levels. The mean N release rates ranged from 0.114 to 0.151 wk^{-1} but were not significantly different (Table 7). The N release rate constants for *L. leucocephala* and *S. siamea* were almost half of the corresponding litter decomposition rate constants whilst for *F. macrophylla,* the two rates were equal. After 16 weeks, the N concentration remaining in *L. leucocephala, F. macrophylla* and *S. siamea* prunings had decreased on average by 46%, 15% and 13% respectively (Fig. 3).

In general, absence of net N release after two weeks suggests N immobilisation. N release rate constants obtained in this study (Table 7), fall within the range reported by Tian *et al*, (1992), but below those reported by Palm (1988). These differences are probably due to differences in residue species, quality or macroclimatic conditions. In the studies by Palm (1988), for example, the N contents were greater or equal to 3.18% and the lignin contents were smaller or equal to 16.35% for *Inga edulis, Cajanus cajan* and *Erythnia spp*. The absence of significant differences in N release rate constants amongst the three residues and across the four fertiliser N levels was unique. The high lignin and polyphenol contents (Table 1) could be major contributing factors on N immobilisation in *L. leucocephala* and *F. macrophylla*, while as for *S. siamea*, the lignin content and the rather high C ; N ratio could be responsible.

It is important to remember that the three species after two to three weeks began to show net immobilisation following the initial rapid loss (Fig. 3). This change in N release coincides with an increase in the N concentration in the tissue remaining. This second phase could be explained by the lignin and polyphenols in these species (Palm, 1988). In the first phase (2-3 weeks), the soluble N fraction is either leached, mineralised or taken up by the alley companion maize crop. At the same time, some of this N may bind to the lignin fraction leaving a resistant form of N (Handayanto *et al*, 1994; Swain, 1979). Another possibility is that N which is mineralised binds to the polyphenols forming a resistant form of N (King and Heath, 1967, Palm, 1988, Handayanto *et al*., 1994). The later explanation is more likely for *L. leucocephala* and *F. macrophylla* which have both high lignin and polyphenol contents. Spain and Le Feuvre (1987), however reported that it is difficult to distinguish between the two because polyphenol-N complexes end up in the same fraction as lignin or acid soluble fraction in most laboratory procedures. Other researchers, Palm and Sanchez (1991), Oglesby and Fownes (1992), concluded that the ratio of polyphenols to N was the parameter which could best be used to predict N mineralisation of various tropical legumes with a critical value of 0.5. The plant residues in this study were all above this critical figure (Table 1) which might explain the pattern obtained.

The presence of inorganic fertiliser did not significantly affect N release constants although it was anticipated that the presence of applied N would increase microbial activity since N would not be limiting. There is a possibility that the inorganic N was complexed by polyphenols and lignin from the decomposing residues after two weeks.

Table 6: The effect of selected parameters on N release rate constant of leguminous tree litters.

Parameters	Partial correlation
N content	0.664*
Lignin	-0.774**
Polyphenol	-0.863**
C: N ratio	-0.432 ns
Polyphenol: N ratio	-0.522 ns
Lignin + Polyphenol: N ratio	-0.311 ns
Inorganic N	0.459 ns

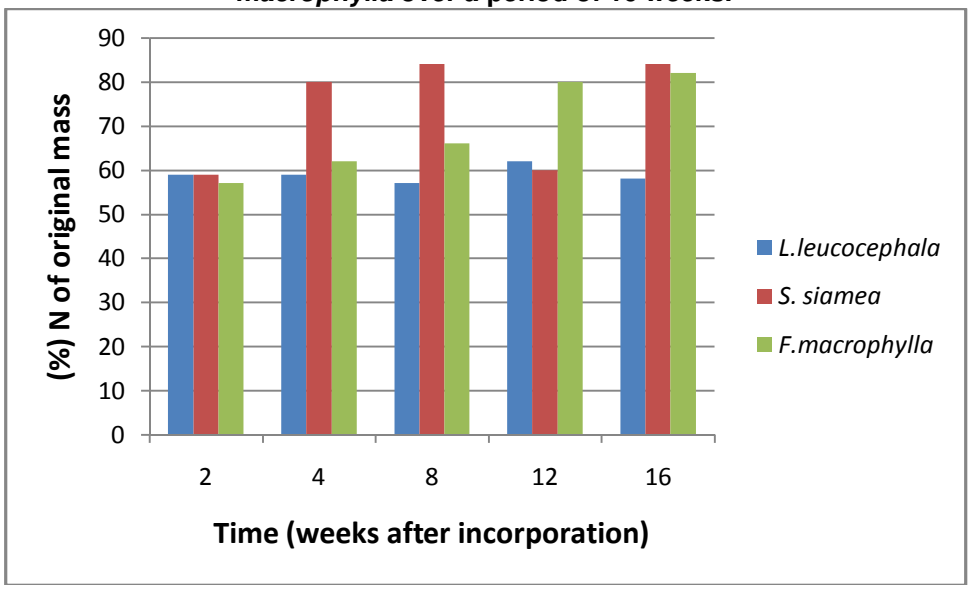
** = significant at P≤0.01, * = significant at P≤0.05 and ns = not significant

Table 7: Nitrogen release rate constants of prunings of three woody species as affected by inorganic N

	N level (kgha^{-1})				
Plant residues	**0**	**34**	**68**	**112**	**Spp mean**
	(kN)				
L. leucocephala	0.163	0.104	0.186	0.152	0.151a
S. siamea	0.125	0.113	0.150	0.126	0.129a
F. macrophylla	0.112	0.117	0.113	0.112	0.114a
N-level mean	0.133a	0.111a	0.150a	0.130a	

Means in the same column (species) and in the same row (N-level) followed by the same letter are not significantly different from each other at (P≤0.05) by the Duncan's Multiple Range Test.

Fig 3: Nitrogen release trends from *L. leucocephala, S. siamea* and *F. macrophylla* over a period of 16 weeks.



CONCLUSIONS

From this study, it is apparent that not all leguminous leaves, despite their high N content are of high quality in terms of rates and pattern of decomposition and N release. While the residues were considered to be of high quality in terms of initial N content and C: N ratios, the amount of polyphenols and lignins reduced the quality with respect to decomposability and nutrient release.

Decomposition and N release are influenced by lignin and polyphenol content of the leaves. These are important factors to consider when selecting legumes as N sources in agroforestry systems. Legumes low in lignins and polyphenols will provide a more rapid flash of N from mineralisation, and may therefore be a better choice for use with annual crops that require large amounts of N for short periods of time. Nitrogen release by legumes higher in lignins and polyphenols will be slower and decompose over a long period of time and may be the better choice for tree production systems.

Combination of pruning residues and inorganic N fertiliser is recommended where annual crops are involved. The 68 $kgNha^{-1}$ in combination with prunings has been proved to be attractive in terms of effect on decomposition. *L. leucocephala* and *S. siamea* had more positive attributes in terms of quality (save for the high polyphenol content for Leucaena), decomposition and N release constants than *F. macrophylla*.

However, further research for more than one season and including some non leguminous residues for comparison is needed. The fate of the resistant complexes formed by polyphenols and lignins with N should also be investigated. More interestingly, the use of tracer/radio isotope techniques in N dynamics in alley cropping or pot experiments would yield more conclusive results on the influence of inorganic N on decomposition and N release in alley cropping.

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