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Decomposition- and nitrogen-mineralization patterns of *Leucaena leucocephala* and *Cassia siamea* mulch under tropical semiarid conditions in Kenya

B.A. Jama[1] and P.K.R. Nair[2]
*School of Forest Resources and Conservation, University of Florida, 118 Newins-Ziegler Hall, Gainesville, FL 32611, USA. [1]Present address: KEFRI/KARI/ICRAF Agroforestry Research Project, P.O. Box 25199, Ontonglo, Kisumu, Kenya. [2]Corresponding author**

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Abstract

In agroforestry systems, loppings from trees and shrubs are commonly used, often as mulch, as sources of nutrients for interplanted crops. Therefore, it is important to understand the rates of mulch decomposition. This paper reports the results of a study on the decomposition and nitrogen (N)-mineralization patterns of the leaves, small twigs, and mulch (leaves plus twigs) of *Leucaena leucocephala* and *Cassia siamea* in a field experiment in an Alfisol in semiarid Kenya. Plant materials contained in 5mm nylon bags were placed below or on the soil surface in an alleycropping system involving the two tree species, with maize (*Zea mays* L.) as the intercrop. For plant materials of both species (except *Leucaena* leaves), there were two phases of decompositions: an initial rapid phase and a slower second one; *Leucaena* leaves had only a single phase. When placed below the soil surface, the decomposition rates of both *Leucaena* and *Cassia* mulch were similar (about 12% week^{-1} in the first phase and 1% week^{-1} in the second phase). When placed on the soil surface, *Leucaena* mulch decomposed 1.3 times more rapidly than *Cassia* mulch in the first phase. The patterns of N release from the mulch of both species were similar to those of mass loss. In general, mulch-decomposition and N-release rates of both species were related more to their C:N ratios than to polyphenol contents; while C:N ratio predicted the rate of first (rapid) phase, the rate of the second (slow) phase appeared to be regulated by lignin and polyphenol contents.

Introduction

Leguminous plants can serve as an important N source for crops in many parts of the tropics where fertilizer use is not economically feasible. Agroforestry, especially the alleycropping (also called hedgerow intercropping) system, in which leguminous trees and shrubs are grown in association with annual crops, has the potential to improve soil fertility and productivity in the tropics (Kang et al., 1990). One of the basic principles of alleycropping management is the periodic pruning of tree hedgerows to reduce the effects of shading and competition on the food crops grown between hedgerows. The prunings left as mulch on the soil surface between the hedgerows may improve the soil physical, chemical, and biological properties. The contribution of the prunings to fertility of the soil will largely depend on the amount and decomposition rate of the biomass applied.

Most studies on decomposition of hedgerow prunings or mulches have been made in the humid tropics (Budelman, 1988; Palm and Sanchez, 1991; Yamoah et al., 1986). Similar studies in the semiarid tropics are scarce, and often have not considered some of the plant factors (e.g. their nutrient-, polyphenol-, and lignin contents) and management practices (e.g., placement below or on soil surface) that are known to influence the patterns and rates of decomposition (Herman et al., 1977; Palm and Sanchez, 1991; Vallis and Jones, 1973). An understanding of the effect of these factors

* FAX No: +19048461277

on mulch decomposition could provide guidelines for increasing the crops' efficiency of using mulch-N, and for improving or sustaining soil fertility in the semiarid tropics.

Plant materials consist of cell contents and a cell wall matrix with various physical and chemical defense mechanisms against intrusion by (micro)organisms during the life of the plant. Consequently, decomposition of a plant material is probably governed by a sequence of events, including leakage of soluble cell compounds, microbial attack on cell wall matrix, and, finally, breakdown of the cell wall matrix itself. It would be surprising if all these could be described by a single exponential decay curve. Although two-stage exponential models have been proposed to describe plant litter decomposition, results of many decomposition studies involving agroforestry tree species are presented as single exponential decay curves (e.g. Handayanto et al., 1994); in several such cases, the authors had not allowed sufficient sampling times to recognize the possibility of more than one phase. Therefore, it seems reasonable to expect two phases of decomposition, an initial phase of rapid decay, followed by a second phase of slow decay of the residue. Key questions then are: what proportion of the biomass and its nutrient content follow the first and the second phases, respectively, and what the decay rates for each phase are.

The objectives of this study were two-fold: 1. to evaluate the effects of placement methods (i.e. below and on the soil surface) on the rates of decomposition of *Leucaena leucocephala* (Lam.) de Wit (hereafter referred to as leucaena) and *Cassia* (syn. *Senna*) *siamea* Lam. (hereafter referred to as cassia) mulch under field conditions and, 2. to determine the effects of mulch quality (i.e. content of nutrients, lignin, and polyphenols) on the rates of decomposition and N mineralization.

Materials and methods

Site description

The study was conducted for two cropping seasons in 1991 at the ICRAF Research Station located at Machakos, Kenya (1 ° 33′ S and 37° 14′ E and 1596 m elevation; mean annual temperature, 19 °C). During the first season, the total rainfall was 214 mm while that during the second was 373 mm (Fig. 1).

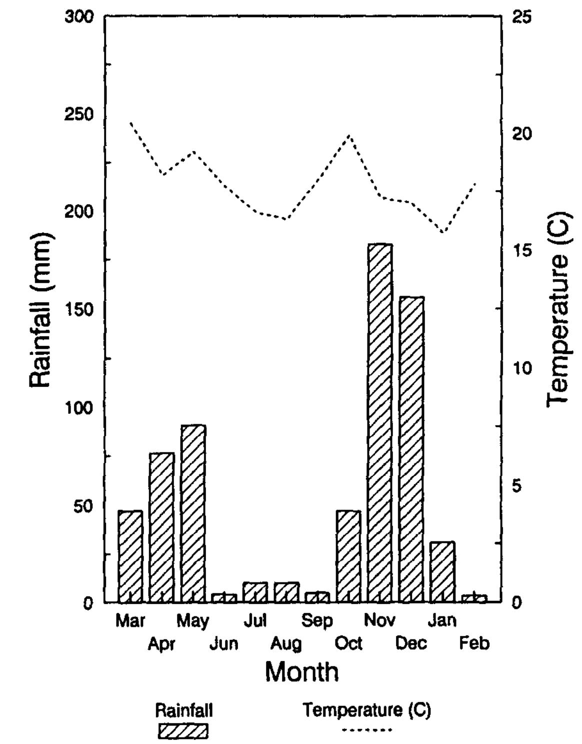

Figure 1. Monthly rainfall and mean temperatune during the study period.

The soil, which is classified as Kandic Rhodustalfs (US Soil Taxonomy) and Luvisol(FAO), is weakly to moderately leached; weakly acidic (pH (1:2.5 w/v water) 6.0 to 6.5); medium in base saturation (50 to 80%); and low to moderate in organic matter (topsoil (0-20 cm) carbon: 10 to 15 g kg^{-1}), total organic nitrogen (0.8 g kg^{-1}), and Olsen's phosphorus (<16 ppm). Other nutrients are reportedly present in levels adequate to support crop production (Kibe et al., 1981).

Decomposition study

Decomposition patterns of soil-surface placed mulch (leaves plus twigs) of leucaena and cassia were evaluated for two seasons in an alley cropping experiment consisting of leucaena and cassia in a randomized block design with three replications. Maize (*Zea mays* cv. Katumani Composite) was planted in the alleys between the hedgerows, and was fertilized at the rate of 40 and 18 kg ha^{-1} of N and P, respectively.

In the first season (beginning 23 March 1991), about 50 g each of fresh mulch samples of leucaena and cassia weighing 50 g (20 g dry weight; approximately 50% leaves in both leucaena and cassia; the twig fraction of the mulch having diameters ranging

Table 1. Chemical composition of the prunings of alley-cropped hedgerows of *Leucaena leucocephala* and *Cassia siamea*

Plant material	N(%)	Polyphenol (%)	Lignin (%)	C:N ratio
Leucaena				
Leaves	4.4	6.9	5.4	11
Twigs	2.6	2.4	10.8	19
Cassia				
Leaves	4.0	5.5	6.8	13
Twigs	1.7	1.9	9.9	29
SED (n=6)	1.1	1.5	2.7	5.2

from 5 to 10mm) were put into litter bags made of exuded polyvinyl (TSBF, 1993); the dimensions of the bags were 33 by 33 cm, mesh size of 5 mm. It was assumed that the use of litter bags with 5-mm openings would give results comparable to changes occurring in unconfined litter (TSBF, 1993). The litter bags were buried 10 cm beneath the soil surface (hereafter called "below the soil surface" or "inside the soil").

Some additional treatments were included in the second season (beginning 24 October 1991). These were: 1. mulch (leaves and twigs), 2. twigs (i.e. excluding the leaves), and 3. leaves only, all in separate litter bags placed on and below the soil surface. Additionally, filter paper (Whatman No. 2), chopped into small pieces but larger than the mesh size of the litter bags, was placed below the soil surface. The purpose of the filter paper was to determine the importance of C:N ratio of the mulch relative to the organic compounds (e.g. lignin and polyphenols) in influencing decomposition rates. The experiment involved a split-plot design with three replications, with the species as main-plots and the mulch placement methods (i.e. placement below or on soil surface) as subplot treatments; the kind of materials (i.e. mulch, leaves, and twigs) was considered as one factor.

Initial properties of the mulch, based on analysis of three samples each of leaves and twigs of both species used, are shown in Table 1. The mulch in the litter bags was retrieved from the field every two weeks for a total of 18 weeks. After retrieval, soil and debris adhering to the mulch were removed carefully with a toothbrush and a soft paint brush. The mulch was then sorted into leaves and twigs. Dry weight of each component was recorded after oven drying at 65 °C for 48 hours. Ash-free dry weight of the mulch retrieved from the soil was obtained following combustion of the mulch in a muffle furnace at 550 °C for 3 hours. Fresh mulch was also ashed to determine initial ash content. The following formula after Cochran (1991) was used to calculate ash-free dry weight:

$$\text{Corrected dry weight} = \frac{(\text{dry weight - increase in total residual ash})}{(\text{ash content of fresh mulch})}$$

Total N (three replicates) was determined using the micro-Kjeldahl acid digestion procedure (Jackson, 1958). In the first season, total N was determined only at the start and end of the study. In the second season, mulch-N content was determined each time it was retrieved from the soil. Carbon content of the mulch was not determined but assumed to be 50% of its ash-free dry weight (TSBF, 1993).

Acid-digestible lignin and ash concentrations were determined by the Van Soest method (Van Soest, 1968). Total soluble polyphenols were determined at the Natural Resources Institute, United Kingdom, using a revised Folin-Denis method (King and Heath, 1967). This involved extraction of the leaves, twigs, and combined leaves plus twigs in 50% aqueous methanol for two hours in a water bath at 80 °C. The materials had previously been air dried for two days and stored at room temperature before analysis. Polyphenol extraction and determination were conducted in duplicate using tannic acid (supplied by Sigma Chemicals; grade and purity not given) as a standard. Total soluble polyphenols are expressed as percent of tannic acid equivalents.

Statistical analyses

Chemical composition data of the materials used (Table 1) were analyzed by ANOVA for a randomized complete block design (RCBD) and SED calculated. A single exponential model $Y_t = Y_o \times e^{-kt}$ (where Y_o is the original amount of material applied and Y_t the proportion of the initial dry matter or N remaining after a period of time t, in weeks) was fitted. A plot of time against logarithm (log) of this first-order exponential model was made for each replicate. The logarithmic plots revealed that the patterns of dry matter or N loss were biphasic and a single negative exponential model could not provide the best fit. Therefore, the nonlinear (NLIN) procedure of SAS for multiphase regression models (SAS, 1992) was fitted. This procedure models the response variable, dry matter or N remaining in the mulch, as a continuous function of time. Regression parameters (i.e. the intercept and slope of each phase) and the spline (meeting) points of the regression lines of the two phases were generated for each replicate of the two species. The spline point represents the end of phase I and beginning of phase II. The slope of the linear regression is the k value, the decomposition rate constant. ANOVA test was performed on each parameter to determine significance of differences ($p < 0.05$) between the two species. Data for the first season, when one bag each of cassia and leucaena mulch was placed below the soil surface (no surface-placement treatment) in each of the three replicates, were analyzed by ANOVA for RCBD. During the second season, when leaves, twigs, and mulch of each species were placed both on and below soil surface, the data were analyzed by ANOVA for split-plot design; as mentioned earlier, the species were the main-plot treatments and placement methods the sub-plot treatments. Thus, there were separate SED values for both species and methods (Table 2). SED values for the filter paper treatment are for comparison against corresponding values of soil-incorporated plant-material samples.

Results

Patterns of mulch decomposition and N-mineralization

With the exception of leucaena leaves, all other materials including filter paper had an initial phase of rapid decomposition followed by a second phase of comparatively lower decomposition rate. Leucaena leaves showed only a single phase of decomposition. The parameters of the two-phase regression lines for the two mulch materials are presented in Table 2.

Effects of placement on or below the soil surface on mulch decomposition

Leaves

Significant interaction effects were observed between species and soil-placement methods on the rate of decomposition of leaves (Fig. 2). No significant difference was detected between the rates of decomposition of leucaena leaves on the surface and below the surface. Averaged across placement methods, the rate of decomposition of leucaena leaves was 129 g kg^{-1} per week, with a corresponding half-life of 4. 5 weeks; leucaena leaves had physically disappeared by week seven.

Between species, the rate of decomposition of leucaena leaves was higher than that of cassia only when surface-placed (Table 2). For cassia, leaves placed below the soil surface had higher rates of phase-one decomposition than surface-placed leaves. The rates of phase-one decomposition of cassia leaves below and on the soil surface were 131g kg^{-1} $week^{-1}$ and 111 g kg^{-1} $week^{-1}$, respectively, with corresponding half lives of 5.3 and 6.2 weeks. Phase-two decomposition of cassia leaves below the soil surface started at week 8.5 (i.e. at 33% of initial dry weight) and that of the soil-surface-placed leaves at week 9.2 (i.e. at 36% of initial dry weight). The differences in the starting time and rates of phase-two decomposition for the leaves below and on the soil surface were not different. On average, the leaves of cassia decomposed at a rate of 30 g kg^{-1} $week^{-1}$ in the second phase with a corresponding half life of 23.1 weeks.

Twigs

No significant effects of species or placement methods were noticed on the decomposition rates of the twigs in either phase (Fig. 3). However, the ratio of twigs to leaves that remained not decomposed was generally higher for leucaena than cassia in both seasons and placement methods (data not presented). This suggested that leucaena leaves decomposed more rapidly relative to their twigs than did cassia leaves.

In the second season, phase-two decomposition of cassia twigs below the soil surface started at week 6.5 (or 17% of initial dry weight); on the soil surface, phase two started at week 6.0 (at 20% of initial dry weight). With respect to leucaena, phase two of twig decomposition below the soil surface started at week 7.4 (or at 18% of initial dry weight); on the soil surface, phase two started at week 7.5 (at 48% of initial dry weight).

Mulch (leaves plus twigs)

In both seasons, there was no difference between species in the phase-one and phase-two decomposition rates of their mulches placed below the soil surface. Averaged across seasons and placement methods, leucaena and cassia mulch decomposed at the rate of 141 g kg^{-1} week $^{-1}$ and 119 g kg^{-1} $week^{-1}$ in phase one, respectively, with corresponding half-lives of 4.9 and 5.8 weeks. On the soil surface, the rate of decompo-

Table 2. Intercepts, slopes, spline points and coefficients of determination (R^2) of the regression lines for phase one and phase two of leucaena and cassia mulch decomposition

	Decomposition rate constant, k, (% week^{-1})				
	Intercept	Phase one	Phase two	Spline point (weeks)	R^2
First season[c]					
Mulch[a] (below soil surface)					
Cassia	2.2	12.1	0.1	9.1	0.82
Leucaena	2.2	13.8	A[b]	A	0.84
SED[c]					
Second season					
Leaves (below soil surface)					
Cassia	2.8	13.1	3.0	8.5	0.94
Leucaena	3.0	15.5	A	A	0.98
Leaves (on soil surface)					
Cassia	3.0	11.1	3.0	9.25	0.91
Leucaena	2.9	15.5	A	A	0.97
SED (method)	0.2	0.6	0.9	1.3	0.3
(species)	0.3	1.3	-	-	0.2
Twids (below soil surface)					
Cassia	1.0	13.0	3.0	6.5	0.96
Leucaena	1.1	7.5	2.0	7.4	0.85
Twigs (on soil surface)					
Cassia	1.1	11.5	3.2	6.0	0.77
Leucaena	1.3	10.5	4.6	7.5	0.77
SED (method)	0.4	2.6	1.4	1.4	0.2
SED (species)	0.3	1.7	1.2	1.3	0.4
Mulch (below soil surface)					
Cassia	2.3	13.1	1.0	11.3	0.96
Leucaena	2.3	12.0	1.0	8.0	0.95
Mulch (on soil surface)					
Cassia	2.4	12.5	2.4	8.5	0.97
Leucaena	2.2	16.5	5.2	6.0	0.98
SED (method)	0.4	1.7	1.2	1.3	0.4
SED (species)	0.3	1.7	1.2	1.3	0.4
Filter paper (below soil surface)	1.8	10.5	5.2	11.1	0.81
SED	0.2	1.3	1.2	1.1	0.2

[a] Mulch refers to leaves plus twigs.
[b] "A" Refers to absence of phase two in the decomposition pattern of the species.
[c] n for SED values is 6 for first season and 12 for second season.

sition of leucaena mulch in the first phase was higher than that of cassia in the second season. Surface-placed leucaena mulch also had a higher rate of phase-one decomposition than leucaena mulch placed below the soil surface (Fig. 4). Soil surface-placed leucaena mulch decomposed at the rate of 165 kg^{-1} week^{-1}

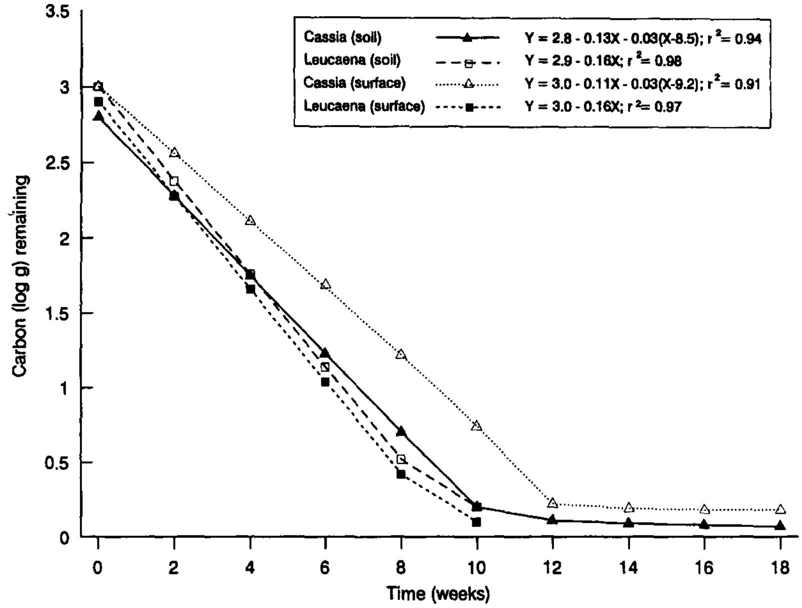

Figure 2. Decomposition patterns of *Leucaena leucocephala* and *Cassia siamea* leaves placed below soil surface, second season

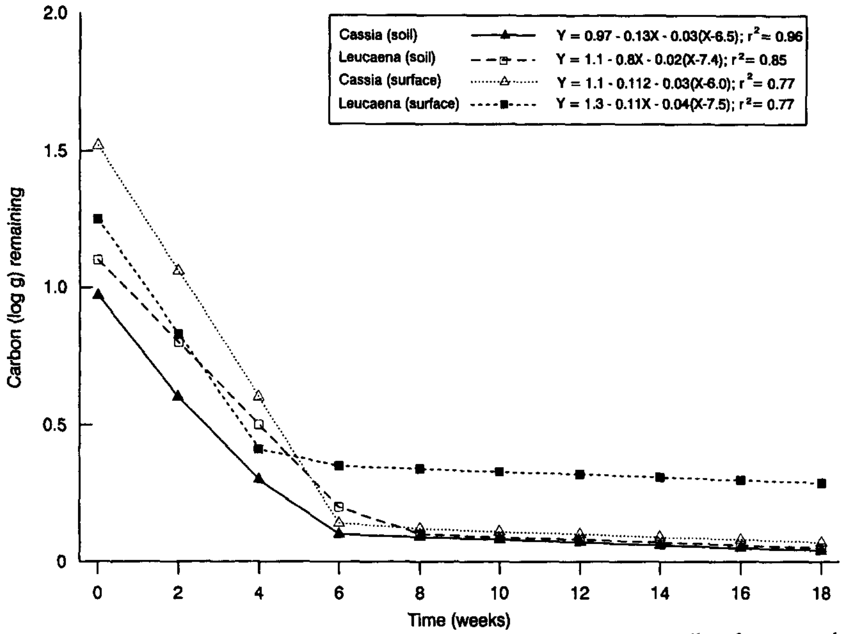

Figure 3. Decomposition patterns of *Leucaena leucocephala* and *Cassia siamea* twigs placed below soil surface, second season.

in phase one, with a half life of 4.2 weeks. On the other hand, surface-placed cassia mulch had a phase-one decomposition rate of 125 g kg^{-1} $week^{-1}$ with a corresponding half life of 5.5 weeks.

In the first season, when mulch was placed only below the soil surface (but not on the surface), phase-two decomposition of cassia mulch started at week 9.1 (at 19.5% of initial dry weight); phase-two decomposition of leucaena was not detectable. In the second season, phase two decomposition of cassia mulch below the soil surface started at week 11. 3 (at 10.9% of initial dry weight); on the soil surface, phase two started at week 8.5 (at 19% of initial dry weight). On the other hand, for leucaena mulch placed inside the soil, phase-two decomposition started at week 8.0 (at 28% of initial dry weight); on the soil surface, it started at

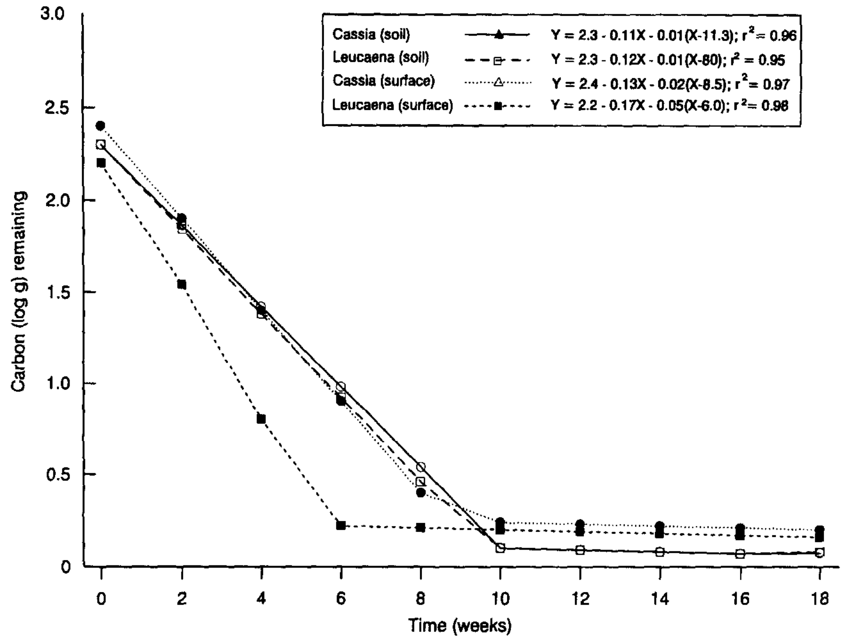

Figure 4. Decomposition patterns of *Leucaena leucocephala* and *Cassia siamea* mulch (leaves + twigs) placed below soil surface, second season

week 6.0. In the second phase of mulch decomposition, the effects of species, placement methods, and season were not significant in the second season. The average C:N ratio of phase-one decomposition of leucaena and cassia mulch placed below the soil surface were 18.9:1 and 23.4:1, respectively; in the second phase, the ratios were 36:1 for leucaena and 31:1 for cassia.

As expected, twigs generally decomposed at slower rates than leaves in phase one. However, in both seasons, the ratio of leaves to twigs of cassia mulch remaining over time was consistently higher than that of leucaena. This was true for mulch placed both below and on the soil surface. As a result, the rates of cassia leaf decomposition were often only marginally higher than those of the twigs. In leucaena, on the other hand, the ratio of leaves to twigs declined rapidly over time, indicating a higher rate of decomposition of leaves, compared to twigs.

Filter paper decomposition

Filter paper placed below the soil surface also had two phases of decomposition. The rates were similar to those of the mulch or the twigs placed below the soil surface (Table 2). Soil-surface placement of filter papers was not included as a treatment.

Trends of nitrogen loss from the mulch

The patterns of N mineralization from the mulch of leucaena and cassia were similar to those of the dry matter loss reported above. In both species, an initial phase of rapid N mineralization was observed which declined gradually with time (Fig. 5). The second-order regression equations of time against log N content of mulch showed that the rates of N mineralization of leucaena and cassia mulch in the first phase were 159 g kg^{-1} $week^{-1}$ and 169 g kg^{-1} $week^{-1}$ respectively which were not different; in the second phase, the rates were lower at 63 g kg^{-1} $week^{-1}$ and 32 g kg^{-1} $week^{-1}$ for leucaena and cassia, respectively; but, again, these rates were not different between each other. The spline points of the regression lines of the two phases occurred at 8.1 weeks (i.e. at 35% of initial dry weight) for leucaena and 8.7 weeks (i.e. at 31% of initial dry weight) for cassia after placement below soil surface. The half life of N mineralization for leucaena and cassia in the first phase were at 4.1 and 4.4 weeks, respectively.

In the first season, cumulative mulch-N mineralized after 16 weeks was 737 g kg^{-1} and 555 g kg^{-1} for leucaena and cassia, respectively. In the second season, N mineralization of both species was similar, 980 g kg^{-1} after 16 weeks. At week four of the second season, 575 g kg^{-1} of the leucaena and 584 g kg^{-1} of the cassia mulch-N were mineralized. At week eight, when the mulch-N concentration of leucaena and cassia

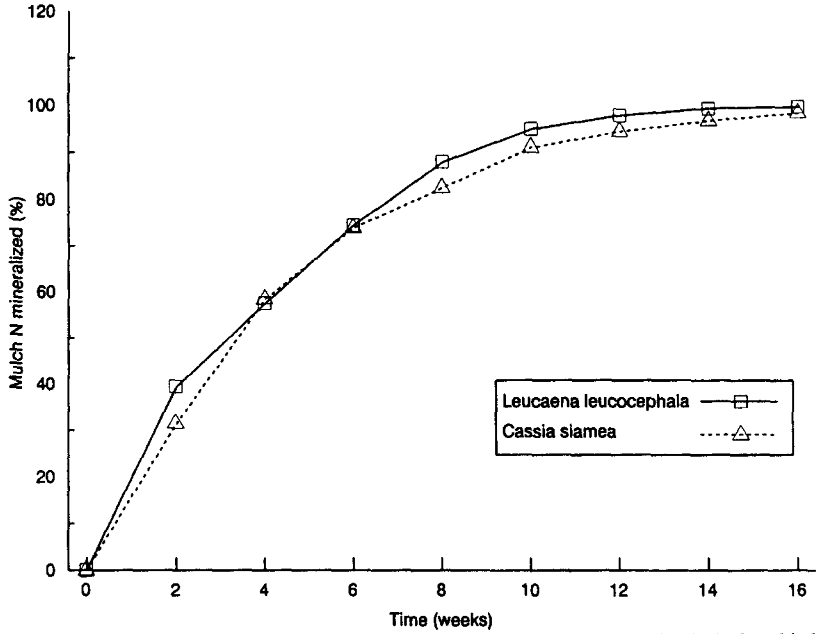

Figure 5. Percent N mineralized from *Leucaena leucocephala* and *Cassia siamea* mulch (leaves and twigs) placed below soil surface, second season.

mulch was 17 and 19 g kg^{-1} respectively, there was little N-mineralization.

Discussion

Mulch decomposition of leguminous species in semi-arid tropics has received little attention; most data available in the literature are from the humid tropics and they generally report variable decomposition-rate constants using single exponential equations (e.g. Palm and Sanchez, 1991). The decomposition rate constants (phase one) observed in both seasons of the present study were remarkably similar to those reported by Yamoah et al. (1986) and Budelman (1988) for soil-surface-placed leucaena mulch in the humid lowland tropics of West Africa. Other studies have also reported leucaena-mulch decomposition-rates similar to those of the present study (Kang and Duguma, 1985; Weeraratna, 1979).

Soil-incorporated mulch is generally observed to decompose faster than surface-placed mulch (Parker, 1962; Read et al., 1985). Also, decomposition rates are generally higher under humid than dry conditions. The absence of significant differences between decomposition rates of cassia mulch placed below and on the soil surface and between seasons were, therefore, interesting. It seems that surface-placed litter bags provided just as much contact between the mulch and the decomposers as those placed below the soil surface. The litter bags could have created more humid conditions for the mulch in the bags compared to the mulch outside the bags (Jensen, 1974). Furthermore, more termite activies were noted (data not reported here) during the second season that was drier than the first; therefore the relatively large mesh size (5mm) of the litter bags used might have resulted in the loss of mulch through the activities of termites. Finally, in this study, the mulch was placed discretely below the soil surface, which is not the same as incorporating it into the soil, and that might have affected the decomposition rate.

We acknowledge that the use of litter bags may alter the decomposition process. Some workers have been concerned about the consequences of experimental artefacts, e.g. 1. exclusion of predatory and saprophagous microarthropods (Hagvar and Kjondal, 1981; Seastedt, 1984); 2. reduction in contact between fungal vegetative structures and confined litter (St John, 1980); and 3. losses or gains of organic particles in large-mesh-size bags. While the first two problems may have been minimized by the large mesh size of bags used in the present study, it may have encouraged the latter.

In this study, quantities of undecomposed mulch remaining were described by a two-stage exponential model. This model, which has also been used by other workers (Wieder and Lang, 1982), has considerable advantages in providing insights into the process of decomposition over statistical procedures commonly used to analyze decomposition data (Howard and Howard, 1974; Hunt, 1977; Lousier and Parkinson, 1976). The first phase of decomposition typically reflects the rapid loss of easily decomposable materials (carbohydrates) while the second phase reflects the slow loss of more recalcitrant materials.

The use of only two species with closely related properties limits the ability of this study to establish the relative importance of variables that regulate the rates of decomposition during different phases. Nevertheless, the detailed characterization of the mulch (Table 1) provides some clues. In the first phase, narrow C:N ratio appears to be the main factor regulating the rate of decomposition of both species. The N concentrations of both leucaena and cassia mulch are higher than the critical levels generally considered as the limit beyond which immobilization may occur (Allison, 1973; Bartholomew, 1965; Stevenson, 1986). For materials with high N concentration (i.e. narrow C:N ratio) such as leucaena leaves, the second phase of decomposition may be undetectable indicating the almost complete decomposition of such materials within a relatively short time (Fox et al., 1990).

In other studies, low rates of decomposition of plant materials with narrow C:N ratio have been attributed to factors such as polyphenols (Vallis and Jones, 1973), polyphenol-to-N ratio (Oglesby and Fownes, 1992; Palm and Sanchez, 1991), and lignin + polyphenol to N ratio (Fox et al., 1990). The concentration of polyphenol in the leaves of leucaena used in the present study were high compared to that used by others (Palm and Sanchez, 1991). However, the rates of decomposition in the first phase did not appear to be influenced by the concentration of polyphenols in the leaves. In fact, leucaena leaves decomposed at a higher rate than cassia leaves with lower polyphenol content. These observations suggest that polyphenols (and their ratio with N) were either not important, or that the levels and the types of polyphenols present in leucaena leaves were not rate limiting. The latter may not be the case with cassia leaves. It is also possible that the water-soluble polyphenols present in the leaves are readily dissolved from the decomposing residues before impacting negatively on the activities of the decomposer community (Baldwin et al., 1983; Olson and Reiners, 1983). Soil water availability (under the rainfed conditions of the semiarid study site) may not have been adequate to allow the water-soluble polyphenols to become involved in decomposition; indeed, as reported by Santo et al. (1993), soil-water availability is an important factor in organic-matter decomposition under conditions similar to those of the present study. However, our study was conducted during the rainy season when soil water may not have been limiting.

Compared to the first phase, it is less clear what factors regulated the rate of decomposition in the second phase. Increased C:N ratio (the C probably being in the form of lignin) and polyphenols could be involved but the former appears to provide the best explanation. Two observations favor high C:N ratio, lignin: N in ratio particular). The first is the increasing ratio of twigs in the mixture of twig and leaves over time in the second phase (data not shown). Leucaena leaves had practically all disappeared at the start of the second phase in spite of their high polyphenol content relative to the twigs. On the other hand, the twigs with higher lignin content than the leaves were more dominant than leaves in the second phase. The second observation was that decomposition rates of cassia and leucaena twigs were similar although the latter had higher polyphenol concentration than cassia twigs.

Filter paper with the highest C:N ratio had rates of decomposition not different from those of twigs; this suggests that in the absence of lignin, wide C:N ratio *per se* may not be a rate limiting factor. These observations support the argument (Herman et al., 1977; Parr and Papendick, 1978) that the form of C, especially lignin, must be taken into account along with the C:N ratio in predicting residue decomposition rates.

It appears that, in addition to high lignin:N ratio, other factors are involved in the low rate in the second phase of decomposition. At the start of phase two, the lignin:N ratio of the leucaena mulch was 6.5:1 while that of cassia was 20:1. While leucaena's lignin:N ratio of 6.5:1 is below the wide range of plant lignin:N ratios of most plants, cassia's ratio of 20:1 is in the upper range (Mellilo et al., 1982). But, the polyphenol levels of leucaena twigs were within the range observed by other workers to limit the rates of decomposition of some leguminous materials (Palm and Sanchez, 1991; Oglesby and Fownes, 1992). Given that leucaena twigs had more lignin and polyphenol than cassia, the combined liignin and polyphenol content (Fox et al., 1990) could explain the lack of significant differences in the rates of decomposition and N-mineralization of the mulch from the two species. However, this explanation is based on results from the samples of only two species and may not extend to other species whose

C:N ratio, lignin, polyphenol concentration and age are outside the range considered.

For materials with high N concentration (i.e. narrow C:N ratio) such as leucaena leaves used in this study, the second phase of decomposition may not exist or be undetectable. Since the phases as well as their rates of decomposition have important implications on the availability of nutrients from the mulch to the crop, it is important to firmly establish the relative importance of each factor involved.

The rates of N release from the mulches of both species were highest during the first four weeks after application, when 80-85% of the mulch N was mineralized (Fig. 5). Despite the differences in initial chemical composition of the two species (Table 1), there were no differences between them in their N-release characteristics.

Conclusions

In this study, the rates of decomposition and N mineralization of leucaena mulch placed on the soil surface were higher than those of the mulch placed below soil surface. For cassia, mulch placement methods did not influence decomposition patterns. Furthermore, there was no difference between the species in their N-release characteristics; 80-85% of the mulch N of both species were released during the first four weeks after mulch application. Mulch decomposition was found to involve two phases; an initial phase of rapid mass loss followed by a second phase of slower rate. Results suggest that narrow C:N ratio of the materials might be an important factor causing the fast rate of their decomposition in the first phase. However, it was not clear what factors regulated the decomposition in the second phase; but lignin:N ratio and (combined polyphenol + lignin):N ratios seem to be important factors in this phase. In the second phase of mulch decomposition, the effects of species and placement methods were not significant.

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