

BIOLOGICAL EFFECTS OF PLANT RESIDUES
with contrasting chemical compositions
on
PLANT AND SOIL
under humid tropical conditions

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BIOLOGICAL EFFECTS OF PLANT RESIDUES
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PLANT AND SOIL
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Proefschrift
ter verkrijging van de graad van
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Stellingen

1. Both soil fauna and the chemical composition of plant residues play important roles in influencing decomposition and nutrient release.
--This thesis
2. The effect of tropical earthworms and millipedes on degradation of plant residues is mainly through biochemical transformation rather than through comminution.
--This thesis
3. In the humid tropics, plant residues with "low quality" may have similar values to those with "high quality" in sustaining crop production, through different mechanisms.
--This thesis
4. In the humid tropics, both the nutritional effect and the mulching effect on microclimate of plant residues influence the population dynamics of soil fauna.
--This thesis
5. Laboratory studies on decomposition may underestimate nutrient release of plant residues.
--This thesis
6. Determining N level in the soil solution is a better tool than N release from litterbags to predict the N supply of plant residues to crop.
--This thesis
7. The definition of soil fertility by Foth and Ellis as "the status of a soil with respect to its ability to supply elements essential for plant growth without a toxic concentration of any element" is of limited value because it neglects biological and physical soil properties important for plant growth.

Foth HD and Ellis BG (1988) Soil Fertility.
John Wiley & Sons, New York etc.

8. International Agricultural Research Centers should foster basic research in addition to applied studies.
9. Science flourishes by both disagreement and co-operation.
10. Further studies for many research projects are always recommended, but often not materialized.
11. Developing countries may promote agricultural development for self-reliance by subsidizing farmers to help them adopt innovative technology.
12. Peoples' nature is far more important than educational background in influencing the development of nations.

Stellingen behorend bij het proefschrift **"Biological effects of plant residues with contrasting chemical compositions on plant and soil under the humid tropical conditions"**. G. Tian, Wageningen, 7 October 1992.

To
Professor Shijia Tang

*The greatest in the kingdom of heaven is the one
who humbles himself.*

From: New Testament

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I reserve my thanks to my wife Jihong, son Tian (Lucas), for their support, patience and cheerfulness.

A handwritten signature in black ink, appearing to read 'Guanglong Tian', with a long, sweeping horizontal stroke extending to the right.

Guanglong Tian
Wageningen, The Netherlands
June 30, 1992

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2.

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1. Introduction

1.1 General introduction

Production of adequate food to meet the needs of an increasing population has become a major challenge for many developing countries, particularly those in tropical South America and Africa (Brown, 1985; Kang et al., 1981). To cope with the encountered problems, either crop production on existing land or production area or both has to be increased (Ofori et al., 1986). Applicability of these options varies greatly between regions depending on local availability of suitable land, viable soil management techniques and inputs, infrastructure and socio-economic conditions. Improvement of food production in these regions is, however, ultimately dependent on the intensification of land use. The task facing agricultural scientists is hence to develop ecologically sustainable, economically viable and environmentally sound food production systems (Kang, 1989).

The essential feature of sustainable agricultural systems is: continual compensation of nutrient export; maintenance of soil organic matter; maintenance of soil physical conditions including control of soil erosion (Okigbo, 1981). To develop sustainable agricultural systems, introduction of organic inputs, such as prunings and crop residues has to be considered (Baldock and Musgrave, 1980; Kang et al., 1981; Lavelle, 1984; van der Heide et al., 1985; Swift, 1986; Bowen et al., 1988; Quintana et al., 1988; Kang and Ghuman, 1989). Although traditional farmers have used fallow vegetations and crop residues as sources of organic fertilizer in their production systems for generations, little quantitative information is available on the manurial value of many of these species.

1.2 Stating the problem

Decomposition determines the effects of plant residues on plant and soil (Swift et al., 1981; Saini et al., 1984; Li et al., 1985), as shown in Figure 1.1. Plant residues decomposing rapidly can supply a large amount of nutrients in early periods of crop growth, but may not contribute much to

maintenance of soil organic matter and soil physical conditions. Plant residues decomposing slowly may have opposite functions, compared to those decomposing rapidly. Understanding the decomposition of plant residues is an essential step for evaluating their impacts on the sustainability of agricultural systems.

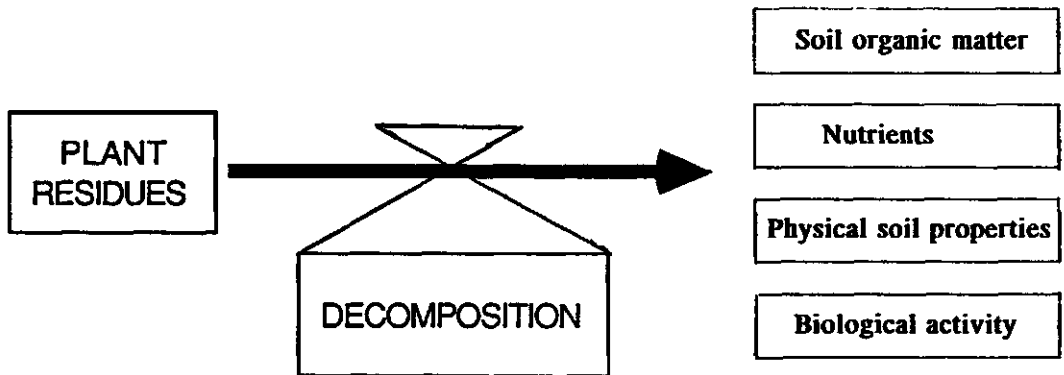


Fig. 1.1 A conceptual model illustrating the controlling role of decomposition in the effect of plant residues on soil properties.

Decomposition of plant residues includes three processes: comminution (physical breakdown by animals and abiotic processes), catabolism (action of microbial and animal enzymes) and leaching of water-soluble materials (Swift et al., 1979). The rate of decomposition of plant residues is influenced by a number of factors (Figure 1.2), in particular resource quality, environmental conditions and decomposer organisms (Swift et al., 1979). The influence of environmental conditions on decomposition is well known (Jenny et al., 1949; Daubenmire and Prusso, 1963; Brinson, 1977; Jenkinson and Ayanaba, 1977; Moore, 1986). Resource quality, as defined by chemical compositions of decomposing materials, is generally considered a critical factor in affecting decomposition and nutrient release. Minderman (1968), van Cleve (1974) and Tate (1987), e.g., reported the role of lignin as a determinant of the decomposition of plant residues. With the increase of lignin content, the rate of decomposition of plant residues generally decreases. Allison and Klein (1962), Alexander (1977) and Frankenberger and Abdelmagid (1985), e.g., reported the correlation between decomposition and N content of plant

residues. Handley (1961), Vallis and Jones (1973) and Palm and Sanchez (1991), e.g., postulated that polyphenols reduced decomposition of plant residues. Abe et al. (1979) and Ma and Takahashi (1989), e.g., stressed the role of silica in the decomposition of plant residues. However, quantitative information on the integrated effect of the above mentioned chemical components is not available.

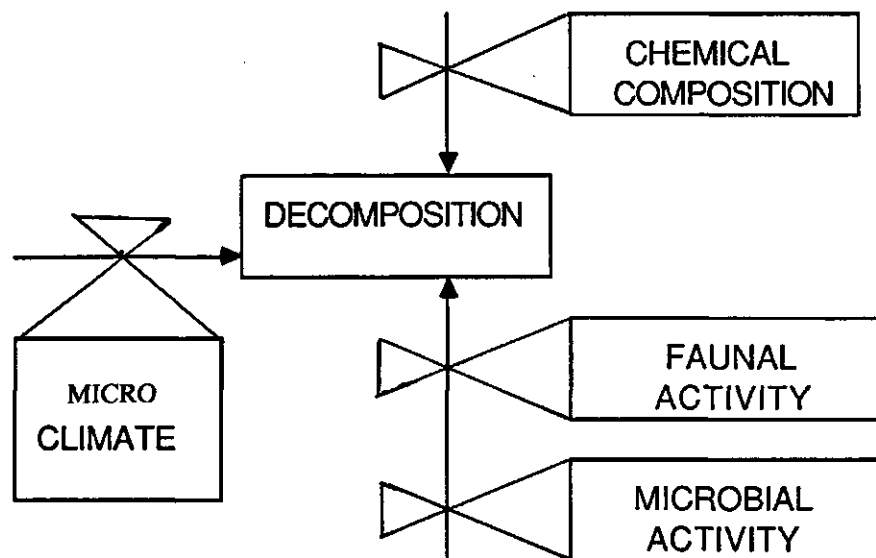


Fig. 1.2 A conceptual model illustrating speed-driving variables on decomposition.

It is well known that fungi and bacteria are responsible for the major chemical transformations during decomposition and nutrient release. Invertebrate animals of soil and litter, however, influence the microbial processes in two important ways. They disrupt plant and microbial cells, which results in the release of mineral elements, and they stimulate microbial action by increasing the surface area for microbial colonization and exposing new surfaces for enzymatic action through comminuting the organic residues into smaller particles (Anderson and Ineson, 1983, e.g.). Although the role of soil fauna has been extensively studied (van der Drift, 1958; Stockdill, 1966; Swift et al., 1979; Edwards and Heath, 1963; Moore et al., 1988; Setälä et al., 1988; Verhoef and Brussaard, 1990; Lee, 1990; Brussaard et al., in press), knowledge on the relationship between faunal

effects and chemical compositions of substrates is far from complete.

The central general hypothesis of this thesis is that the saprophagous soil fauna play a critical role in the process of decomposition and, thereby, in the rate with which inorganic nutrients are released. Effects of plant residues and soil fauna on soil organic matter and physical properties are beyond the scope of the study.

1.3 Research approach

The objective of the research was to test the above-mentioned hypothesis and, hence, the thesis concentrates on interactions between soil fauna and decomposition of selected plant materials, nutrient release and crop uptake. First, laboratory studies were conducted to select plant residues with very contrasting C/N ratios, lignin, silica and polyphenol contents (chapter 2). Field trials were set up to assess mass loss and nutrient (especially nitrogen) release from five selected species of plant residues with contrasting chemical compositions (chapter 3) and their effects on four groups of soil fauna (chapter 4). *Mutatis mutandis*, field and growth chamber trials were carried out to assess the effects of specific soil fauna groups (earthworms and millipedes) on degradation of plant residues and associated N release (chapter 5). Finally, the effects of the five selected plant residues on the performance of maize as a test crop were evaluated (chapter 6). Management implications are discussed to manipulate the decomposition of plant residues towards better synchronization between crop demand and availability of nutrients, using residue quality, soil fauna and mulching-induced microclimate as interrelated variables (chapter 7).

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2. Effects of chemical composition on N, Ca, and Mg release during incubation of leaves from selected agroforestry and fallow plant species

Abstract

Nitrogen, Ca and Mg release from leaves of ten selected plant residues with varying chemical compositions was studied under laboratory conditions. Three patterns of N-release were observed over a seven week incubation period: (a) *Gliricidia sepium*, *Leucaena leucocephala*, *Mucuna pruriens* and *Centrosema pubescens* leaves showed rapid N release, (b) *Acioa barteri* and *Dialium guineense* leaves immobilized N, and (c) *Alchornea cordifolia*, *Anthonata macrophylla*, *Cassia siamea* and *Pterocarpus santalinoides* leaves initially showed N immobilization which gradually changes to net mineralization after about four weeks of incubation. Nitrogen mineralization rate constant (k) ranged from -0.0018 (*A. barteri*) to 0.0064 day⁻¹ (*G. sepium*). Statistical analysis of data showed that N mineralization rate constants are significantly correlated with initial N, polyphenol and lignin contents of leaves. Nitrogen release increased with increasing N content and decreased with increasing contents of polyphenols and lignin.

Addition of leaves from all species significantly increased soil exchangeable Ca and Mg levels. *L. leucocephala*, *G. sepium*, *C. pubescens* and *M. pruriens* showed relatively high Ca and Mg release rates. Calcium release rate was related to N release rate rather than to initial Ca content.

2.1 Introduction

Application of plant residues is a well known agricultural practice for maintaining soil nutrient levels and ameliorating soil physical properties to sustain crop production (Baldock and Musgrave, 1980; Fu et al., 1987). This is commonly practiced in many developing countries in the tropics where fertilizer use is limited due to economic reasons or unavailability (Kang and Wilson, 1987; Kang, 1988). Many researchers have indicated

that plant residues from planted fallows or prunings from hedgerows in alley cropping systems can contribute significant quantities of nutrients to the associated crop (Kang et al., 1981; Mulongoy and van der Meersch, 1988). To better evaluate the potential of plant residues from planted fallow species as a nutrient source, more information is needed about their chemical composition and nutrient release patterns.

Determination of N release is often included in decomposition studies of plant materials. Lignin levels and C/N ratios of plant residues are known to affect decomposition rate and N mineralization (Peevy and Norman, 1948; Herman et al., 1977). Although C/N ratio is accepted as a good indicator for N mineralization and immobilization (Allison, 1973), polyphenol content appears to also affect the processes (Vallis and Jones, 1973). Palm and Sanchez (1991) reported that mineralization of leaves of some tropical legumes was not correlated with N or lignin contents, but negatively correlated with the polyphenol levels. However, knowledge on the polyphenol effect is incomplete, particularly for agroforestry fallow plant species with potential for use as sources of nutrients in farming systems in the humid tropics.

A large area of soils in the tropics particularly Oxisols and Ultisols is known to have low Ca and Mg supply for crop needs (Brady, 1990). Plant residues can be a very important source of these nutrients. Information on Ca and Mg release patterns can therefore be used as a method for predicting the potential of plant residues as sources of these nutrients.

The chemical composition of leaves of widely used woody species in agroforestry systems and commonly used cover crops in southern Nigeria was determined, and their effects on N, Ca and Mg release were studied in incubation experiments. Phosphorus and K releases were not determined in this trial, as P release was small particularly for species such as *A. barteri* and *P. santalinoides* which made measurements unreliable. Since, KCl extraction was used in assessing nutrient release, K was not determined in this trial.

2.2 Materials and methods

Plant material

Leaves (blades and petioles) from five indigenous (*Acioa barteri*,

Alchornea cordifolia, *Anthonata macrophylla*, *Dialium guineense*, and *Pterocarpus santalinoides*) and three exotic (*Cassia siamea*, *Gliricidia sepium*, and *Leucaena leucocephala*) woody perennials and two herbaceous cover crops (*Centrosema pubescens* and *Mucuna pruriens*) were used in the study. About five kilograms of fully matured leaves were collected from several plants grown on an Alfisol (Oxic paleustalf) at the International Institute of Tropical Agriculture (IITA) main station at Ibadan, Nigeria. This soils is adequately supplied with Ca and Mg. Samples were oven dried at 60°C till constant weight and ground to pass a 2 mm size sieve.

Leaf samples were analysed for total C by the modified wet digestion technique (Shaw, 1959) using a mixture of $K_2Cr_2O_7$ - H_2SO_4 - H_3PO_4 . Total N was determined by micro-Kjeldahl digestion followed by distillation and titration (IITA, 1982). For determination of P, K, Ca and Mg, leaf samples were wet-digested with a mixture of $HClO_4$ - HNO_3 , P was measured colorimetrically by auto-analyzer, K was measured by flame photometry, and Ca and Mg were measured using atomic absorption spectrophotometry (IITA, 1982). Extractable polyphenols were determined by the Folin-Denis method (Anderson and Ingram, 1989). Lignin, cellulose and hemicellulose were determined by the acid detergent fiber method (Goering and van Soest, 1970). All chemical analyses were done in triplicate, except for lignin, cellulose and hemicellulose contents.

Incubation procedure

The incubation procedure, adapted from Quintana et al. (1988) consisted of placing 10 g of soil, passed through a 2 mm sieve and 150 mg of dry leaves passed through a 1 mm sieve in an 150 ml Erlenmeyer flask. The leaves and soil were thoroughly mixed before 2 ml of distilled water was added to bring the soil moisture content to 50% of water holding capacity. In the control no leaves were added. The flask was covered with a double layer of 0.08 mm thick polyethelene sheet which allows gas but not water exchange (Gordon et al., 1987). Flasks were kept at 25°C, with about 12 hours of natural light each day. At the end of each of the eight incubation periods, mineralized N, Ca and Mg were extracted with 2 N KCl (10 g soil in 50 ml extract, shaken for 60 minutes). Total N in the extract was determined by the micro-Kjeldahl method. Calcium and Mg in the extract were determined by atomic absorption spectroscopy (IITA, 1982). The experiment was run for seven weeks.

Surface (0-15 cm) soil (Oxic paleustalf) for incubation studies was

Table 2.1 Chemical characteristics and N release rate constants of leaves of selected herbaceous and woody species.

Species	C	N	Ca	Mg	P	K	Poly-phenols	Cellulose	Lignin	Hemi-cellulose	k	R ^{2a}
						(%)					(10 ⁻³ d ⁻¹)	
<i>A. barteri</i> ^{be}	45.1	1.51	0.99	0.20	0.09	0.77	3.86	28.9	24.5	9.3	-1.8	0.93
<i>L. leucocephala</i> ^{ce}	45.5	5.87	1.77	0.36	0.20	1.82	4.90	10.3	7.1	5.6	4.2	0.95
<i>G. sepium</i> ^{ce}	47.3	5.04	1.31	0.34	0.23	2.14	2.12	10.9	8.6	6.8	6.4	0.97
<i>C. siamea</i> ^{de}	44.0	2.62	2.76	0.18	0.14	1.11	1.57	18.0	6.5	21.6	2.8	0.65
<i>P. santalinoides</i> ^{ce}	45.4	3.01	1.39	0.38	0.11	1.23	2.63	20.5	24.1	19.2	0.8	0.56
<i>D. guineense</i> ^{ce}	43.8	1.80	0.72	0.13	0.14	0.51	4.84	18.9	14.5	15.7	-1.3	0.86
<i>M. pruriens</i> ^{cf}	45.5	6.05	0.59	0.23	0.40	1.88	4.00	17.3	16.8	4.2	5.4	0.94
<i>C. pubescens</i> ^{cf}	44.1	5.51	0.77	0.29	0.38	1.89	1.50	40.2	10.1	5.0	5.5	0.91
<i>A. cordifolia</i> ^{be}	46.2	2.69	0.50	0.15	0.20	0.88	5.30	14.5	8.7	11.6	0.5	0.59
<i>A. macrophylla</i> ^{de}	48.0	2.59	1.51	0.18	0.15	0.62	4.36	23.0	32.3	11.0	-0.5	0.45
SE (±)	0.1	0.01	0.18	0.03	0.01	0.08	0.10					
LSD (0.05)	0.4	0.03	0.57	0.09	0.02	0.27	0.28					

a : R² (0.05) = 0.44, R² (0.01) = 0.62

e : woody species

b : non leguminous species

f : herbaceous species

c : N₂-fixing leguminous speciesd : Non N₂-fixing leguminous species

collected from the IITA main station at Ibadan, Nigeria. Soil was air-dried and sieved through a 2 mm sieve. The soil used for the study had the following characteristics; 1.08% organic C, 0.082% total N, pH-H₂O 6.5, ECEC 5.68 meq 100 g⁻¹, and 71.0% sand, 11.7% silt and 17.3% clay.

The trial was carried out, using a randomized complete block design with four replications. Data were subjected to ANOVA, partial correlation and regression of N release rate constants against C, N, polyphenol, lignin, cellulose and hemicellulose contents, with backward selection using the statistical analysis system program (SAS, 1985).

2.3 Results and discussion

Chemical composition of fallow species

Table 2.1 shows large differences in the chemical composition of the leaves of the ten fallow species studied. Nitrogen content ranged from 1.51% (*A. barteri*) to 6.05% (*M. pruriens*). Leaves of some woody species have lower N content than those of herbaceous species. Phosphorus content of leaves ranged from 0.09% (*A. barteri*) to 0.4% (*M. pruriens*). Woody species appeared to be a poorer source of P than herbaceous species. Combining with their slow P release, materials from the woody species will provide only small amount of P unless applied in large quantities. It is important to note the low P levels in *A. barteri* and *P. Santalinoides* leaves, these are species normally grown in acid and low P soils, which probably reflects a mechanism of adaptation for low P soils. Potassium content of leaves ranged from 0.51% (*D. guineense*) to 2.14% (*G. sepium*). *Acioa barteri*, *A. cordifolia*, *A. macrophylla*, *D. guineense* leaves showed lower K levels than other species. Calcium levels ranged from 0.5% (*A. cordifolia*) to 2.76% (*C. siamea*). Magnesium levels ranged from 0.13% (*D. guineense*) to 0.36% (*L. leucocephala*). Soluble polyphenol contents of leaves ranged from 1.5% (*C. pubescens*) to 5.30% (*A. cordifolia*). *Gliricidia sepium*, *C. siamea*, *P. santalinoides*, *C. pubescens* leaves showed relatively low levels of polyphenols. The carbon content of leaves showed little variability among species. Lignin contents of leaves ranged from 6.5% (*C. siamea*) to 32.3% (*A. macrophylla*). Cellulose contents of leaves ranged from 10.3% (*L. leucocephala*) to 40.2% (*C. pubescens*), with the majority having a cellulose content of less than 25%. *Cassia siamea*, *P. santalinoides* and *D. guineense* leaves had high hemicellulose contents (> 15%), the other

species had low hemicellulose content (< 12%).

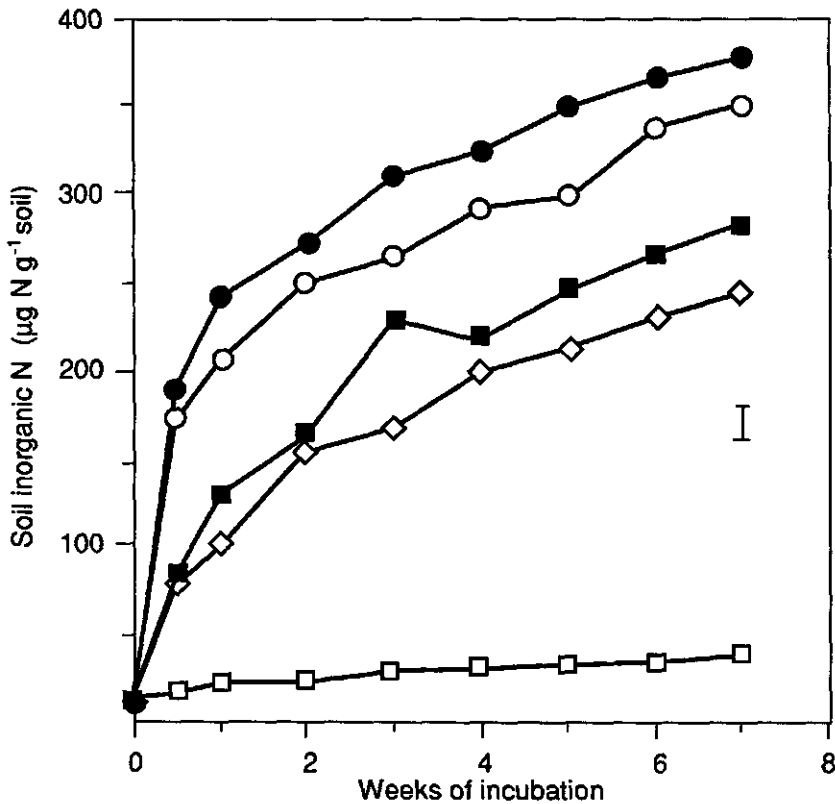


Fig. 2.1 Changes in soil inorganic N levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *L. leucocephala* (◇), *G. sepium* (○), *M. pruriens* (●), *C. pubescens* (■). Bar represents LSD (0.05) at 7 weeks of incubation.

Pattern of nitrogen release of plant residues

Mineral N in the control treatment showed a small and gradual increase, from 11.3 to 36.4 $\mu\text{g N g}^{-1}$ soil during the incubation. Rapid increase in soil mineral N was observed in treatments with *L. leucocephala*, *G. sepium*, *C. pubescens* and *M. pruriens* (Figure 2.1). With addition of *A. barteri* and *D. guineense* leaves, soil mineral N was reduced to a very low level (2.2 μg

N g^{-1} soil) (Figure 2.2). Incubation with *C. siamea*, *P. santalinoides*, *A. cordifolia* and *A. macrophylla* leaves decreased soil mineral N during the first four weeks followed by a slight increase during the remaining three weeks incubation period (Figure 2.3).

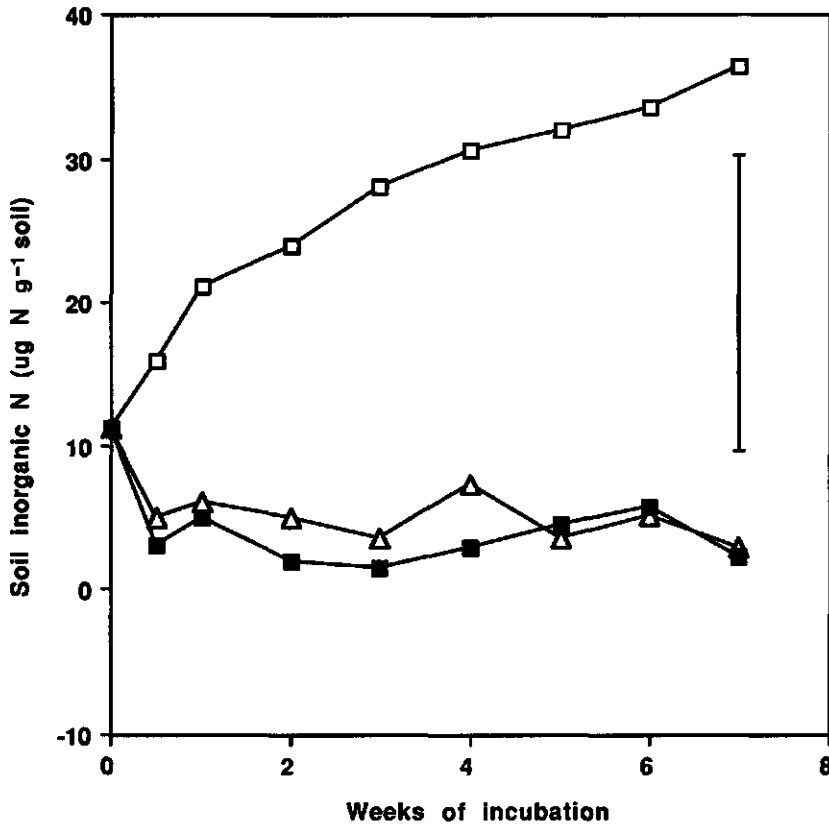


Fig. 2.2 Changes in soil inorganic N levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *A. barteri* (Δ), *D. guineense* (■). Bar represents LSD (0.05) at 7 weeks of incubation.

Net N mineralization after 7 weeks of incubation differed considerably from $3.3 \mu\text{g N g}^{-1}$ soil in *A. macrophylla* to $365.4 \mu\text{g N g}^{-1}$ soil in *M. pruriens* (Figures 2.1, 2.2 and 2.3).

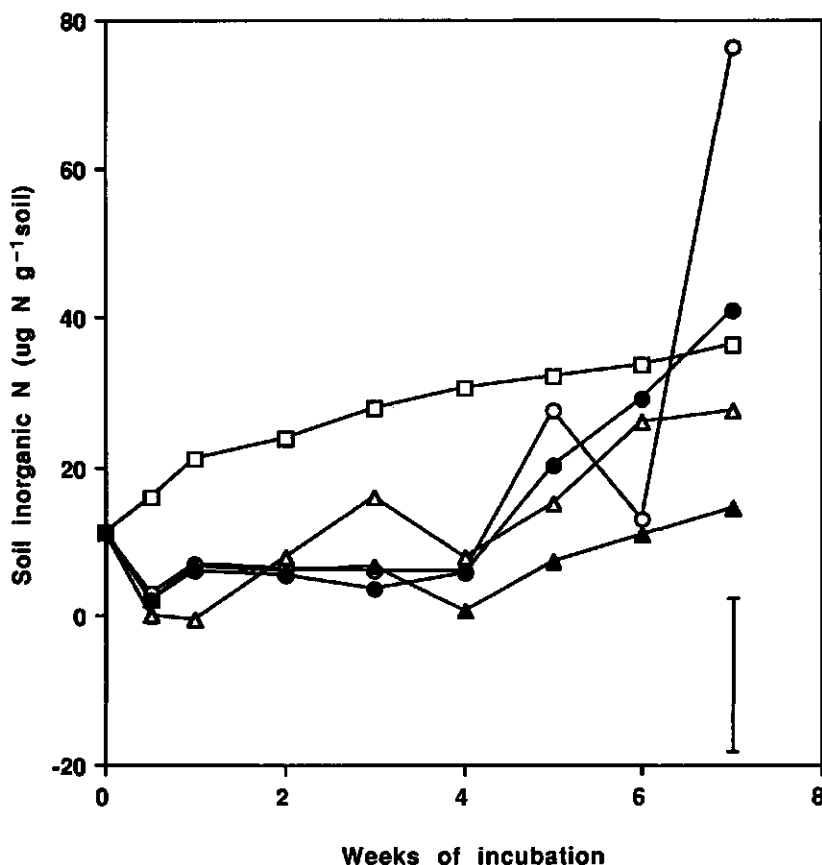


Fig. 2.3 Changes in soil inorganic N levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *C. siamea* (○), *P. santalinoides* (●), *A. cordifolia* (Δ), *A. macrophylla* (▲). Bar represents LSD (0.05) at 7 weeks of incubation.

Percentage of N recovery as inorganic N after the 7-week incubation was relatively high for treatments with *G. sepium* and *M. pruriens*, and relatively low for treatments with *C. siamea* and *P. santalinoides*. *Acioa barteri*, *D. guineense*, *A. cordifolia* and *A. macrophylla* showed negative N recovery values which indicated N-immobilization (Figure 2.4).

Nitrogen release rate constant

According to van Faassen and Smilde (1985), decomposition of added

organic material follows the first order kinetics equation:

$$dy/dt = ky$$

where y is the amount of organic material at any time t , and k is the decomposition rate constant. On integration this equation yields:

$$Y_t = Y_0 e^{-kt}$$

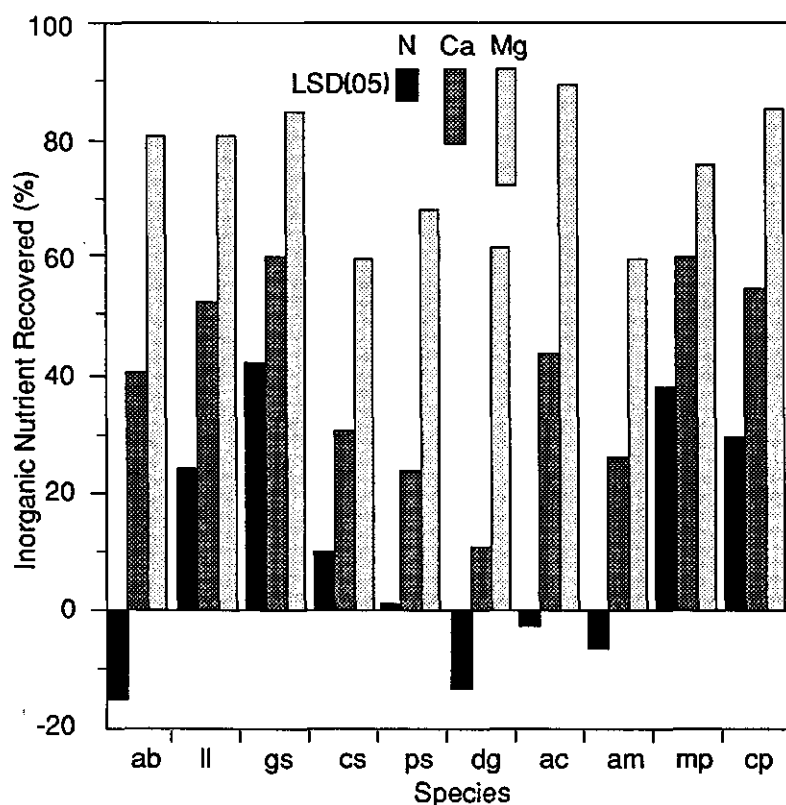


Fig. 2.4 Percentage nutrient release from leaves of fallow species following 7 weeks of incubation. ab: *A. barteri*, ll: *L. leucocephala*, gs: *G. sepium*, cs: *Cassia siamea*, ps: *P. santalinoides*, dg: *D. guineense*, ac: *A. cordifolia*, am: *A. macrophylla*, mp: *M. pruriens*, cp: *C. pubescens*.

Since organic N is one of the major constituents of organic material, it can be postulated that the process of N release also follows the first order equation.

$$N_t = N_0 e^{-kt}$$

The N release rate constant k can thus be estimated by fitting the N release curve using the above equation. Table 2.1 shows the calculated N release rate constants (k) of leaves from the ten fallow species. The N release rate constant declined in the following order *G. sepium* > *C. pubescens* > *M. pruriens* > *L. leucocephala* > *C. siamea* > *P. santalinoides* > *A. cordifolia* > *A. macrophylla* > *D. guineense* > *A. barteri*. Higher k values for *L. leucocephala*, *G. sepium*, *M. pruriens* and *C. pubescens* indicated their rapid N release. Negative k values for *A. barteri*, *D. guineense* and *A. macrophylla* reflect N immobilization. Hence, we can use the positive k values to predict the N release pattern and the potential N contribution from fallow leaves to crop.

Relationship between N release rate and chemical characteristics

Nitrogen release is known to be strongly affected by the chemical composition of leaves (Muller et al., 1988). Partial correlation analysis of data in Table 2.2 showed that N, polyphenol and lignin contents of leaves were significantly related to N release rate constants (k). Stepwise analysis (Table 2.2) showed significant regression coefficients between N, polyphenol and lignin contents and N release rate constants (k), which indicates the importance of these parameters in predicting N release from plant materials during incubation in soil. According to the model, release of N increased with increasing N content and decreased with increasing contents of polyphenols and lignin in leaves.

Previous studies have stressed the importance of initial N content on N release (Herman et al., 1977). Frankenberger and Abdelmagid (1985) reported a high correlation between net mineralization of N and the initial N concentration of 12 different leguminous plant materials ($r = 0.93^{**}$). The present study, including both leguminous and non-leguminous species, confirms this relationship (Table 2.2).

Polyphenols are known as a disinfectant and act as bactericide (Stokes, 1977). A high polyphenol content in leaves can therefore slow down the decomposition of leaves by lowering the activity of

microorganisms and enzymes. Azhar et al. (1986) also found that phenolic compounds bound mineralized N in the nitro and nitroso-forms in soil humus. Reaction of polyphenols with mineralised N resulting in N fixation can take place at room temperature (Stokes, 1977). High levels of polyphenols in leaves can, therefore, be expected to slow down N release. Sivapalan et al. (1985) reported that a high plant-N content resulted in increased N-mineralization, but the effect was lowered in the presence of high concentration of polyphenols in the decomposing residue. Vallis and Jones (1973) attributed immobilization of nitrogen with addition of *Desmodium intortum* to polyphenols in the leaves. Palm and Sanchez (1991) reported a similar effect of polyphenols on N mineralization.

Table 2.2 Regression coefficient (n = 10) for N release rate constant (k) from leaves of different fallow species (Data from Table 2.1).

Variable	Regression coefficient	F	Prob > F	Partial correlation	R ²
Initial N content	0.001236	114.3	0.0001	0.94	
Polyphenol content	0.000702	31.4	0.0025	-0.91	
Lignin content	0.000096	15.8	0.0105	-0.75	
Constant	-0.00084				0.97

Berendse et al. (1987) studied the effect of C/N ratio on plant residue decomposition and reported that N release was reduced at high lignin concentrations. Muller et al. (1988) also reported that N release was highly correlated with lignin content. Lignin is known to be a recalcitrant substance, highly resistant to microbial decomposition (Melillo et al., 1982; Spain and le Feuvre, 1987; van Cleve, 1974). This results in slow mineralization of lignin-bound nitrogen. It has also been found that lignin with two phenolic hydroxyls could fix much N, part of which was resistant to 72% sulphuric acid or strong alkaline solution (Bennett, 1949).

Ca and Mg release

Addition of leaves from each of the different fallow species significantly increased the concentration of soil exchangeable Ca (Figures 2.5 and 2.6). Highest Ca release during the 7 weeks incubation was observed with *L. leucocephala*, and lowest with *D. guineense*. The recovery of added Ca after 7 weeks of incubation was relatively higher with *L. leucocephala*, *G. sepium*, *M. pruriens* and *C. pubescens* (Figure 2.4). Calcium release was highly related to N release. A significant correlation coefficient was recorded between the percentages of N and Ca release after 7 weeks of incubation (Figure 2.7).

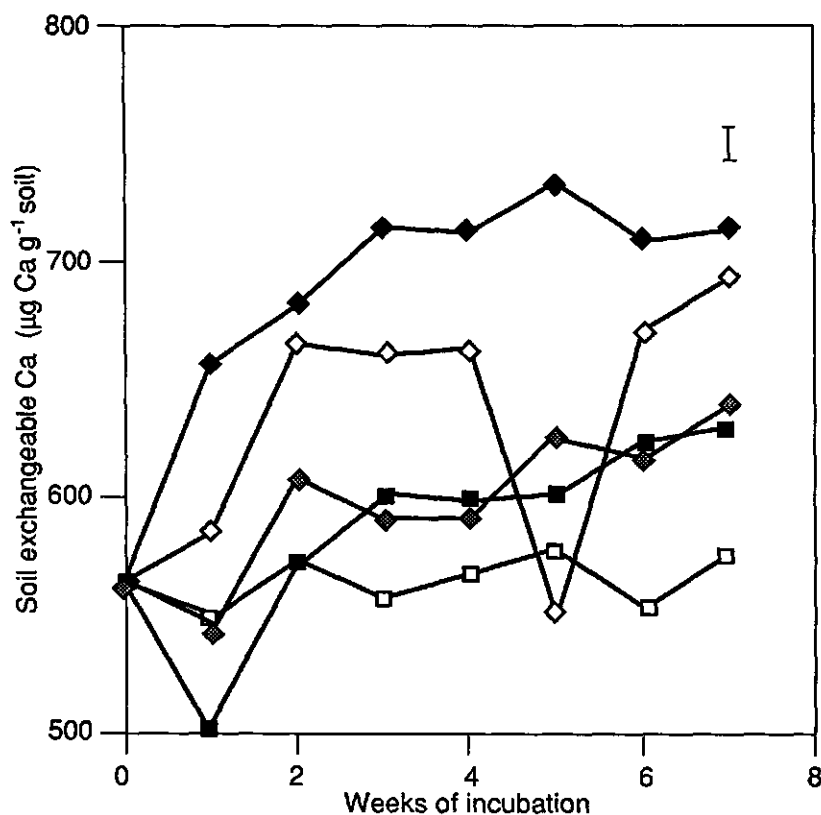


Fig. 2.5 Changes in soil exchangeable Ca levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *L. leucocephala* (◆), *G. sepium* (◇), *M. pruriens* (■), *C. pubescens* (◈). Bar represents LSD(0.05) at 7 weeks of incubation.

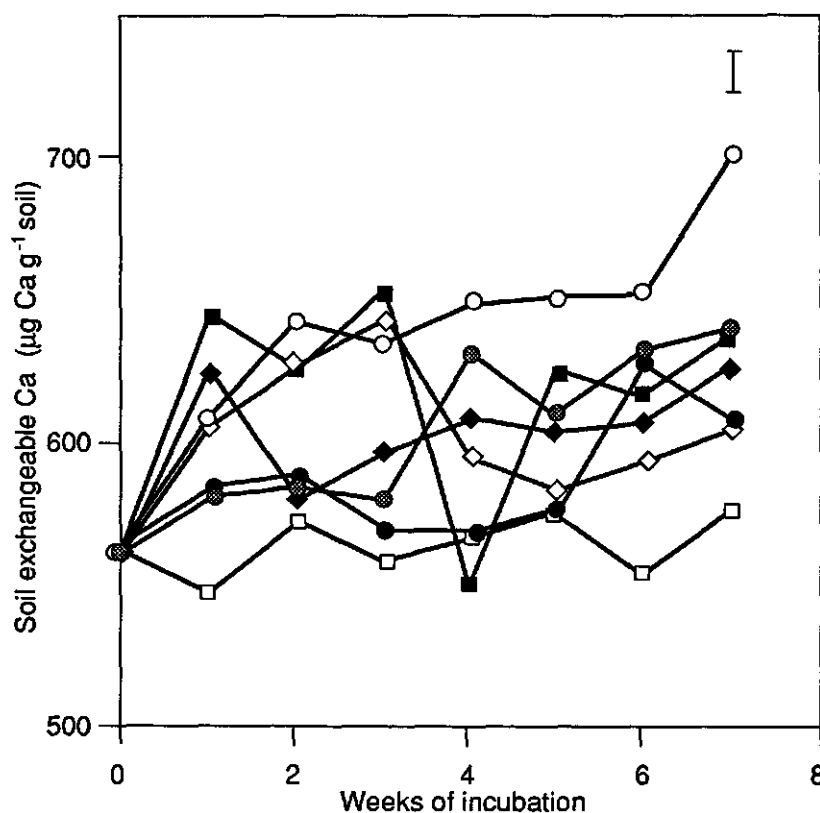


Fig. 2.6 Changes in soil exchangeable Ca levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *A. barteri* (■), *C. siamea* (○), *P. santalinoides* (◆), *D. guineense* (◇), *A. cordifolia* (●), *A. macrophylla* (⊗). Bar represents LSD(0.05) at 7 weeks of incubation.

Addition of leaves from the different fallow species also resulted in increased exchangeable Mg concentration (Figure 2.8 and 2.9). Highest Mg release was obtained with addition of *L. leucocephala* and *G. sepium*, and lowest with *D. guineense* leaves. Magnesium recovery as exchangeable Mg after 7 weeks of incubation was relatively high for *A. cordifolia*, *C. pubescens*, *G. sepium*, *L. Leucocephala* and *A. barteri* (Figure 2.4).

Differences in Mg release between leaves from different fallow species were less pronounced than those in Ca release. Magnesium release

does not show a clear relationship with either the initial Mg content or N release rate ($R^2 = 0.17$). This may be due to partial immobilization of Mg in this trial. No explanation can be given for the lack of relationship between initial Ca and Mg content of leaves and Ca and Mg release rates.

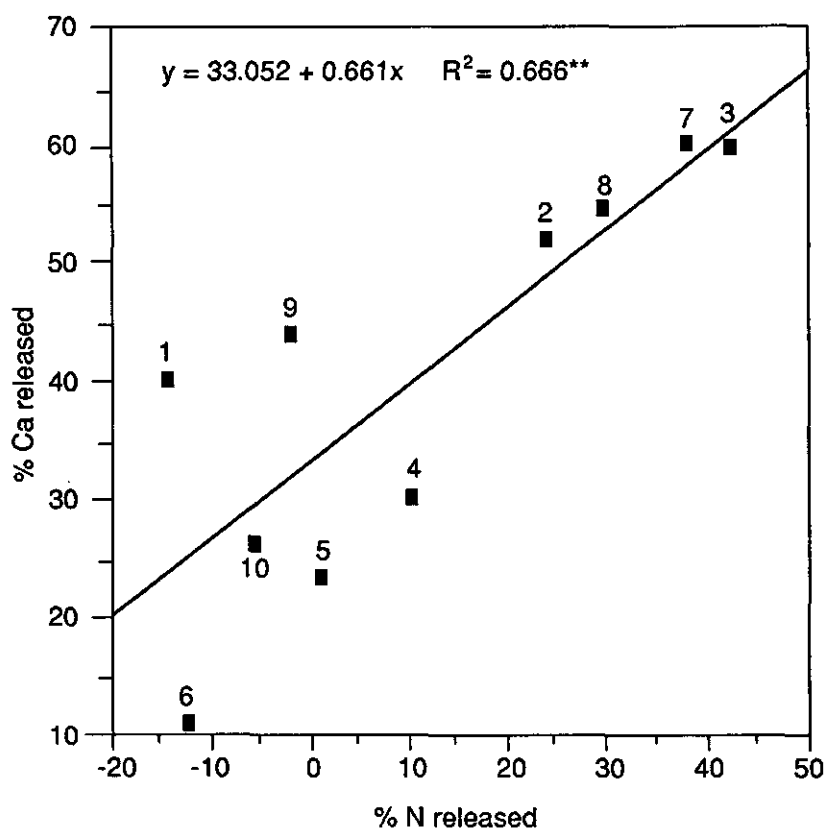


Fig. 2.7 Relationship between N and Ca releases from leaves of fallow species following 7 weeks of incubation. (1: *A. barteni*, 2: *L. Leucocephala*, 3: *G. sepium*, 4: *C. siamea*, 5: *P. santalinoides*, 6: *D. guineense*, 7: *M. pruriens*, 8: *C. pubescens*, 9: *A. cordifolia*, 10: *A. macrophylla*).

2.4 Conclusions

The present study indicates the wide variability of leaves of fallow species in chemical composition and N, Ca and Mg release. Data on N release confirms results of other studies (Berendse et al., 1987; Frankenberger and

Abdelmagid, 1985), that chemical characteristics of plant residues play a key role in determining nutrient, particularly N release. The regression model on N release reflects the integrated effect of initial N, polyphenol and lignin contents, in decreasing order of importance.

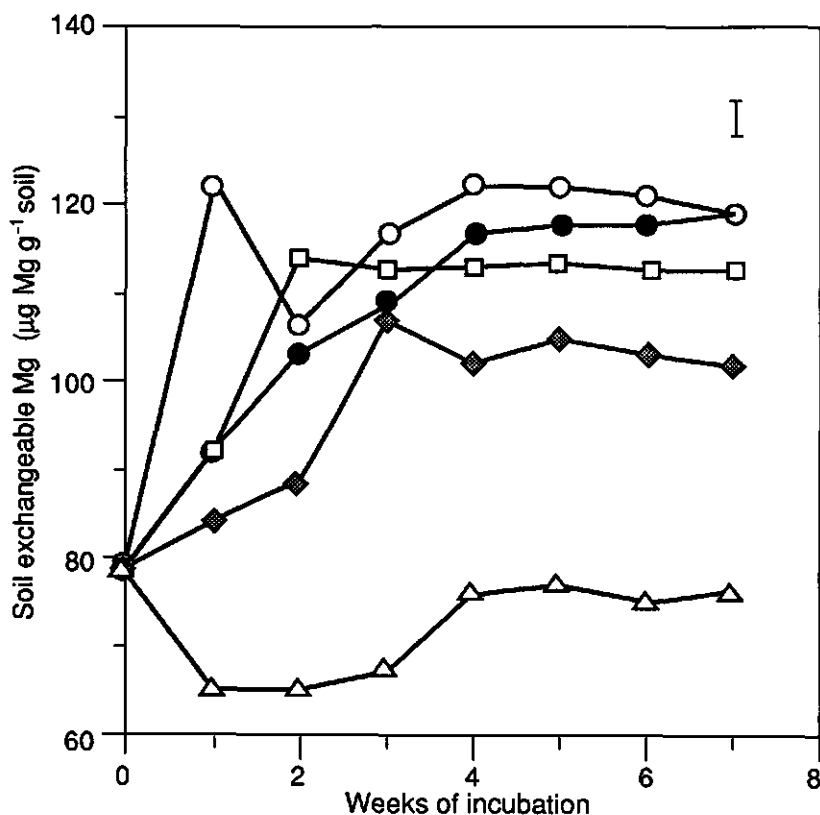


Fig. 2.8 Changes in soil exchangeable Mg levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (Δ), *L. leucocephala* (○), *G. sepium* (●), *M. pruriens* (◆), *C. pubescens* (□). Bar represents LSD(0.05) at 7 weeks of incubation.

It should be noted that this study was carried out in the absence of soil meso- and macrofauna, which are known to affect decomposition and N release rates (Verhoef and Brussaard, 1990). The magnitude of effects of N, polyphenols and lignin in plant residues in regulating N release under field conditions is indeed affected by soil fauna as shown in subsequent investigations conducted in southern Nigeria (G. Tian, unpublished data).

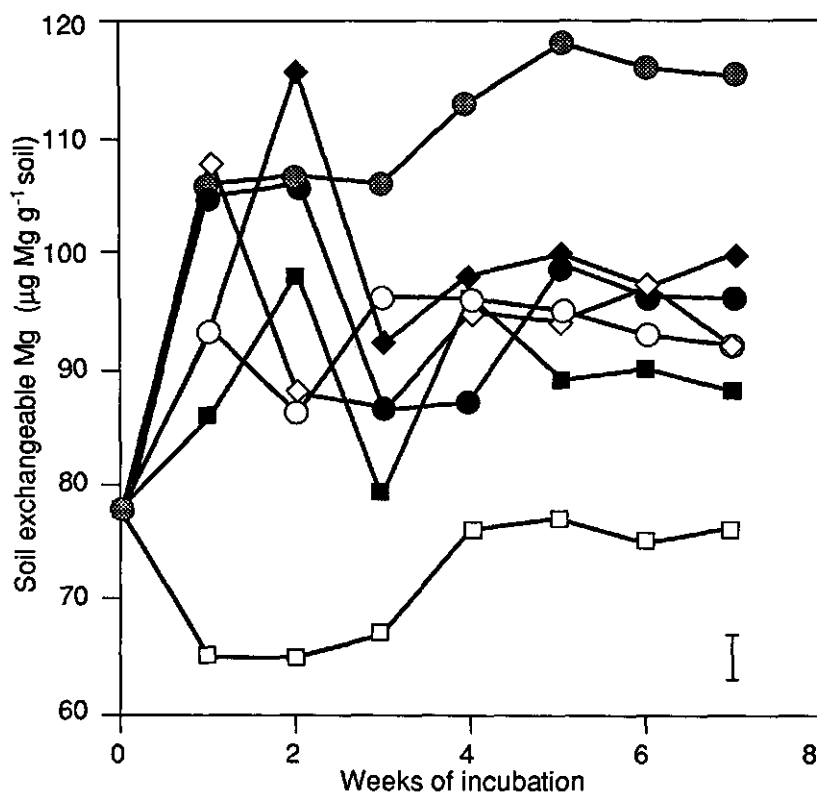


Fig. 2.9 Changes in soil exchangeable Mg levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *A. barteri* (◆), *C. siamea* (○), *P. santalinoides* (⊙), *D. guineense* (■), *A. cordifolia* (●), *A. macrophylla* (◇). Bar represents LSD(0.05) at 7 weeks of incubation.

For the application of the materials used in this study in crop production, the high N containing materials (*L. leucocephala*, *G. sepium*, *M. pruriens* and *C. pubescens*) are useful N sources for quick maturing crops. For example the merits of prunings of *L. leucocephala* and *G. sepium* as N source in alley cropping (Plate 2.1) with food crops have been shown (Kang and Wilson, 1987). Slower N releasing materials (*A. cordifolia*, *A. macrophylla*, *C. siamea* and *P. santalinoides*) can be a more efficient N source for slower maturing crops. Low N materials (*A. barteri* and *D. guineense*) are poor N sources and can be better used as mulch

materials. All the materials studied can serve as a source of Ca and Mg in nutrient recycling in crop production.

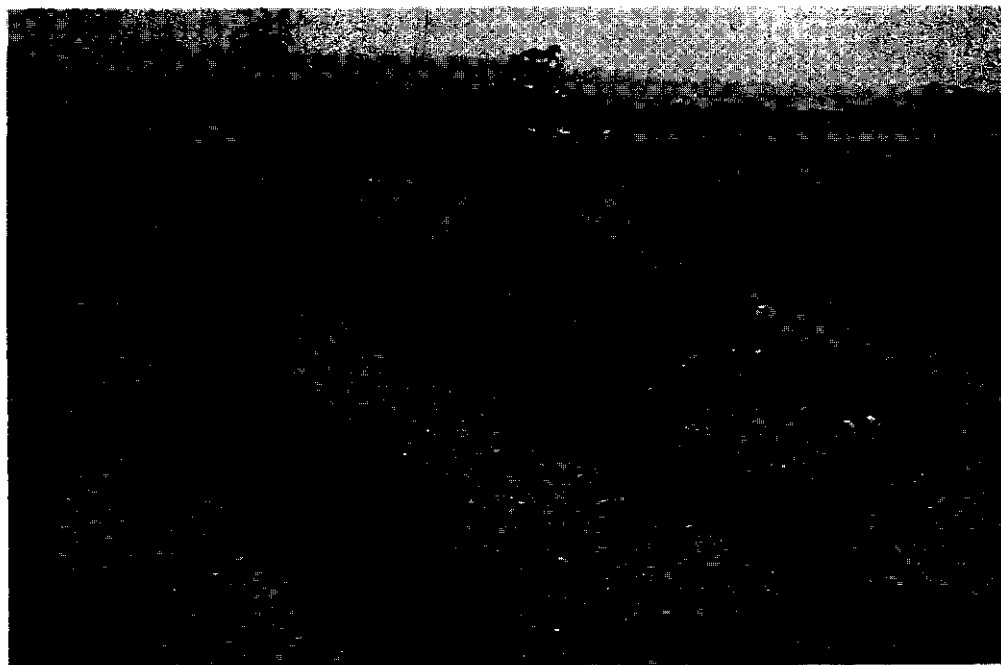


Plate 2.1 Alley cropping of cowpea with *Leucaena leucocephala* in International Institute of Tropical Agriculture, Ibadan, Nigeria.

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3. Biological effects of plant residues with contrasting chemical compositions under humid tropical conditions - decomposition and nutrient release.

Abstract

Decomposition and nutrient release patterns of prunings of three woody agroforestry plant species (*Acioa barteri*, *Gliricidia sepium* and *Leucaena leucocephala*), maize (*Zea mays*) stover, and rice (*Oryza sativa*) straw, were investigated under field conditions in the humid tropics, using litterbags of three mesh sizes (0.5 mm, 2 mm, and 7 mm) which allowed differential access of soil fauna. The decomposition rate constants ranged from 0.01 to 0.26 week⁻¹, decreasing in the following order; *Gliricidia* prunings > *Leucaena* prunings > rice straw > maize stover > *Acioa* prunings. Negative correlations were observed between decomposition rate constants and C/N ratio ($P < 0.004$), percent lignin ($P < 0.014$), and polyphenol content ($P < 0.053$) of plant residues. A positive correlation was observed between decomposition rate constant and mesh-size of litterbag ($P < 0.057$). These results indicate that both the chemical composition of plant residues and nature of the decomposer community played an important role in plant residue decomposition.

Nutrient release differed with quality of plant residues and litterbag mesh-size. Total N, P, Ca, and Mg contents of plant residues decreased with time for *Gliricidia* and *Leucaena* prunings, maize stover, and rice straw, and increased with time for *Acioa* prunings. There was some indication of N immobilization in maize stover and rice straw; P immobilization in *Leucaena* prunings and rice straw; and Ca immobilization in maize stover, rice straw, and *Gliricidia* and *Leucaena* prunings. *Acioa* prunings immobilized N, P, Ca, and Mg. All plant residues released K rapidly. Nutrient release increased with increasing mesh-size of litterbags, suggesting that soil faunal activities enhanced nutrient mobilization.

3.1 Introduction

There is increasing interest in using plant residues for improving soil productivity in agricultural systems in the tropics which use low external inputs. Although the role of plant residues in regeneration of soil nutrients and organic matter, and to ameliorate soil physical and biological properties is well known, little information is available on the role of residues from woody species used in agroforestry systems (Kang et al., 1990). Plant residue decomposition and nutrient release are known to be affected by their chemical composition and the nature of soil organisms (Berendse et al., 1987; Swift et al., 1979).

Plant residues with high nitrogen content show high decomposition rates and nutrient release (Swift et al., 1979). Frankenberger and Abdelmagid (1985) and Melillo et al. (1982) reported high correlations between N content, N release and biomass loss. The role of lignin as a regulator in the decomposition process has been elucidated in several studies (Meentemeyer, 1978; Berendse et al., 1987). Increasing lignin concentration reduces the decomposition rate of plant residues. High lignin content of plant residues could also enhance nutrient immobilization especially nitrogen (Melillo et al., 1982). The negative effect of polyphenols on decomposition and nutrient release was reported by Vallis and Jones (1973). Swain (1979) postulated that polyphenols reduce the decomposition by inhibiting enzyme action. Sivapalan et al. (1985) reported that N mineralization was lowered by the presence of high concentrations of polyphenols, due to the binding of mineralized N into an insoluble organic compound. A high silica content in plant residues may also affect decomposition as it has been reported to reduce the digestibility of plant residues (Goering and van Soest, 1970; Ma and Takahashi, 1989). Little is known, however, about the integrated effect of chemical characteristics of plant residues on their decomposition and nutrient release.

Soil fauna are also known to play a critical role in the biological turnover and nutrient release of plant residues by fragmenting the plant residues, resulting in enhanced microorganism activities and grazing of microflora by fauna (Anderson et al., 1983a; Edwards and Heath, 1963). Edwards and Heath (1963) reported that when soil animals are excluded from a decomposing litter, fragmentation is insufficient and this leads to reduced consumption by microorganisms. Edwards and Fletcher (1988) suggested a symbiotic interaction between earthworms and microorganisms

in the breakdown and fragmentation of organic matter.

On the assumption that litterbags of various mesh-sizes differ in the access they allow soil fauna and that litter quality determines the palatability and decomposability for the fauna, we studied the effects of soil fauna on decomposition and nutrient release of plant residues with contrasting chemical compositions.

The following specific hypotheses were tested:

1. Low quality plant residue (high C/N ratio, lignin content or polyphenol level) is largely avoided by soil fauna. Hence, litterbag mesh-size will not influence decomposition and nutrient release to a measurable extent.
2. High quality plant residue (low C/N ratio, lignin content or polyphenol level) is microbially easily decomposable so that there is no effect of soil fauna on the decomposition rate.
3. The rate of decomposition and nutrient release of plant residues with intermediate quality is enhanced by soil fauna.

3.2 Materials and methods

Experimental site

The investigation was conducted at the International Institute of Tropical Agriculture (IITA) headquarter at Ibadan, Nigeria (3°54'E, 7°30'N, 213 m asl.). The area has a bimodal rainfall pattern with an annual mean of 1278 mm, and a mean annual temperature of 26.2°C. The main growing season is from April to August and a minor growing season is from August to October, followed by a long dry season from November to April. The experiment was conducted during the 1990 growing season. The soil of the experimental site is classified as an Oxic paleustalf (USDA), with the following surface (0-15 cm) soil properties; organic carbon, 1.99%; total N, 0.183%; pH-H₂O (1:1), 6.52; ECEC, 6.22 cmol kg⁻¹, and sandy loam texture (57.9% sand, 16.8% silt and 25.3% clay). Before the experiment the land was mainly under grass (*Pinnisetum purpureum*) fallow.

Plant residues

Based on results of earlier investigations by the authors (Tian et al., 1992) the following plant materials which have contrasting chemical

compositions were chosen for the field study: prunings of three widely grown agroforestry species (*Acioa barteri*, *Gliricidia sepium* and *Leucaena leucocephala*), maize (*Zea mays*) stover, and rice (*Oryza sativa*) straw. Prunings (leaves and small twigs) of the three woody species, maize stover and rice straw were collected, cut to a length of about 10 cm and air-dried for the experiment.

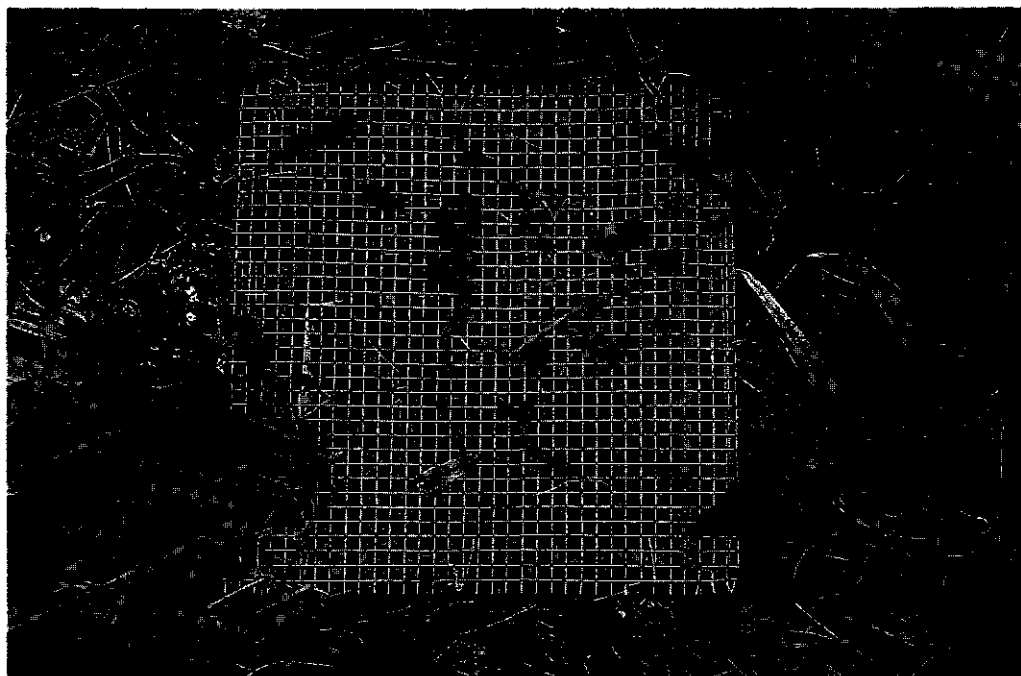


Plate 3.1 Litterbag with mesh-size of 7 mm.

Litterbags

Decomposition and nutrient (N, P, K, Ca, Mg) release were studied using stainless-steel litterbags measuring 30 x 30 cm, with three mesh sizes, 0.5 mm, 2 mm and 7 mm. Mesh-size of 7 mm (Plate 3.1) could allow access to all mesofauna (termites, collembola, mites, and enchytraeids) and virtually all macroinvertebrates (earthworms, insects, millipedes, isopods, etc). Mesh size of 2 and 0.5 mm could exclude the soil macro- and mesofauna respectively (Swift et al., 1979). Forty five grams of dry material (equivalent to 5 tons ha⁻¹) was placed in each litterbag. In order to prevent compression of plant residues inside the litterbags, pieces of

wood 3 cm in diameter were placed inside the four corners of the litterbags. The litterbags were surface-placed in a field with maize crop (TZSRW cultivar with 40,000 plants ha⁻¹) during the main growing season. A split-plot design was used with four replications. Plant residues made up the main plot treatments, while mesh sizes of litterbags were the subplot treatments. Sampling was done at 5, 11, 21, 41, and 98 days for *Gliricidia* and *Leucaena* prunings, and 5, 14, 28, 49, and 98 days for *Acioa*, maize stover, and rice straw. At each sampling, the plant residues in the litterbags were water-cleansed, oven-dried, and weighed. They were ground to pass a 20 mesh (0.85 mm diameter) sieve. Subsamples were taken to determine the ash-free dry weight, and at alternate sampling dates the residues were analyzed for N, P, K, Ca, and Mg contents.

Plant analysis

Samples of plant residues were analyzed for initial contents of lignin, cellulose, hemicellulose, polyphenols, C, N, Si, P, K, Ca, and Mg. Lignin, cellulose, and hemicellulose contents were determined by the acid detergent fiber method (Goering and van Soest, 1970). Extractable polyphenols were determined by the Folin-Denin method (Anderson and Ingram, 1989), and total C by the modified wet combustion technique adapted from Shaw (1959), using a mixture of K₂Cr₂O₇-H₂SO₄-H₃PO₄. Total N was analyzed by micro-Kjeldahl digestion, followed by distillation and titration. For determination of P, K, Ca, and Mg, plant samples were wet-digested with a mixture of HClO₄-HNO₃. Phosphorus was measured colorimetrically by molybdate blue method in an auto-analyzer, K by the flame photometry, and Ca and Mg by the atomic absorption spectrophotometry. Determination of Si included two steps: extracting with a mixture of HCl and HF and measuring Si concentration by the atomic absorption spectrophotometry. Ash-free dry weight was determined by ashing a plant sample in a muffle furnace at 550°C for 3 hours.

Data analysis

The single exponential equation, $Y = e^{-kt}$, where Y is the percent remaining of initial weight of plant material at time t in weeks, was used to calculate the decomposition and nutrient loss rate constant (k) (Wieder and Lang, 1982). Ash-free dry weights of remaining plant materials and decomposition rate constants were subjected to ANOVA, to determine

Table 3.1 Chemical composition of prunings of woody species and crop residues

Plant residues	Lignin	Cellulose	Hemicellulose	Polyphenols	C	N	C/N	P	K	Ca	Mg	SiO ₂
	----- (%) -----			----- (%) -----			----- (%) -----			----- (%) -----		
<i>Actia</i>	47.6	30.4	2.2	4.09	45.1	1.61	28.0	0.069	0.80	0.74	0.31	2.71
<i>Gliricidia</i>	11.6	19.4	12.2	1.62	47.3	3.60	13.1	0.129	2.74	1.63	0.45	0.59
<i>Leucaena</i>	13.4	21.1	13.5	5.02	45.5	3.55	12.8	0.092	2.79	1.59	0.40	0.53
Maize stover	6.8	36.7	35.6	0.56	42.6	1.00	42.6	0.133	2.06	0.42	0.29	2.22
Rice straw	5.2	40.1	22.9	0.55	35.5	0.84	42.3	0.053	2.34	0.58	0.31	11.35
LSD (05)				0.25	0.4	0.12	1.1	0.024	0.25	0.06	0.02	0.24

differences in decomposition and nutrient release patterns of the five plant materials studied as affected by litterbag mesh-size. Decomposition rate constants were also subjected to partial correlation analysis and backward stepwise regression to determine the effects of initial chemical composition and litterbag mesh-sizes on decomposition rates. All statistical analyses were performed using the Statistical Analysis System (SAS, 1985).

3.3 Results and discussion

Chemical composition of plant residues

The chemical composition of materials used in the investigation is shown in Table 3.1. *Gliricidia* prunings have low C/N ratio and lignin, silica and polyphenol contents. *Leucaena* prunings have a similar chemical composition to *Gliricidia*, except for a higher polyphenol content. *Acioa* prunings are characterized by a high C/N ratio and contents of lignin and polyphenols. Rice straw is characterized by a high silica content. Cellulose content ranged from 19.4% (*Gliricidia*) to 40.1% (rice straw). Hemicellulose content ranged from 2.2% (*Acioa*) to 35.6% (maize stover). Materials from the woody species appeared to be lower in cellulose and hemicellulose compared to the crop residues (maize stover and rice straw). Higher K, Ca, and Mg contents were observed in the *Leucaena* and *Gliricidia* prunings. *Acioa* prunings and rice straw show low P contents. Compared to the results reported by Tian et al. (1992), the contents of lignin and cellulose in the prunings of three woody species are higher. This is due to the inclusion of small twigs in this study instead of leaves only in Tian et al. (1992). Variations of other nutrients also reflected the influence of sampling sources.

Decomposition patterns of plant residues

A rapid decrease in ash-free dry weight was observed for *Gliricidia* and *Leucaena* prunings during the first 41 days after incubation, followed by rice straw and maize stover (Figure 3.1). On the contrary, *Acioa* prunings showed slow decomposition. *Leucaena* prunings showed higher decline in weight than *Gliricidia* during the first two weeks. However, at later dates *Gliricidia* showed higher decomposition rates than *Leucaena*. No differences in decomposition rates were observed between maize stover and

rice straw.

The decomposition rate constants (Table 3.2) showed a decline in the following order *Gliricidia* > *Leucaena* > rice straw > maize stover > *Acioa*. *Gliricidia* prunings decomposed significantly faster, and *Acioa* significantly slower than the other materials. However, differences in k values between *Leucaena* prunings, maize stover and rice straw were not significant.

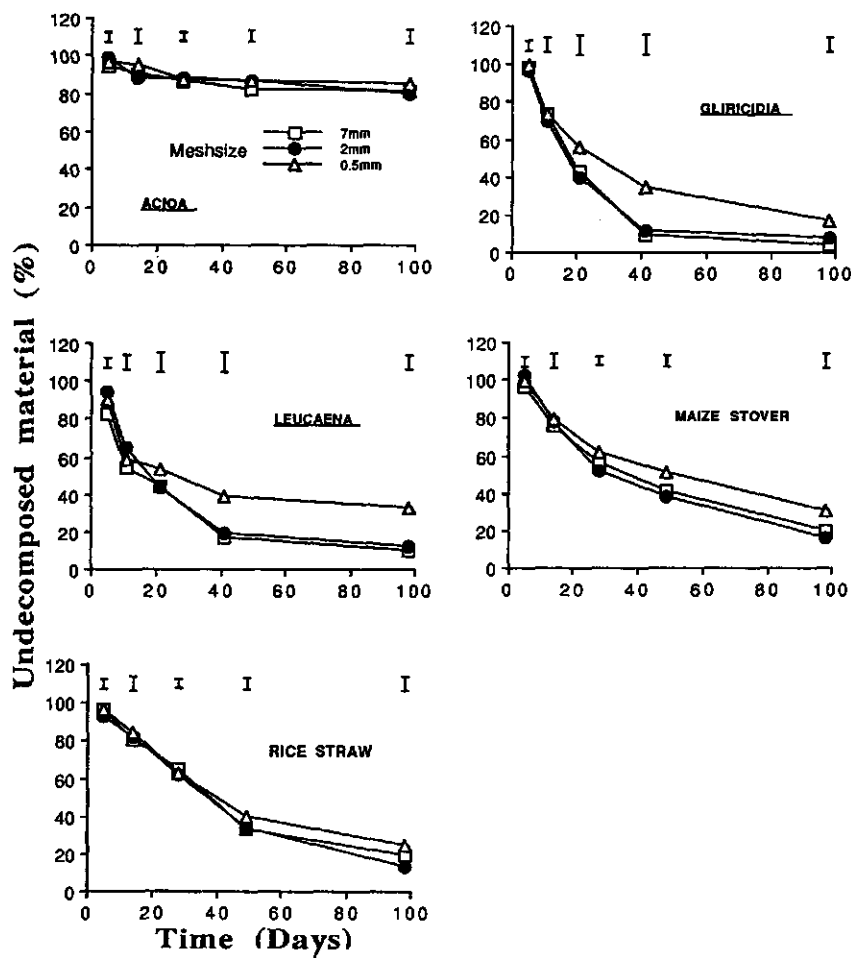


Fig. 3.1 Decomposition of plant residues as affected by litterbag mesh-size. Bar represents LSD_{0.05}.

Decomposition rates of all plant residues in 0.5 mm mesh-size litterbags were significantly lower than those in 2 mm and 7 mm mesh-size litterbags. Rice straw and maize stover showed the highest decomposition rate in the 2 mm mesh-size litterbag. For *Leucaena* and *Gliricidia* prunings, decomposition rate constants increased with increased litterbag mesh-size.

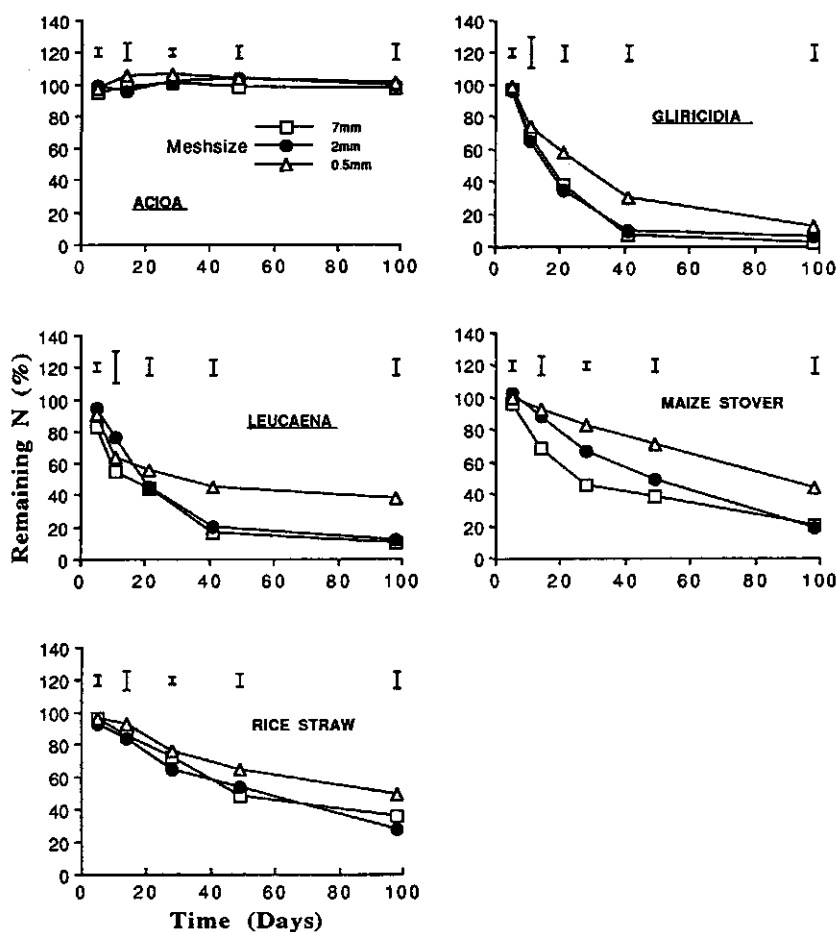


Fig. 3.2 Nitrogen release from plant residues as affected by litterbag mesh-size. Bar represents $LSD_{0.05}$.

Table 3.2 Decomposition rate constant k (week⁻¹) of prunings of woody species and crop residues as affected by mesh-size of litterbags.

Plant Residues	Mesh-size			Mean
	7 mm	2 mm	0.5 mm	
<i>Acioa</i>	0.011	0.012	0.010	0.011
<i>Gliricidia</i>	0.255	0.194	0.127	0.192
<i>Leucaena</i>	0.166	0.147	0.062	0.125
Maize stover	0.118	0.134	0.085	0.113
Rice straw	0.124	0.157	0.106	0.129
Mean	0.135	0.129	0.078	

LSD₀₅: for species means, 0.038; for mesh-size means, 0.022; for different mesh sizes for same species, 0.050; for different mesh sizes for different species, 0.056.

Effect of residue quality and soil fauna on decomposition

The decomposition rate constants of plant residues observed in this study, ranged from 0.012 to 0.255 week⁻¹ and fall within the range reported by other workers (Anderson et al., 1983b), except for that of *Acioa* prunings. The extremely low decomposition rate for *Acioa* prunings may be due to their extremely low quality. Stepwise regression analysis (Table 3.3) showed that decomposition rate constants of plant residues were correlated with C/N ratio ($P < 0.004$), lignin ($P < 0.014$) and polyphenols ($P < 0.053$) contents, and litterbag mesh size ($P < 0.057$), indicating the significant roles of quality of plant residue and litterbag mesh size on decomposition. The effect of polyphenol content on plant residue decomposition in this study was less pronounced than in a laboratory incubation investigation conducted by the authors (Tian et al., 1992). This may be due to leaching and digestion of plant residues by soil fauna in the field, which reduce the inhibiting effect of polyphenols.

The high correlation between decomposition rate constants and C/N ratio, lignin, and polyphenol contents and litterbag mesh-size indicates, that all these components need to be considered in assessing the quality of plant

residues for predicting their decomposition and nutrient release patterns. Based on data presented in Table 3.3, the following decomposition rate constant equation can be established for the materials studied: $k = 0.2736 - 0.0035 \text{ C/N} - 0.0023 \text{ lignin} - 0.0188 \text{ polyphenols} + 0.0068 \text{ mesh-size}$, where k is decomposition rate constant (week^{-1}). Statistical analysis showed no significant correlation between decomposition rate constant and silica content.

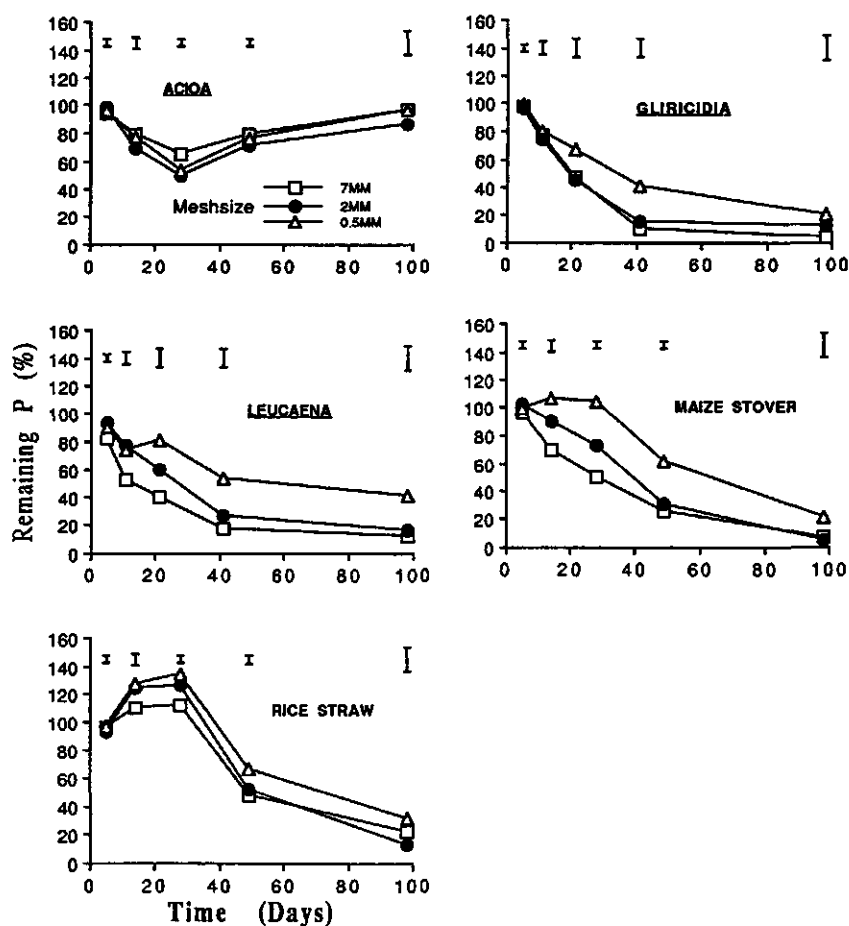


Fig. 3.3 Phosphorus release from plant residues as affected by litterbag mesh-size. Bar represents $\text{LSD}_{.05}$.

The positive correlation between decomposition rate and litterbag mesh-size indicates the effect of accessibility of plant residues in the litterbag to soil fauna. Although decomposition rate increased with increasing mesh-size, no significant differences were observed between 2 mm and 7 mm mesh-size litterbags (Table 3.2). This implies, that the 2 mm mesh-size was large enough for access to most soil fauna including earthworms which are able to stretch the body to pass through. The soil fauna data gathered during the investigation will be addressed in a forthcoming paper.

Table 3.3 Regression coefficient and partial correlation of effects of selected parameters on decomposition rate constant (k) from plant residues

	Regression coefficient	F	Prob > F	Partial correlation
C/N	-0.0035	13.30	0.004	-0.755
Lignin	-0.0023	8.90	0.014	-0.686
Polyphenols	-0.0188	4.82	0.053	-0.570
Mesh-size	0.0068	4.63	0.057	0.562
Constant	0.2736			

R^2 of the regression model: 0.828 ($p < 0.01$).

Nutrient release pattern

Nitrogen release from plant residues followed the same pattern as decomposition of plant residues (Figure 3.2). Nitrogen release rates varied with the plant residues and litterbag mesh-size (Table 3.4). The N release rate constant of *Gliricidia* prunings was larger than their decomposition rate constant, while those of maize stover, rice straw, and *Acioa* prunings were smaller than their decomposition rate constants. This means that N release is faster in *Gliricidia* prunings, slower in *Acioa* prunings, maize stover, and rice straw than C decomposition. Data on change of N concentration in decomposing plant residues with time as shown in Table

3.5 confirm these results. After 98 days the N concentration remaining in *Gliricidia* prunings, had decreased on average by 26%, while those for *Leucaena* and *Acioa* prunings, maize stover, and rice straw had increased by 4%, 19%, 26%, and 96% respectively. It thus appears that during decomposition of *Acioa* prunings, maize stover, and rice straw some N was immobilized despite the decrease in total N in the remaining maize stover and rice straw. During decomposition of *Leucaena* prunings, N release was slower and some N was even immobilized as compared to *Gliricidia*.

Table 3.4 Nitrogen release rate constants (week^{-1}) of prunings of woody species and crop residues as affected by mesh-size of litterbags.

Plant residues	Mesh-size			
	7 mm	2 mm	0.5 mm	mean
<i>Acioa</i>	-0.0002	-0.001	0	-0.001
<i>Gliricidia</i>	0.288	0.210	0.152	0.217
<i>Leucaena</i>	0.153	0.152	0.055	0.120
Maize stover	0.110	0.128	0.077	0.100
Rice straw	0.077	0.096	0.052	0.075
Mean	0.125	0.117	0.064	

LSD₀₅: for means of plant residues, 0.040; for means of mesh sizes, 0.022; for different mesh sizes for same plant residues, 0.050; for different mesh sizes for different plant residues, 0.057.

Parnas (1975) studied the relationship between N immobilization and C/N ratio, and concluded that N immobilization occurs if the plant residue has a C/N ratio of > 30 . The C/N ratios of *Acioa* prunings, rice straw and maize stover were higher than this critical value. This is also in agreement with results reported by Saini (1989) on the N immobilization of rice straw. However, the low C/N ratio for *Leucaena* prunings does not explain the lower N mineralization of this material as compared to *Gliricidia* prunings. The high polyphenol level in *Leucaena* prunings is probably a factor that contributed to the lower N release. Similarly, high polyphenol and lignin concentration in *Acioa* prunings could be major factors in N

immobilization during decomposition.

Compared to the results in Tian et al. (1992), N release in this study is higher. This is the result of the contribution of leaching and faunal activity to the decomposition and N release in the field.

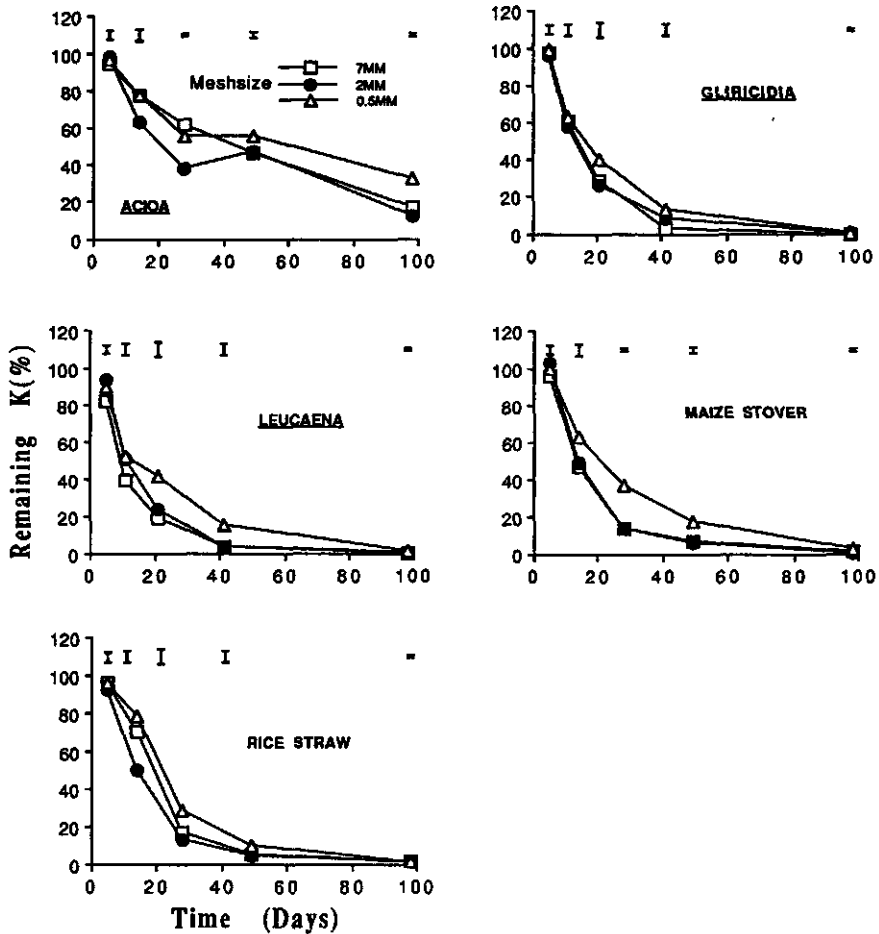


Fig. 3.4 Potassium release from plant residues as affected by litterbag mesh-size. Bar represents LSD_{0.05}.

Data in Table 3.5 also show that increasing mesh-size of litterbags resulted in lower N concentration in the decomposing residues, indicating an increased N release. This suggests that the increased presence of soil

Table 3.5 Change in concentration of nutrients (%) of decomposing materials with time

Plant residues	Time (days)	N			P			K			Ca			Mg		
		L ^a	M ^b	S ^c	L	M	S	L	M	S	L	M	S	L	M	S
<i>Acioa</i>	0	1.61			0.07			0.80			0.74			0.31		
	28	1.86	1.88	1.85	0.05	0.04	0.04	0.57	0.35	0.50	0.81	0.79	0.81	0.30	0.30	0.29
	98	1.92	1.97	1.89	0.08	0.07	0.08	0.17	0.12	0.30	1.13	1.06	0.90	0.30	0.29	0.37
<i>Gliricidia</i>	0	3.60			0.13			2.74			1.63			0.45		
	21	3.19	3.16	3.72	0.14	0.15	0.15	1.81	1.79	1.96	2.49	2.94	3.13	0.65	0.74	0.54
	98	2.27	2.82	2.86	0.12	0.20	0.16	0.19	0.32	0.11	0.42	0.76	0.68	0.28	0.74	0.36
<i>Leucaena</i>	0	3.55			0.09			2.79			1.59			0.40		
	21	3.54	3.68	4.18	0.08	0.13	0.11	1.21	1.55	2.18	1.99	2.09	2.04	0.48	0.52	0.49
	98	3.53	3.53	4.01	0.11	0.13	0.12	0.09	0.10	0.13	1.31	1.40	1.08	0.43	0.42	0.45
Maize stover	0	1.00			0.13			2.06			0.42			0.29		
	28	0.80	1.27	1.14	0.12	0.18	0.23	0.51	0.55	1.23	0.34	0.47	0.47	0.23	0.28	0.35
	98	1.04	1.32	1.43	0.11	0.15	0.15	0.18	0.14	0.20	0.72	0.91	0.67	0.20	0.21	0.34
Rice straw	0	0.84			0.05			2.34			0.58			0.31		
	28	0.93	0.87	1.00	0.09	0.10	0.10	0.62	0.49	1.04	0.70	0.58	1.08	0.35	0.34	0.40
	98	1.52	1.75	1.68	0.06	0.05	0.07	0.16	0.14	0.16	0.89	0.70	0.81	0.32	0.23	0.31

a: Plant residues in 7 mm mesh-size litterbag

b: Plant residues in 2 mm mesh-size litterbag

c: Plant residues in 0.5 mm mesh-size litterbag

fauna during decomposition enhances N release. The enhancement by soil fauna is particularly conspicuous for N release of *Leucaena* prunings, where N immobilization was less apparent with the 2 mm and 7 mm mesh size litterbags.

Phosphorus release from plant residues was also different among plant residues and litterbag mesh-size (Figure 3.3). Phosphorus release from *Gliricidia* and *Leucaena* prunings showed the same pattern as the ash-free mass loss (Figure 3.1). For rice straw, P level increased during the initial 4 weeks, and decreased afterwards. *Acioa* prunings showed an opposite pattern of P release compared to rice straw. After 98 days of incubation calculated cumulative P release from plant residues in the litterbags decreased in the following order: *Gliricidia* prunings > maize stover > *Leucaena* prunings > rice straw > *Acioa* prunings. Larger mesh-size litterbags also enhance P release (Figure 3.3).

Decline in P concentration in decomposing plant residues with time was only observed for maize stover in the 7 mm mesh-size litterbags (Table 3.5). This indicates some P immobilization in all other plant residues. Phosphorus immobilization may be due to the low initial P concentration in plant residues (Budelman, 1988).

Rapid K release was observed for all plant residues, including *Acioa* prunings. Most of K in plant residues was released in less than 41 days (Figure 3.4). At 98 days, most K of *Gliricidia* and *Leucaena* prunings, maize stover, and rice straw had been released and *Acioa* prunings lost over 77% of K content. Potassium release was less affected by chemical characteristics and soil faunal activities than N and P release. This may be due to the high mobility of K by which it is easily leached.

Release of Ca from *Gliricidia* and *Leucaena* prunings, maize stover, and rice straw increased with time throughout the experimental period. On the contrary, Ca levels in *Acioa* ash-free materials increased with time. At 98 days, Ca release had decreased in the following order: *Gliricidia* prunings > *Leucaena* prunings > rice straw > maize stover > *Acioa* prunings. Calcium release from all plant residues in the litterbags of 0.5 mm mesh-size was lower than that in 2 and 7 mm bags (Figure 3.5).

Release of Mg from the materials followed the same pattern as that of Ca. Although *Acioa* prunings in the 2 and 7 mm mesh-size litterbags appeared not to immobilize Mg, the Mg release was lower (Figure 3.6). Differences in Mg release between the other four plant residues at 98 days were not significant.

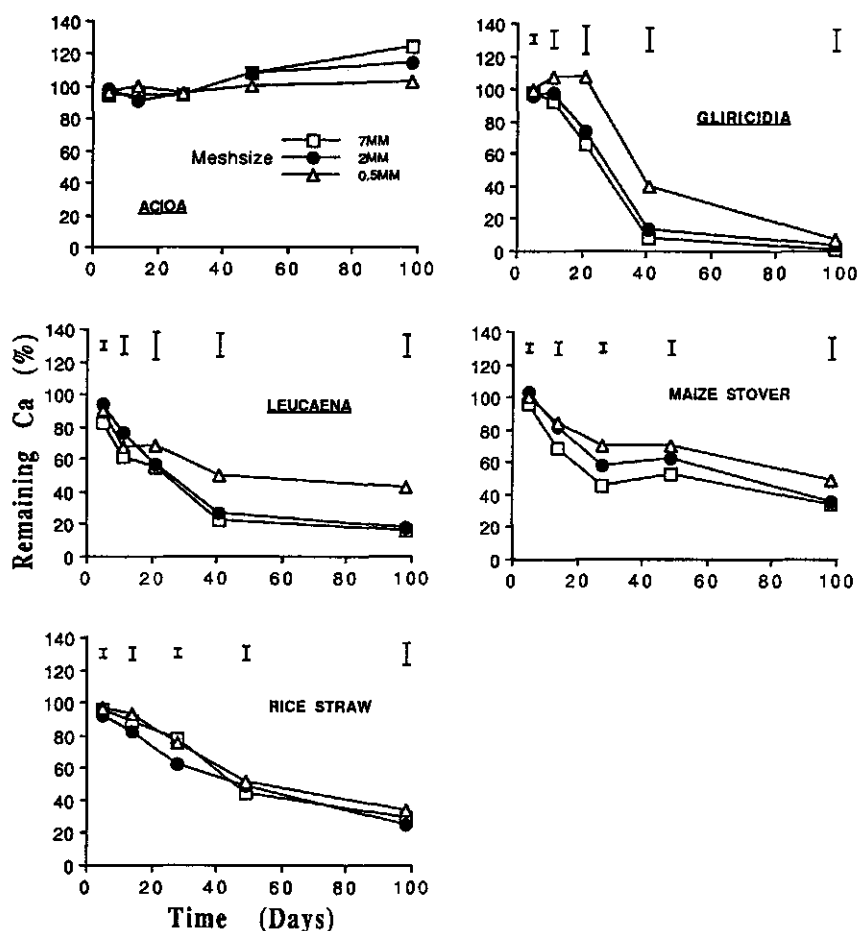


Fig. 3.5 Calcium release from plant residues as affected by litterbag mesh-size. Bar represents $LSD_{.05}$.

The fast release of Ca and Mg from plant residues, except that of *Acioa* prunings is in agreement with the results reported earlier by Budelman (1988), but is inconsistent with the results of others (Swift et al., 1981), who showed slow release of Ca and Mg.

The data obtained in this study thus indicate that except for K, releases of nutrients (N, P, Ca and Mg) follow the same pattern as loss of plant residue biomass.

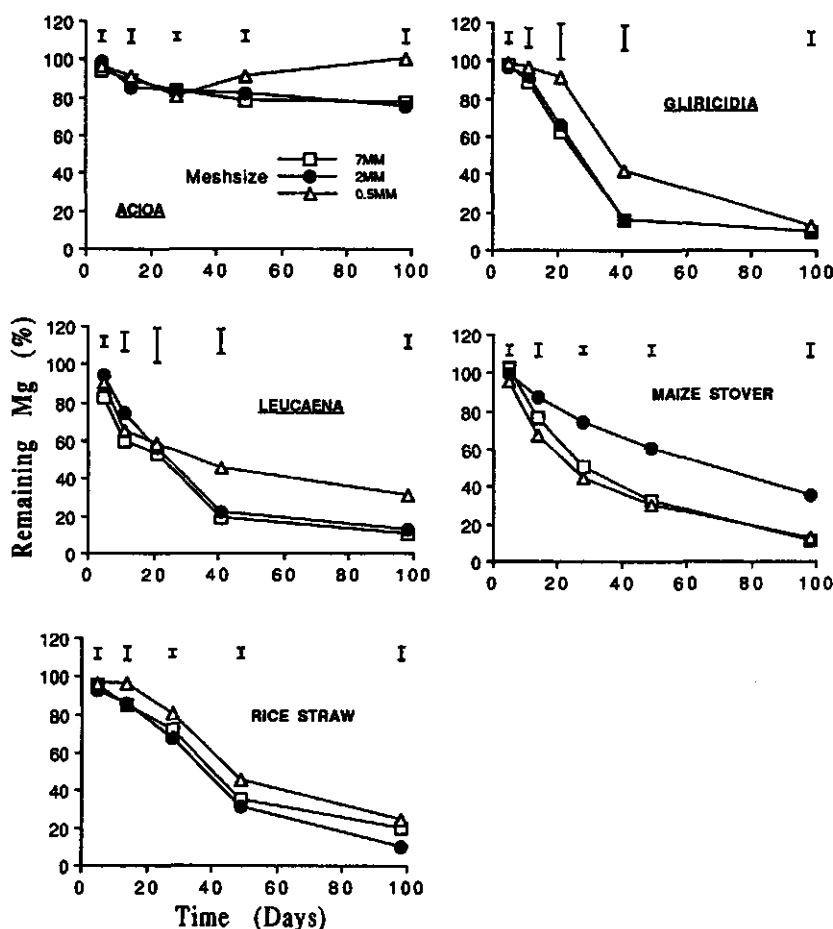


Fig. 3.6 Magnesium release from plant residues as affected by litterbag mesh-size. Bar represents $LSD_{0.05}$.

3.4 Conclusions

The integrated effects of C/N ratio, lignin, and polyphenol content of plant residues needs to be considered for assessment of decomposition and nutrient release rates. Plant residues low in C/N ratio, lignin, and polyphenol contents decompose and release nutrients fast, hence they are good sources of nutrients for fast growing crops. Plant residues high in C/N ratio, lignin and polyphenol contents decompose and release nutrients

slowly. Hence, the quality of plant residues added is open to manipulation to suit the crop nutrient demand during a growing season or a cropping cycle.

The effects of soil fauna on the decomposition of plant residues with extremely low quality, such as *Acioa*, was insignificant, as expected. The results confirmed the hypothesis that soil fauna significantly increase decomposition and nutrient release of plant residues of intermediate quality. This effect was also detected with high quality plant residues. The presence of soil faunal effects on decomposition and nutrient release implies that decomposition and nutrient release of plant residues can be improved by enhancing soil faunal activities.

It is suggested that laboratory trials on decomposition underestimate the rate of nutrient release.

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4. Biological effects of plant residue with contrasting chemical compositions under humid tropical conditions - effects on soil fauna.

Abstract

Effects of five types of plant residues [*Acioa barteri*, *Gliricidia sepium* and *Leucaena leucocephala* prunings, maize (*Zea mays*) stover and rice (*Oryza sativa*) straw] applied as mulch on soil fauna were examined under field conditions in the humid tropics in 1990 and 1991. Earthworm mean population over a two years period was on average higher under any type of plant residues by 41% compared to the control. *Leucaena* prunings supported the highest earthworm population. The effect of other plant residues on earthworm population decreased in the following order; rice straw > *Gliricidia* prunings > maize stover > *Acioa* prunings. Mulched plots also showed 177% higher mean termite population over two years than the control. Highest termite population was observed in plots mulched with *Acioa* prunings followed by maize stover > rice straw > *Leucaena* prunings > *Gliricidia* prunings. The mean ant population was 36% higher with *Leucaena* and *Gliricidia* prunings and lower by about 9% with *Acioa* prunings, maize stover and rice straw as compared to the control. Millipede populations were not significantly affected by mulching. Earthworm populations were negatively correlated with the ratio of lignin:N of plant residues. Ant populations were significantly related to the N content of plant residues ($R^2 = 0.87$ and 0.84 for 1990 and 1991 respectively). The results imply that chemical plant composition, particularly N and lignin contents, plays a critical role in faunal abundance in the soil through their impact on palatability and decomposability. Mulching effects on microclimate may also be important.

4.1 Introduction

Soil fauna play an important role in enhancing and sustaining soil productivity through their effects on soil organic matter decomposition and

availability of plant nutrients (Lee, 1990; Anderson, 1988; Anderson and Ingram, 1989). Exclusion of macrofauna was reported to reduce decomposition rate and nutrient release from leaf litter (Witkamp and Ausmus, 1976). Earthworms are able to increase the decomposition of organic matter and availability of nutrients by comminuting residues and incorporating organic matter into the soil, and by producing casts enriched with microflora (Edwards and Lofty, 1972; Syers et al., 1979). Termites and ants are known to be efficient in digesting cellulose and in some cases also lignified substances (Lee and Wood, 1971). Millipedes break down plant litter and mix it with mineral soil, which they ingest (Kevan, 1968).

A number of factors has been identified that influence faunal abundance in the soil (Lavelle, 1983a). Climate is one of the important factors (Madge, 1969). Lavelle (1983b) reported a linear increase in earthworm biomass with increase in amount of rainfall for different regions of the tropics. On the other hand, litter quality has been reported to affect soil fauna populations (Swift et al., 1979). Hendrikson (1990) studied the food preference of leaf litter by earthworms and observed that the number of earthworms was significantly and negatively correlated with the C/N ratio and polyphenol concentration of plant materials.

Application of plant residues as mulch is known to attenuate the increase of soil temperature and to retain higher soil moisture levels (Lal et al., 1980) in addition to providing food for soil animals. As plant residues with different chemical compositions vary in their palatability for the soil fauna and their effect on soil microclimate, they are expected to have differential effects on soil fauna populations (Tian et al., 1992). Little information is however available on the effects of plant residues with different chemical compositions on soil fauna populations in the field particularly in the humid tropics. Tian et al. (1992) studied the decomposition of plant residues in the field under humid tropical conditions using litterbags with various mesh-size. They suggested that some of the observed differences in decomposition were due to differential effects of the soil fauna. This paper aims to supplement the previous study with evidence about the effects of plant residues with contrasting chemical compositions on soil fauna populations.

4.2 Materials and methods

A field experiment was carried out on an Egbeda series soil (Oxic

paleustalf) at the main station of the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria (3°54'E longitude, 7°30'N latitude, 213 m altitude). The area has a bimodal rainfall pattern with an annual mean of 1278 mm and a mean annual temperature of 26.2°C. The experiment was conducted during the 1990 and 1991 rainy seasons. Prior to the experiment the land had been under grass fallow dominated by *Pinnesetum purpureum* for six years. The surface (0 - 15 cm) soil of the experimental site has the following properties: Organic C, 1.99%; pH-H₂O 1:1, 6.5; ECEC, 6.22 cmol kg⁻¹ and a sandy loam texture.

A randomized complete block design with four replications was used for the trial. The treatments were: (1) no plant residue added (control), (2) *Acioa barteri* prunings; (3) *Gliricidia sepium* prunings, (4) *Leucaena leucocephala* prunings, (5) maize stover, and (6) rice straw. Dry plant residues were added as mulch at a rate of 5 tons ha⁻¹. Details on composition of materials used are shown in Table 4.1. Plots were cropped with maize cultivar TZSRW at a density of 40,000 plants ha⁻¹. Maize crop was fertilized with 45N - 20P - 37K kg ha⁻¹. Plot size was 4 x 6 m.

Table 4.1 Some chemical composition of prunings of woody species and crop residues (Tian et al., 1992)

Plant residues	Lignin	Poly-phenols	N	SiO ₂
		(%)		
<i>Acioa</i>	47.6	4.09	1.61	2.71
<i>Gliricidia</i>	11.6	1.62	3.60	0.59
<i>Leucaena</i>	13.4	5.02	3.55	0.53
Maize stover	6.8	0.56	1.00	2.22
Rice straw	5.2	0.55	0.84	11.35
LSD(.05)		0.25	0.12	0.24

Populations of earthworms, ants, termites and millipedes were measured at 4, 9 and 14 weeks after application of plant residues, using the TSBF hand-sorting method (Anderson and Ingram, 1989). Sampling was

done using 25 cm x 25 cm by 30 cm deep soil monoliths and populations of earthworms (*Hyperiodrilus africanus* and *Eudrilus eugeniae*), termites (*Ancistrotermes cavithorax*), ants (*Dorylus fimbriatus* and *Myrmicaria striata*) and millipedes (*Spirostreptus spp.*) were sorted by hand. Two samples were taken from each plot. Ants and termites were identified by the Natural History Museum in London, U.K.

Soil moisture at 0-10 cm depth was monitored using tensiometers. Data of fauna populations were normalised by Log(n+1) transformation, and subjected to analysis of variance. Statistical analyses were run using the SAS package (SAS, 1985). Effects of N, lignin, polyphenol and silica contents of mulch materials on fauna populations were assessed by partial correlation and backward selection regression analysis.

4.3 Results

Earthworms

The earthworm populations in the soil were affected by mulching, particularly during the first two observations at 4 and 9 weeks after mulching (WAM) (Figure 4.1). Except for *Acioa* mulch, at 4 WAM large increases in earthworm populations were observed. Differences were less pronounced at the later dates of observations. *Leucaena* prunings supported the highest earthworm populations; 67% and 82% higher in 1990 and 1991, respectively, than the control. The mean effect of the other mulches on earthworm populations was statistically not significantly different from the control and decreased in the following order; rice straw > *Gliricidia* prunings > maize stover > *Acioa* prunings in 1990 and *Gliricidia* prunings > rice straw > maize stover > *Acioa* prunings in 1991 (Table 4.2). Over the two-year period mulching increased earthworm population by about 41%. Earthworm populations were correlated more with N and lignin ratios (Figure 4.2) particularly at 4 WAM, in both years than with polyphenol and silica contents of plant residues. The outliers in Figure 4.2 might be considered to bias the correlation. The explained variation between is, however, higher not lower, if they are omitted. The lower effect in 1991 was probably due to the partial drought experienced during the first five weeks after mulching.

The dynamics of earthworm populations were also affected by types of plant residues (Figure 4.1). Plots mulched with *Leucaena* and *Gliricidia*

prunings had the highest earthworm populations at the initial stage of the experiment, while those with the more resistant *Acioa* prunings, maize stover and rice straw showed increase in population between 4 and 9 WAM.

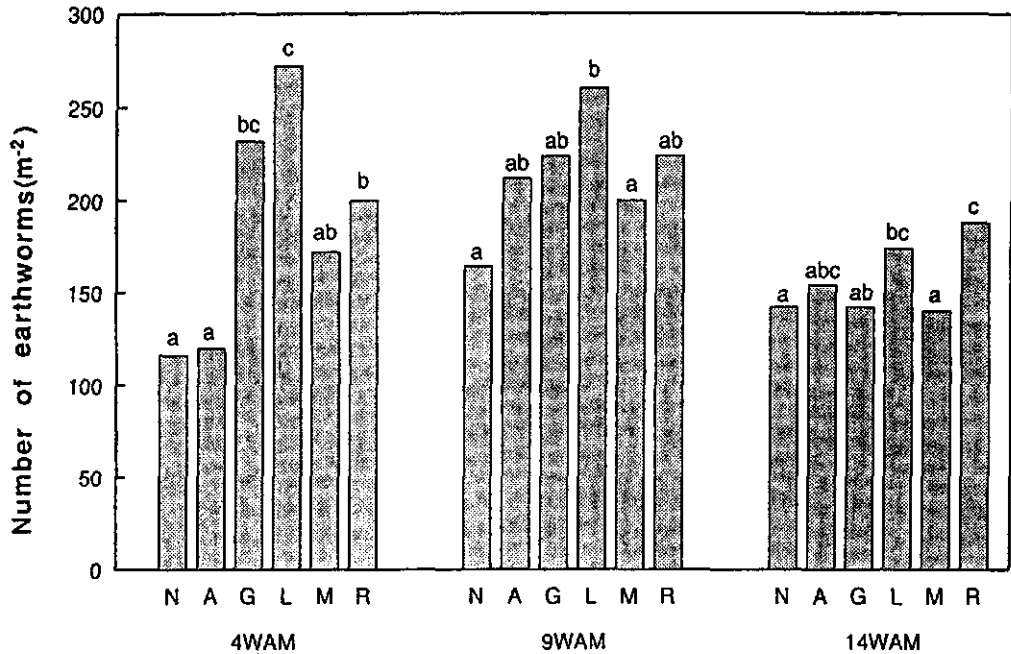


Fig. 4.1 Earthworm numbers in soil (0 - 30 cm depth) at 4, 9 and 14 weeks after mulching (WAM) with different plant residues in 1990. (N, control-no plant residue; A, *Acioa* prunings; G, *Gliricidia* prunings; L, *Leucaena* prunings; M, maize stover, and R, rice straw). For each observation date, columns carrying different letter(s) were significantly different at 5% level using Duncan's test.

Termites

Figure 4.3 shows that termites were generally more abundant in the mulched treatments in both years. As shown in Table 4.2, over the two years mulching increased termite population by 177% over the control. *Acioa* mulch supported the highest termite population, which was six times

Table 4.2 Means of three observations of soil fauna populations (number m⁻²) (X ± SE)¹ within soil layer of 0-30 cm, as affected by mulching.

Plant residues	Earthworms			Termites			Ants			Millipedes		
	1990	1991	1990	1990	1991	1990	1990	1991	1990	1990	1991	1991
Control	141 ± 45a	79 ± 17a	135 ± 60a	360 ± 243a	466 ± 97a	555 ± 122a	12 ± 8a	8 ± 5a				
<i>Acioa</i> prunings	162 ± 24ac	100 ± 12a	811 ± 203d	1082 ± 255c	349 ± 94a	566 ± 155a	15 ± 4a	12 ± 8a				
<i>Gliricidia</i> prunings	200 ± 53ac	113 ± 35ab	407 ± 157b	528 ± 203b	601 ± 216a	786 ± 217b	13 ± 6a	12 ± 4a				
<i>Leucaena</i> prunings	235 ± 70bc	144 ± 46b	435 ± 147b	629 ± 191b	697 ± 256b	692 ± 93ab	17 ± 12a	8 ± 5a				
Maize stover	171 ± 48ac	107 ± 11ab	782 ± 268d	900 ± 304c	372 ± 90a	540 ± 90a	9 ± 4a	8 ± 5a				
Rice straw	204 ± 49ac	112 ± 18ab	594 ± 173c	689 ± 184b	381 ± 118a	582 ± 110a	17 ± 4a	8 ± 5a				

¹ANOVA based on log (n + 1) transformed data; values for same column with the same letter(s) are not significantly different at P = 0.05 level based on Duncan's test.

higher than in the control. *Leucaena* and *Gliricidia* prunings had less effect on termite populations, compared to other mulch materials. Maize stover showed about the same effect as *Acioa* prunings (Table 4.2). Rice straw initially had a strong effect, but the effect decreased in subsequent observations (Figure 4.3). On the average the effect of rice straw was more pronounced than that of *Leucaena* or *Gliricidia* mulches (Table 4.2). Although stepwise regression analysis showed no significant correlation between N, lignin and polyphenol contents of plant residues and termite numbers, the slower decomposing mulches showed higher termite populations in both years.

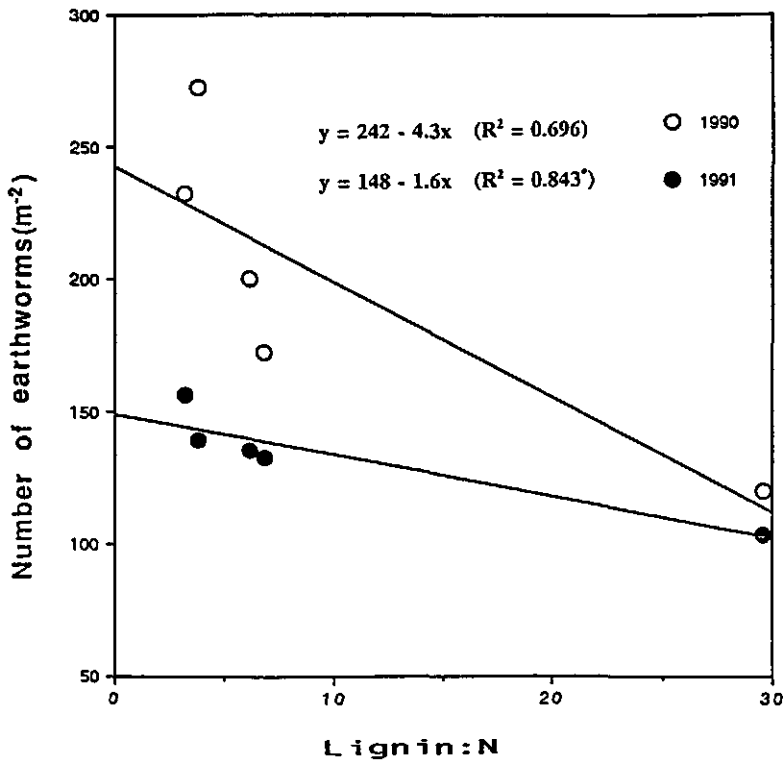


Fig. 4.2 Relationship between earthworm numbers (4 WAM) and the lignin:N ratio of the five type plant residues.

The low termite population in the control plot hardly changed

throughout the maize growing season, while under *Acioa* and *Gliricidia* mulches it increased with time. Under rice straw the termite population increased rapidly after mulching, but decreased between 4 and 9 WAM and levelled off. Maize stover maintained a high termite population throughout the season (Figure 4.3).

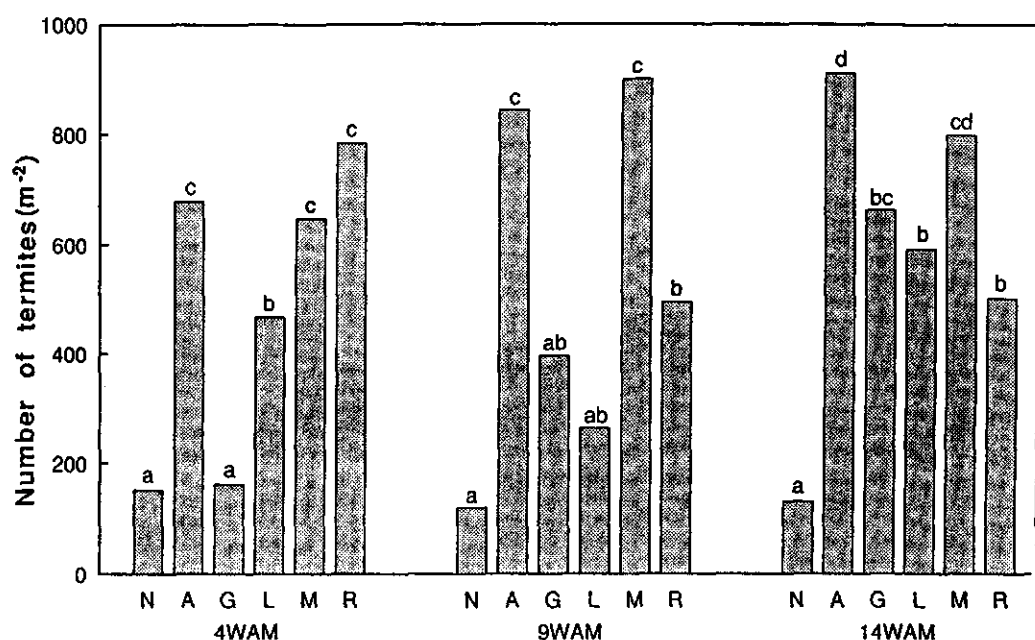


Fig. 4.3 Termite numbers in soil (0 - 30 cm depth) at 4, 9 and 14 weeks after mulching with different plant residues in 1990. (Legend as in Fig. 4.1).

Ants

The effect of mulching on ant populations was less pronounced than on earthworms and termites (Figure 4.4). Only *Leucaena* and *Gliricidia* prunings showed higher ant populations as compared to the control. Over the two year mulching with *Leucaena* and *Gliricidia* showed 36% higher ant population (Table 4.2). Mulching with *Acioa* prunings, maize stover

and rice straw decreased soil ant populations at the first two observations, but showed no effect at the last observation. Over the two years *Acioa* prunings, maize stover and rice straw had no significant effect on ant populations and lowered ant population by 9% (Table 4.2). Statistical analysis showed a significant relationship between ant numbers and N content of plant residues (Figure 4.5).

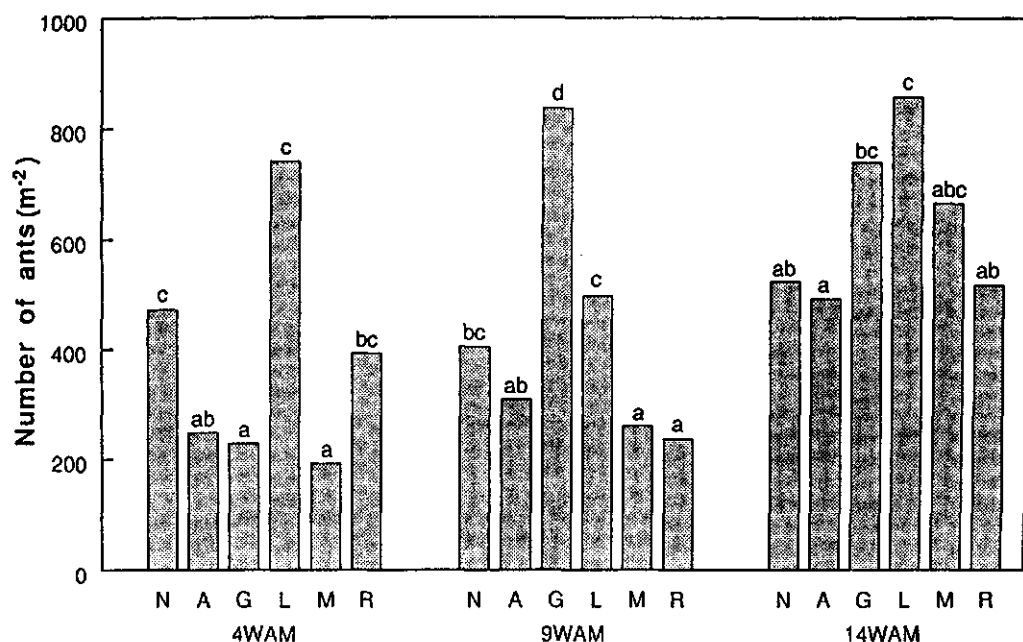


Fig. 4.4 Ant numbers in soil (0 - 30 cm depth) at 4, 9 and 14 weeks after mulching with different plant residues in 1990. (Legend as in Fig. 4.1).

Ant populations increased as the season progressed. However, the populations changed with time in response to mulch type (Figure 4.4). *Gliricidia* mulch, which showed lower ant populations initially, supported higher populations at 9 and 14 WAM. *Leucaena* mulch increased and maintained high ant populations. Under *Acioa* prunings and maize stover, ant populations increased throughout the experiment.

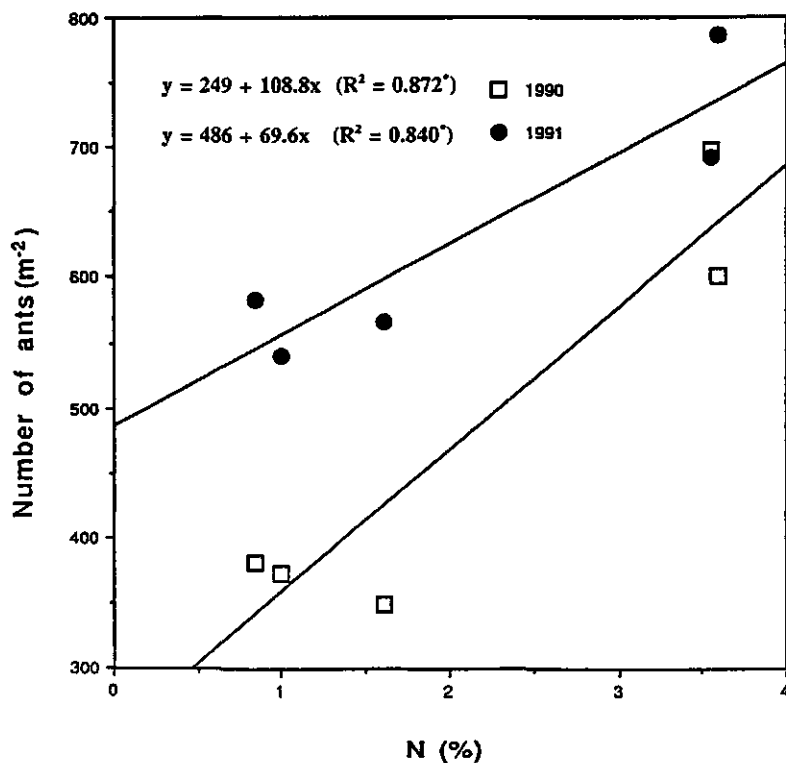


Fig. 4.5 Relationship between (overall mean) ant number and N content of plant residues.

Millipedes

Millipede populations were also influenced by the type of mulch, although significant treatment differences were only observed with rice straw at 14 WAM in 1990 (Figure 4.6). On the average plant residues did not affect millipede populations (Table 4.2).

4.4 Discussion

Results of this study show that mulching with plant residues has a clear effect on soil fauna populations, and the effects vary with chemical composition of plant residues added. Apart from the nutritional quality of plant residues, mulching effects on soil microclimate may have major effects on soil fauna populations.

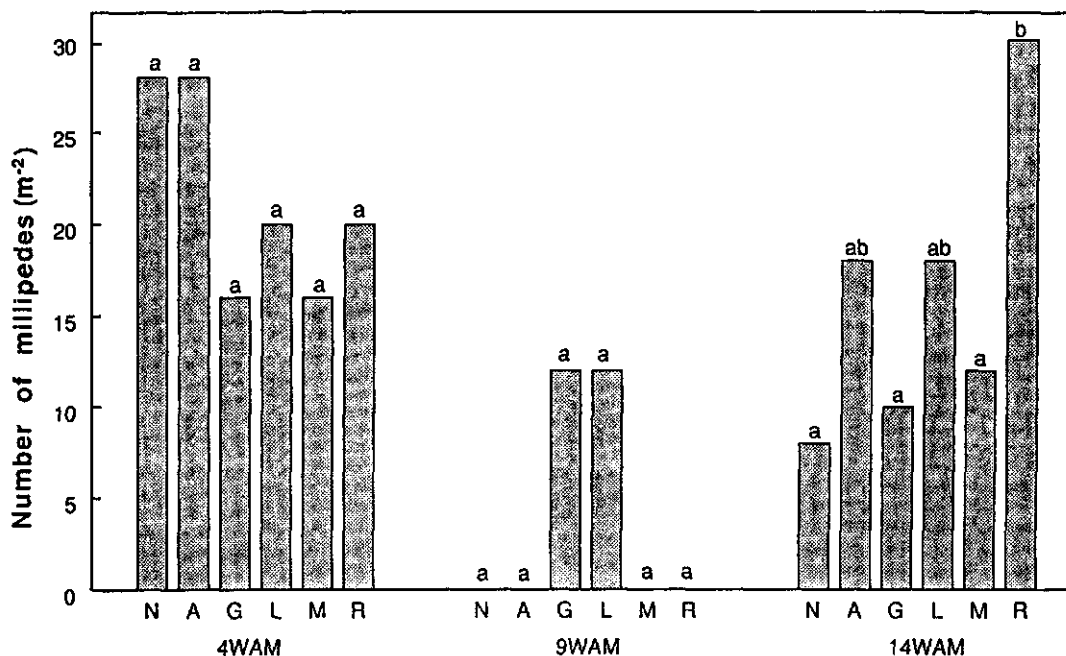


Fig. 4.6 Millipede numbers in soil (0 - 30 cm depth) at 4, 9 and 14 weeks after mulching with different plant residues in 1990. (Legend as in Fig. 4.1).

The microclimatic effects of various mulches differed as shown in Figures 4.7 and 4.8. Although all plant residues tested retained higher soil moisture (Figure 4.7) and attenuated the increase of soil temperature (Figure 4.8), the magnitude of effects differed.

The increased earthworm populations following application of any plant residue indicate the physical importance of the mulch layer for

earthworm. However, the microclimate effect alone cannot explain the high earthworm populations observed with application of *Leuceana* prunings which are known to have a short-term mulching effect due to their high decomposition rate. Neither can the microclimatic effect explain the low earthworm populations observed with application of *Acioa* prunings, which are known to have a long-term mulching effect due to their low decomposition rate. The nutritional quality of plant residues thus appears to play an important role in influencing earthworm population.

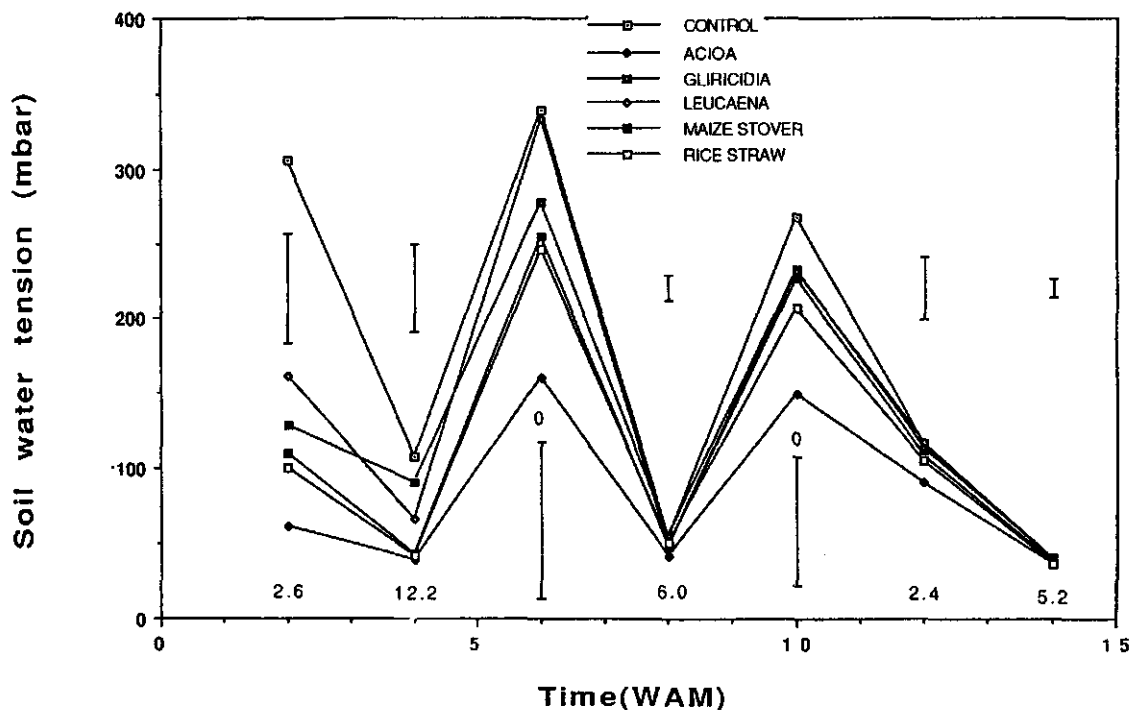


Fig. 4.7 Effect of mulching with various plant residues on surface soil (0 - 10 cm) moisture tension determined at various weeks after mulching. Data collected at 3.00 p.m. during the 1990 cropping season. (Bar represents $LSD_{.05}$).

The effect of the chemical composition of plant material on earthworm populations has been reported by a number of workers. Satchell

and Lowe (1967) reported that N, soluble carbohydrate and polyphenol contents are the main factors affecting the attraction of earthworm to plant residues. King and Heath (1967) and Satchell (1967) reported that total polyphenolic content was inversely related to palatability of leaves.

The high correlation observed between earthworm population and lignin:N ratio of plant residues in the present study (Figure 4.2) confirms the importance of N content of plant residues for earthworms. Polyphenols and silica appeared not to have clear effects on the soil fauna population. The fact that the earthworm population was not affected by polyphenols may be due to their low stability in plant residues under humid tropical conditions.

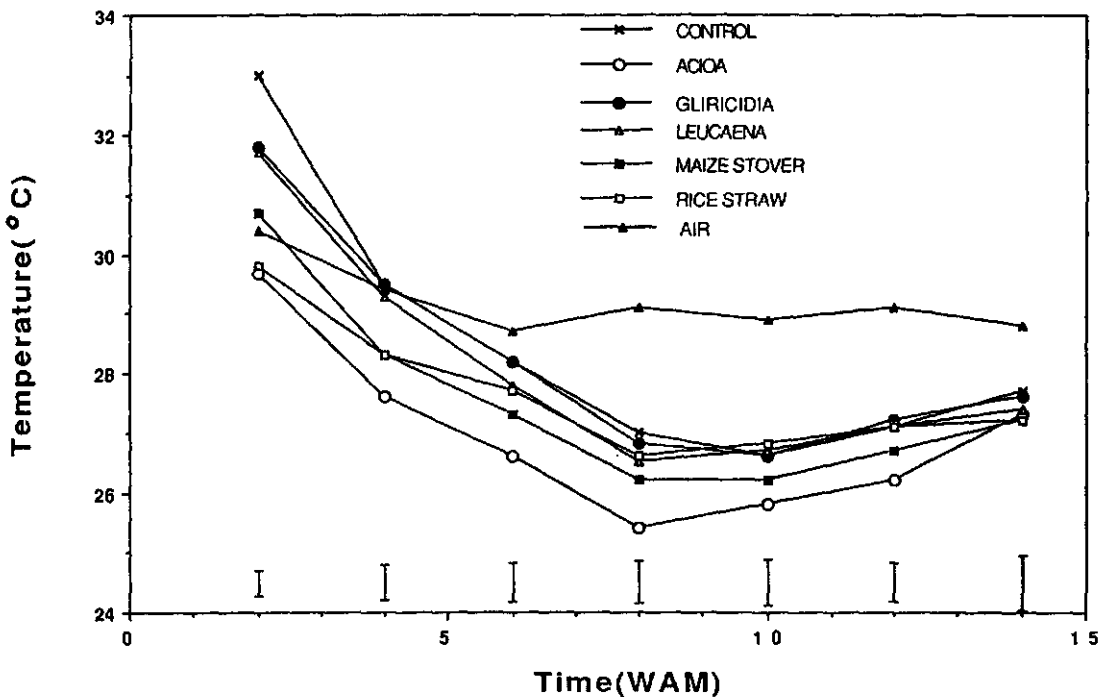


Fig. 4.8 Effect of mulching with various plant residues on surface soil (10 cm) temperature, determined at various weeks after mulching (WAM). Data collected at 3.00 p.m. during the 1990 cropping season. (Bar represents $LSD_{.05}$).

The companion paper (Tian et al., 1992) reports that: (1) Highly nutritional plant residues (with low lignin:N ratio) decompose and release nutrients (particularly N) fast and gradually show an increase in their lignin:N ratio, resulting in a shorter period of mulching effect on the microclimate, and (2) Plant residues low in nutritional value decompose slowly, immobilize N, and gradually decrease their lignin:N ratio, resulting in a longer-lasting mulching effect on the microclimate. These findings explain the decrease of earthworm populations under *Leucaena* and *Gliricidia* mulches from 4 WAM to 14 WAM, and the increase in populations under *Acioa* prunings, maize stover and rice straw from 4 WAM to 9 WAM (Figure 4.1). The small differences in earthworm populations among treatments observed at the last observation date, are due to the small amount of plant residues remaining (except for *Acioa* prunings) or to the seasonal phenology of the earthworms involved.

The effects of mulch on termite populations indicate that termites prefer plant residues with low nutritional quality, which decompose slowly and have a great effect on the microclimate (Figure 4.7 and Figure 4.8). This means that decomposability or mulching effects on microclimate of plant residues rather than nutritional contributions determines their impact on termite populations.

Moore (1969) pointed out that termites are susceptible to desiccation, having a soft cuticle with poor water-retaining properties. Maintenance of humidity is therefore essential for termite survival and growth. *Acioa* prunings and maize stover maintained high termite populations throughout the experiment due to their slow decomposition rate, while *Gliricidia* and *Leucaena* mulch supported low termite populations, due to their high decomposition rates. Shading due to the better growth of maize in the plots mulched with *Leucaena* and *Gliricidia* decreased treatment differences in termite populations at 14 WAM.

Little is known about the effect of the chemical composition of plant residues on ant populations, although the food resource has been considered to be the main factor (Levieux, 1983). The observed significant correlation between ant number and N content of plant residues (Figure 4.5) indicates some effect of N content on ant population.

Absence of any correlation between millipede number and chemical composition of plant residues may stem from the high mobility of millipedes, as is also indicated by the high variability in population counts between replications (Figure 4.6).

4.5 Conclusions

Results of this study provide evidence that plant residues applied as mulch differentially affect soil fauna populations. Application of certain plant residues significantly increases earthworm or termite populations, with less distinct effects on ants and no effects on millipedes.

The effects on soil fauna abundance is determined by the chemical composition and associated decomposability of plant residues. The factors controlling the effects of plant residues on soil fauna are microclimatic and nutritional.

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5. Earthworm- and millipede-enhanced degradation of plant residues in relation to their chemical compositions, incubation temperature and soil moisture

Abstract

Studies were carried out under field and growth chamber conditions to assess the effects of earthworms and millipedes on the degradation of plant residues and their response to chemical compositions of plant residues and microclimate. Inoculation with earthworms and millipedes increased the CO₂ emission from soil with added *Gliricidia* or maize leaves regardless of size and placement of plant residues. Differences in emissions of CO₂ due to size of plant residues added were not statistically significant. No marked differences in CO₂ emissions were observed between residue mulching and incorporation. Lower temperature and/or higher moisture promoted the contribution of earthworms and millipedes to the degradation of plant residues. The effects of earthworms and millipedes on degradation of plant residues were influenced by the chemical compositions of plant residues. Millipedes highly contributed to degradation and N release of plant residues with high C/N ratio and lignin and polyphenol contents. Earthworms showed strong effects on degradation of plant residues with low lignin and polyphenol contents. The "high quality" materials (low lignin and polyphenol contents and C/N ratio) were more affected at an early stage of decomposition, whereas "low quality" materials (high lignin and polyphenol contents and C/N ratio) were more affected later. Earthworms and millipedes appeared to contribute more to degradation of "low" than "high quality" plant residues. The results demonstrate the possibility to enhance N release of plant residues with "low quality" by improving the activity of millipedes and earthworms.

5.1 Introduction

Decomposition of organic matter and release of nutrients by the soil

microflora are often accelerated in the presence of soil fauna (Swift et al., 1979; Seastedt, 1984; Tian et al., 1992). Comminution of plant residues by soil fauna increases the exposure of substrates to the microflora, which facilitates decomposition (Scheu and Wolters, 1991). Soil fauna also digest plant residues through symbiotic interactions with gut microorganisms (Edwards and Fletcher, 1988). Verhoef and Brussaard (1990) estimated that for various natural ecosystems, such as prairies and forests, and for agroecosystems the faunal contribution to nitrogen mobilization is about 30%. The present study aims to quantify the effects of tropical earthworms and millipedes on the degradation of plant residues, which were mechanically fragmented to various sizes.

Application of plant residues as mulch is known to have an effect on the soil microclimate. Lowering of soil temperature and better retention of soil moisture with mulching can enhance soil faunal activity (Tian et al., manuscript submitted for publication). This is hypothesized to result in an increase in degradation of plant residues. However, no information is available at present to support this hypothesis.

Plant residues are known to have diverse chemical compositions, which influence their palatability to soil fauna (Swift et al., 1979), different effects of earthworms and millipedes on the decomposition and mineralization process can therefore be expected for different types of plant residues. This study also aims to clarify the relationships between degradation of plant residues by earthworms and millipedes and both the chemical compositions of the residues and the microclimatic conditions observed with mulching.

5.2 Materials and methods

Growth chamber trial I

A growth chamber trial was carried out to quantify the contributions of earthworms and millipedes to degradation of plant residues, using a randomized complete block design with three replications. Treatments included 24 combinations of two plant residues (maize and *Gliricidia sepium* leaves), three residue sizes (6 x 2.5, 0.5 x 2.5 and 0.05 x 0.05 cm) of plant residues, two methods of placement of plant residues (mulching or incorporation) and two faunal treatments (with or without earthworms (*Eudrilus eugeniae*) and millipedes (*Spirostreptidae*)), and a control with

soil only. The choice of 6 cm as the longest residue length was based on the observation that mature leaflets of *Gliricidia* are about 6 cm long.

Five hundred grams of air-dried defaunated soil were placed in a 1.5 l polyethelene jar with a lid. Dry maize or *Gliricidia sepium* leaves were added at the surface of soil or thoroughly mixed with the soil at a rate equivalent to 5 t dry matter ha⁻¹. Four mature earthworms or 1 millipede, which is equivalent to two times of mean population density observed in the field reported by Tian et. al (manuscript submitted for publication), were added to each jar. Tap water was added to bring the soil water potential to 0.01 MPa. All jars were kept in a growth chamber at constant 24°C with 12 hours of fluorescent light per day for incubation. Soil water loss was determined weekly by weighing the jars, and the soil water status was corrected accordingly.

At the end of each of the 5 incubation periods (4, 8, 16, 32, 48 days), a 25 ml test tube filled with 15 ml 1.0 N NaOH was placed in the jar with the lid air-tighted by parafilm for 24 hours following 4, 8 and 16 days of incubation and for 72 hours following 32 and 48 days of incubation. The remaining NaOH and CO₃⁻ produced following the absorption of CO₂ were titrated by 0.5 N HCl to determine instantaneous and cumulative CO₂ emission. The incubation ran for eight weeks, as death of some of the animals was observed beyond this period.

Growth chamber trial II:

Another growth chamber trial was conducted to assess the effect of temperature and soil moisture on the contribution of earthworms and millipedes to plant residue decomposition.

Tian et al., (manuscript submitted for publication) observed that plant residue mulching decreased soil temperature and increased soil moisture. To further assess the effects of soil temperature and/or soil moisture on the decomposition process by soil fauna, a growth chamber trial was thus initiated. The trial was carried out using a split-plot design with three replications. The main treatments consisted of two levels of water potential: 0.01 MPa and 0.1 MPa. Three subtreatments were compared: control (no fauna), with earthworms (*Eudrilus eugeniae*), and with millipedes (*Spirostreptidae*). The trial was run simultaneously at three temperatures: 24, 28 and 32°C. A soil temperature as high as 32°C and soil water potential as high as 0.1 MPa were chosen as they are commonly observed during the growing season under unmulched conditions.

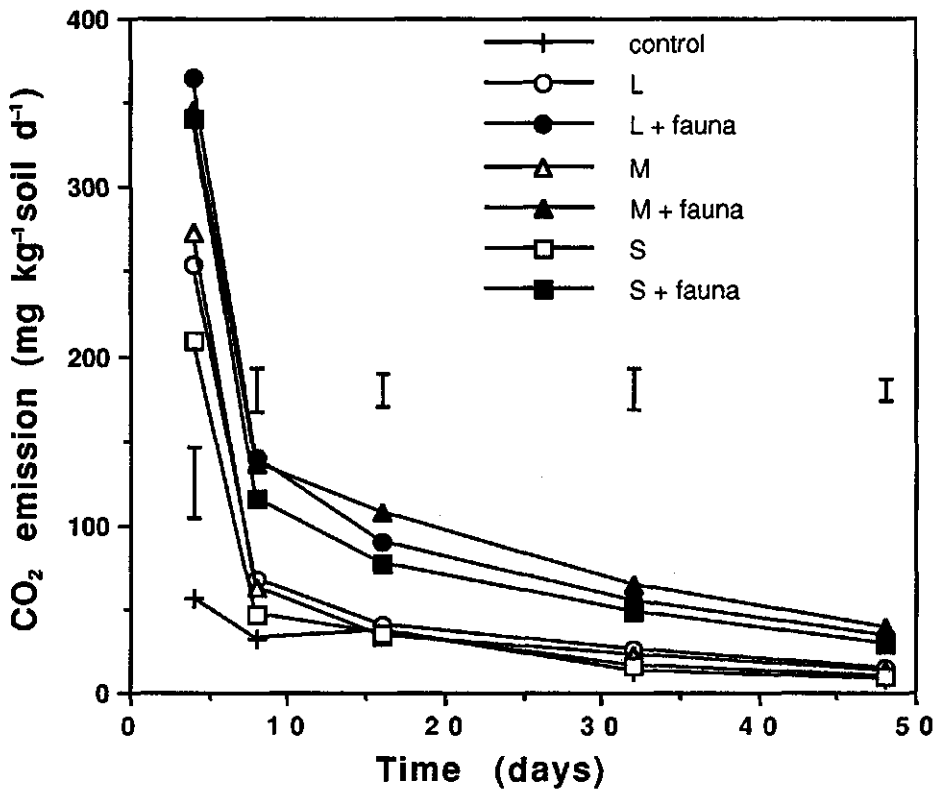


Fig. 5.1 Instantaneous soil respiration as affected by incorporation of different sizes of *Gliricidia* leaves: 0.05 x 0.05 cm (S), 0.5 x 2.5 cm (M) and 6.0 x 2.5 cm (L) and inoculation with soil fauna (earthworms and millipedes). Bars represent $LSD_{0.05}$.

Two kilograms of air-dried defaunated soil were placed in a 2.5 l polyethylene jar with the same surface area as in growth chamber trial I. The lid and bottom of the jar were perforated (0.3 mm mesh) for sufficient gas exchange. Dry maize leaves (6.0 x 2.5 cm) were added at the soil surface at a rate equivalent to 5 t dry matter ha⁻¹. Four mature earthworms or 1 millipede, equivalent to 2 x mean population density observed in the field reported by Tian et. al (manuscript submitted for publication), were added to each jar. Tap water was added to bring the water potential to 0.01

or 0.1 MPa. All jars were kept in a growth chamber with 12 hours fluorescent light per day during the observation period. Soil water loss was corrected weekly by weighing the jar and adding water accordingly. The incubation ran for eight weeks. The remaining maize leaves were collected using a floatation method. Plant residues were washed and dried at 65°C.

Field experiment

The field experiment was carried out to determine the relationships between the contribution of earthworms and millipedes to the degradation of plant residues and the chemical compositions of plant residues.

The experiment was carried out using a split-plot design with three replications. Main treatments consisted of control (with no plant residues) and treatments with each of the following plant residues: *Acioa barteri*, *Gliricidia sepium* and *Leucaena leucocephala* prunings (leaves and small twigs cut to 10 cm long), maize stover and rice straw cut to 10 cm long. There were four sub-treatments: without fauna, with earthworms, with millipedes and with earthworms and millipedes.

The experiment was conducted during the 1991 crop growing season at the International Institute of Tropical Agriculture station at Ibadan in southern Nigeria which is located in the humid tropical zone. The field was monocropped with maize. Large pots (38 cm in diameter and 27 cm in height) filled with Egbeda series (Oxic Paleustalf) surface (0-15 cm) soil (defaunated by sun drying and removing fauna by hand) were used in the experiment. The pots were installed to a depth of 25 cm in the soil. Dry plant residues were added on top of the soil column using a rate equivalent to 5 t dry matter ha⁻¹. Eighteen mature earthworms (*Eudrilus eugeniae*) and/or 3 millipedes (*Spirostreptidae*) per pot were placed in the fauna treatments at the start of the experiment. The number of soil animals added was equivalent to the mean population density observed in the field reported by Tian et. al (manuscript submitted for publication). During the experiment, the top and bottom of the pot were covered with nylon screen (0.8 mm mesh) to prevent animals from escaping and to allow free movement of rain water. At 4 and 10 weeks after addition (WAA), pots were removed. The remaining plant materials were collected by a floatation method. The floating residues were collected by sieving with a 1.0 mm mesh sieve and washed. Plant residues were dried at 65°C and ground to pass a 0.5 mm mesh sieve. Plant residues collected at 10 WAA were analyzed for total N content (IITA, 1979).

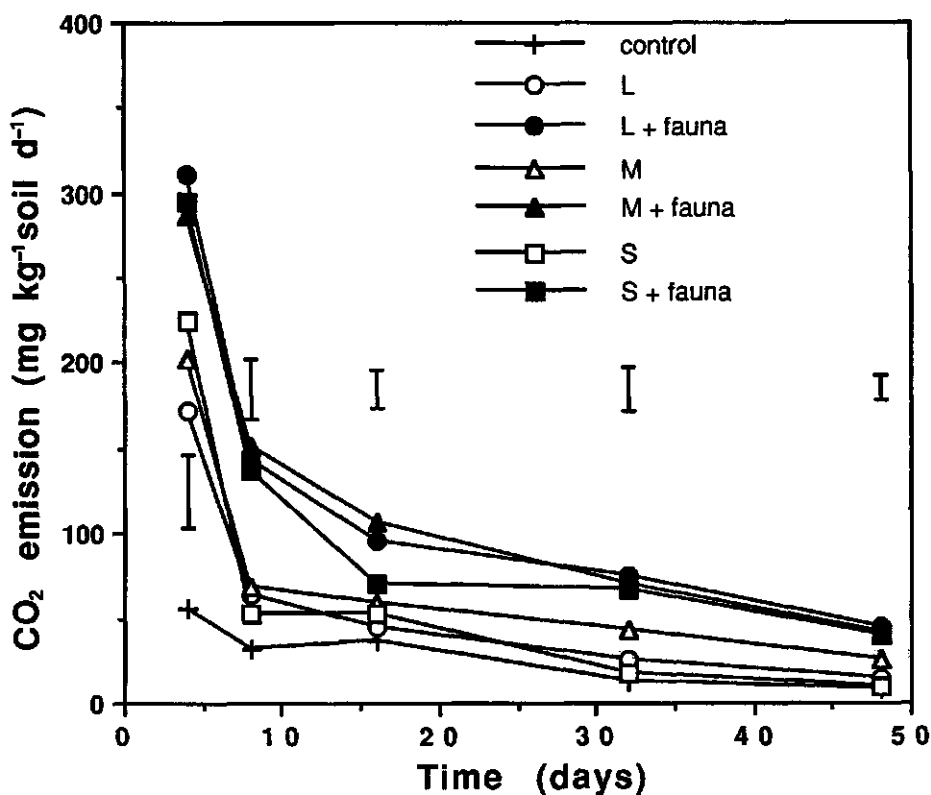


Fig. 5.2 Instantaneous soil respiration as affected by incorporation of different sizes of maize leaves: 0.05 x 0.05 cm (S), 0.5 x 2.5 cm (M) and 6.0 x 2.5 cm (L) and inoculation with soil fauna (earthworms and millipedes). Bars represent $LSD_{0.05}$.

5.3 Results

Earthworms and millipedes and CO₂ emission

Results of growth chamber experiment I show that in the control, CO₂ emission was lowest and showed little variation during the incubation period (Figures 5.1, 5.2, 5.3 and 5.4). There was large variation in respiration between sampling dates with addition of plant residues, with or without addition of earthworms and millipedes. Under all conditions, CO₂

emissions were high initially and declined gradually towards the end of the experiments. Treatments with earthworms and millipedes resulted in significantly higher CO₂ emission (Figures 5.1, 5.2, 5.3, 5.4 and 5.5) for each of the sampling dates. The instantaneous CO₂ emission with addition of earthworms and millipedes was on average 90.4% higher than without these animals. The cumulative CO₂ emission during the 7 weeks incubation was on average 107.7% higher than that without these animals.

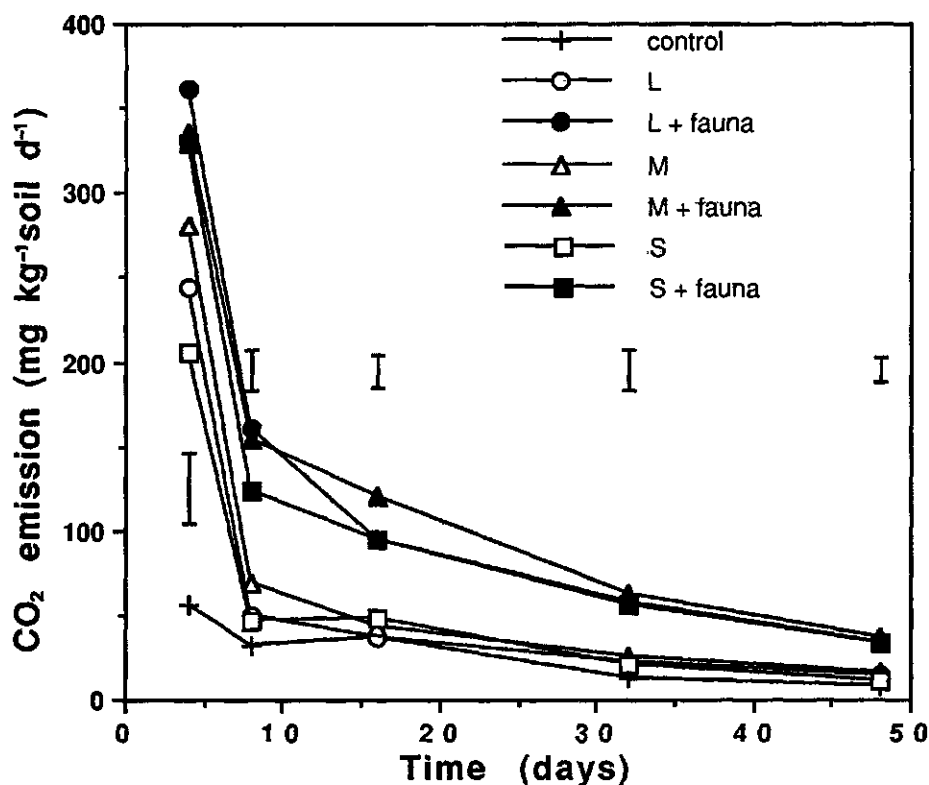


Fig. 5.3 Instantaneous soil respiration as affected by mulching of different sizes of *Gliricidia* leaves: 0.05 x 0.05 cm (S), 0.5 x 2.5 cm (M) and 6.0 x 2.5 cm (L) and inoculation with soil fauna (earthworms and millipedes). Bars represent LSD_{0.05}.

There was no effect of leaf size on the instantaneous amount of CO₂ emission. The difference in cumulative CO₂ emissions over 7 weeks of

incubation between the treatments with different sizes of leaves with or without addition of earthworms and millipedes was not significant either (Figure 5.5).

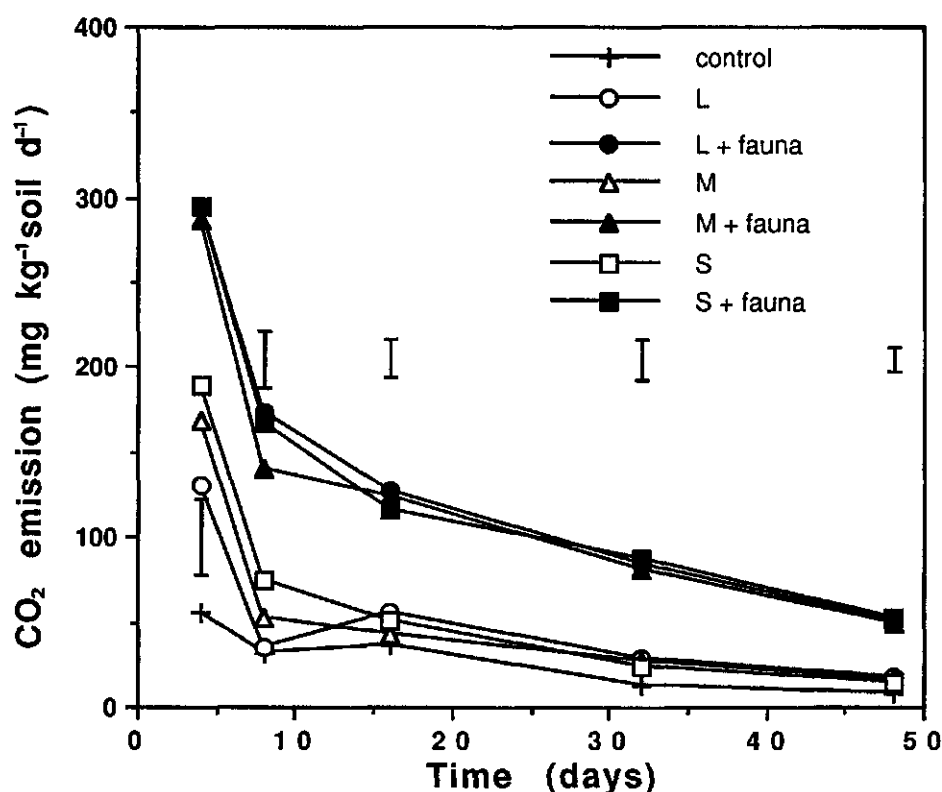


Fig. 5.4 Instantaneous soil respiration as affected by mulching of different sizes of maize leaves: 0.05 x 0.05 cm (S), 0.5 x 2.5 cm (M) and 6.0 x 2.5 cm (L) and inoculation with soil fauna (earthworms and millipedes). Bars represent $LSD_{0.05}$.

Under the same conditions, mulching or incorporation of leaves showed no significant differences in the instantaneous CO_2 emissions (Figures 5.1 and 5.3 for *Gliricidia* leaves; Figures 5.2 and 5.4 for maize leaves). The cumulative CO_2 emission was also not affected by method of leaf placement in the experiment (Figure 5.5).

Table 5.1 Effect of incubation temperature and soil moisture on contributions¹⁾ of earthworms and millipedes to percentage degradation of maize leaves over the control (no fauna).

Temperature (°C)	Soil water potential (MPa)	
	0.1	0.01
Earthworms		
32	-4.5 a A	-2.2 a A
28	1.0 a B	3.1 a B
24	0.8 a B	10.6 b C
Millipedes		
32	4.0 a A	8.6 a A
28	21.4 a B	30.9 a B
24	30.3 a B	44.8 b B

¹⁾: "maize leaf disappearance with fauna (%)" – "maize leaf disappearance in control (%)". For each group of fauna, figures within the same column (upper case) or on the same line (lower case) indicated by the same letter are not significantly different according to Duncan's test at $P < 0.05$.

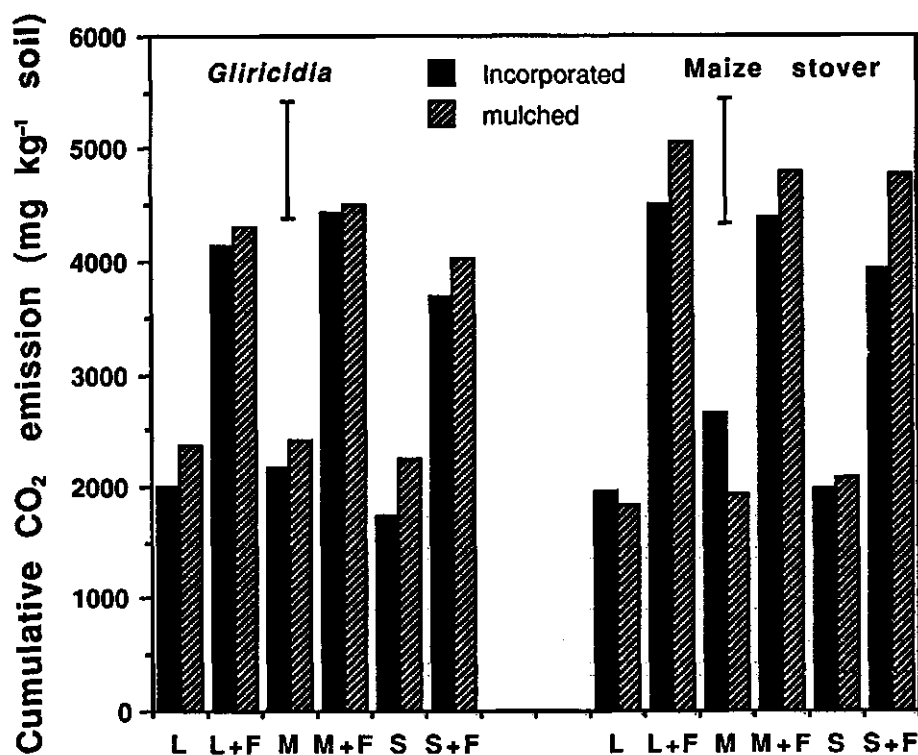


Fig. 5.5 Cumulative soil respiration during 7 weeks of incubation as affected by addition of different sizes of maize and *Gliricidia* leaves: 0.05 x 0.05 cm (S), 0.5 x 2.5 cm (M) and 6.0 x 2.5 cm (L) and inoculation with soil fauna (F) (earthworms and millipedes). Bars represent $LSD_{0.05}$.

Effects of earthworms and millipedes in relation to incubation temperature and soil moisture

Results of growth chamber experiment II showed that the contributions of earthworms and millipedes to degradation of maize leaves responded to temperature and soil moisture conditions (Table 5.1). Lower temperature or higher moisture status increased the contributions of earthworms and millipedes to the degradation of maize leaves. There were marked interactive effects between temperature and soil moisture. The temperature

effect decreased with decreasing moisture level, and the moisture effect decreased with increasing temperature in the case of earthworms. A combination of lower temperature and higher moisture resulted in more rapid degradation of maize leaves by earthworms and millipedes. Earthworms were more susceptible than millipedes to changes in soil moisture and temperature. At 32°C and 0.1 MPa, they showed no contribution to maize leaf degradation. Unlike earthworms, millipedes showed some contribution, though not significant, to the disappearance of maize leaves even at a temperature of 32°C and a soil water retention of 0.1 MPa.

Table 2 Increase¹⁾ in percentage degradation of plant residues with earthworms and millipedes over the control (no fauna) during 10 weeks of incubation.

Plant residues	Animal groups		
	Earthworms	Millipedes	Earthworms + Millipedes
For first 4 weeks			
<i>Acioa</i> prunings	3.4 b	7.2 a	9.0 a
<i>Gliricidia</i> prunings	9.7 b	13.3 b	21.3 b
<i>Leucaena</i> prunings	-4.3 a	4.9 a	6.7 a
Maize stover	19.4 c	30.8 d	42.0 c
Rice straw	7.2 b	21.8 c	19.9 b
For 10 weeks			
<i>Acioa</i> prunings	4.6 a	23.6 b	31.9 b
<i>Gliricidia</i> prunings	1.3 a	10.0 a	10.6 a
<i>Leucaena</i> prunings	4.2 a	11.0 a	15.0 a
Maize stover	9.7 a	23.8 b	25.5 b
Rice straw	3.1 a	21.4 b	31.8 b

¹⁾:"plant residue disappearance with fauna (%)" - "plant residue disappearance in control (%)". Figures carrying the same letter within a column are not significantly different at $P < 0.05$, based on Duncan's test.

Effect of earthworms and millipedes in relation to chemical compositions of plant residues

Data from the field trial (Tables 5.2 and 5.3) showed large variations in the effect of incubation with earthworms and millipedes on the disappearance and N release of plant residues. The cumulative effect of earthworms and millipedes on the degradation of plant residues during 10 weeks of incubation was significantly higher for maize stover, rice straw and *Acioa* prunings than for *Gliricidia* and *Leucaena* prunings, but there was no significant difference in the cumulative contribution for earthworms alone (Table 5.2). Earthworms and millipedes appeared to enhance the breakdown of decomposing maize stover, rice straw and *Gliricidia* prunings at the initial period of the experiment, degradation of *Acioa* and *Leucaena* prunings were accelerated mainly at the later period and *Leucaena* prunings were apparently not affected. Inoculation of both earthworms and millipedes generally increased their effects on the degradation of plant residues over inoculation of each of these groups alone. Compared to that of maize stover, the early breakdown of rice straw was little affected by inoculation with earthworms.

Table 5.3 Increase¹⁾ in percentage N release from plant residues by earthworms and millipedes over the control (no fauna) during 10 weeks of incubation.

Plant residues	Animal groups		
	Earthworms	Millipedes	Earthworms + Millipedes
<i>Acioa</i> prunings	10.4 b	27.6 c	28.5 c
<i>Gliricidia</i> prunings	2.4 a	10.7 a	11.1 a
<i>Leucaena</i> prunings	4.1 a	13.8 ab	16.2 ab
Maize stover	5.1 a	22.5 bc	23.1 bc
Rice straw	-4.2 a	25.1 c	31.1 c

¹⁾:"N release from plant residues with fauna (%)" - "N release from plant residues in control (%)".

Figures carrying the same letter within a column are not significantly different at $P < 0.05$, based on Duncan's test.

The N release from the decomposing plant residues was also significantly enhanced by the introduction of earthworms and millipedes (Table 5.3). The highest effect was observed in the case of *Acioa* prunings. The effect of millipedes on the N release from maize stover and rice straw was very similar to that from *Acioa* prunings.

5.4 Discussion

The role of soil fauna in enhancing decomposition process has been documented by a number of workers (Drift, 1958; Witkamp, 1971; Edwards and Heath, 1983; Setälä et al., 1988; Verhoef and Brussaard, 1990; Brussaard et al., in press). Setälä and Huhta (1990) reported that decomposition of substrates proceeds at different rates depending on the composition of the faunal community. The increase in the CO₂ emission following addition of earthworms and millipedes in this trial (Figures 5.1-5.5) is the result of increase in the decomposition of substrates, contributed by both these animals and animal-associated microorganisms. This result therefore confirmed the importance of soil fauna in the decomposition process.

Setälä and Huhta (1990) estimated that in "macrocosms" with leaf litter of birch, needle litter of spruce and humus the proportion of total CO₂ production contributed by the fauna (a mixture of nematoda, enchytraeidae, collembola, oribatida, mesostigmata, prostigmata and astigmata) was on average about 10%. The large increase in the CO₂ emission in our study following addition of earthworms and millipedes may be partially explained from the high metabolism of the adult millipede (weighing approximately 18 g individual⁻¹). Even so, the results imply the potential of millipedes for enhancement of degradation of plant residues with slow decomposition rate.

In many cases, the importance of macrofauna in the decomposition process is considered to be restricted to the mechanical fragmentation of plant residues (Kheirallah, 1990). The insignificant effect of different sizes of plant residues on CO₂ emissions in our study (Figures 5.1, 5.2, 5.3, 5.4 and 5.5) suggests that the effects of soil fauna on decomposition are not mainly through mechanical fragmentation. The contribution of soil fauna to biochemical degradation of plant residues is probably of more importance in our case. Soil fauna are known to digest plant residues through microorganisms in their guts and/or to stimulate microbial activity through improving conditions for growth (Scheu, 1987a; Lee, 1990).

Insignificant difference in CO₂ emission between the treatments with incorporated and mulched materials provides evidence for the bioturbation of soil by the fauna (Scheu, 1987b).

The higher contribution of earthworms and millipedes to degradation of plant residues under lower temperature and/or higher moisture confirmed the beneficial effects of mulching in increasing nutrient mineralization through enhancing faunal activity. Manipulation of environmental conditions conducive to the soil fauna may have a profound influence on the management of agricultural systems in the humid tropics.

As reported by Tian et al. (1992), *Acioa* prunings have a high C/N ratio and high contents of lignin and polyphenols. *Gliricidia* prunings have a low C/N ratio and low lignin and polyphenol contents. *Leucaena* prunings have a similar chemical composition to *Gliricidia*, except for their higher polyphenol content. Both maize stover and rice straw are high in C/N ratio, but the latter is also high in SiO₂ content. Differences in contributions of earthworms and millipedes to the degradation of these plant residues (Table 5.2) reflect the differences in their chemical compositions.

Millipedes showed a stronger effect on degradation of *Acioa* prunings, maize stover and rice straw during 10 weeks of incubation than on *Gliricidia* and *Leucaena* prunings, suggesting that millipedes may play a more important role in the degradation of "low quality" plant residues. This may be due to the higher resistance of such materials to the decomposition by microorganisms. Malone and Reichle (1973) and Seastedt (1984) also reported that the role of soil fauna is relatively greater in the decomposition of materials with high C/N ratios.

Compared to the other plant residues, degradation of maize stover appeared to be more enhanced by earthworms during the experimental period. Low lignin in the maize stover may account for its high consumption by earthworms. It appears that the importance of C/N ratio may be second to lignin in influencing the palatability of plant residues. Insignificant effect of earthworms on the decomposition of *Leucaena* and *Gliricidia* prunings is attributed to their high decomposibility by microorganisms.

Decreasing effects of earthworms and millipedes on the degradation of *Gliricidia* prunings and maize stover from 4 to 10 weeks of incubation were due to the high decomposition rate during the early period of incubation (Tian et al., 1992). There is, however, no good explanation for a decreasing effect of earthworms and millipedes on the degradation of rice

straw during the same period (Table 5.2).

The higher increase in N release from "low quality" plant residues with addition of millipedes and both millipedes and earthworms (Table 5.3) as compared to the "high quality" materials, further confirmed the importance of these animals in biochemical degradation of substrates, as "low quality" materials often immobilize N during their decomposition. It also implies the possibility to facilitate N release from "low quality" tropical plant residues through enhancing millipede and earthworm activity.

5.5 Conclusions

This study revealed the important role of earthworms and millipedes in the degradation of plant residues. It appears that increase in degradation by earthworms and millipedes is mainly through biochemical degradation, not through comminution. The contribution of earthworms and millipedes to the degradation of plant residues is promoted at lower temperature and high soil moisture which can be achieved by mulching in the field. The magnitude of effects of earthworms and millipedes depends on the chemical composition of plant residues. Millipedes show a relatively stronger effect on degradation of plant residues with high C/N ratio, lignin and polyphenol content. Earthworms contribute more to the degradation of plant residues with low lignin contents.

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6. Mulching effects of plant residues with chemically contrasting compositions on crop performance

Abstract

Effects of application of prunings of three woody species (*Acioa barteri*, *Gliricidia sepium* and *Leucaena leucocephala*), maize (*Zea mays*) stover and rice (*Oryza sativa*) straw as mulch on maize were studied on an Alfisol in southern Nigeria in 1990 and 1991. Maize dry matter and grain yield increased with applications of plant residues and N fertilizer in both years. Highest maize biomass yield was obtained with addition of *Leucaena* prunings in 1990, and *Acioa* prunings in 1991. Addition of *Leucaena* prunings gave the highest maize grain yield in both years. Of all treatments, mulching with *Acioa* prunings showed the least grain yield decline in 1991, as compared to 1990.

Nutrient uptake was enhanced by applications of plant residues. *Leucaena* prunings had the highest effect in both years and increased the mean N, P and Mg uptake by 96%, 84% and 50%, respectively over the control. Addition of *Acioa* prunings increased K and Ca uptake by 59% and 92%, respectively over the control. Efficiency of nutrient utilization from added plant residues was high for *Acioa* prunings and low for *Leucaena* and *Gliricidia* prunings, maize stover and rice straw. It is concluded that "high quality" plant residues mainly enhance crop performance through direct nutritional contributions, whereas "low quality" plant residues mainly through mulching effects on microclimate, presumably associated with enhanced mineralization of soil organic matter. "Intermediate quality" plant residues have no clear effects on crop performance.

6.1 Introduction

A major part of upland soils in the humid and subhumid African tropics is susceptible to degradation with intensive farming because of their low buffering capacity (Balasubramanian and Nnadi, 1980; Kang and Wilson,

1987). Although high crop yields can be obtained with judicious fertilizer use, the practice of high chemical input agriculture has not been widely adopted in the region. Various factors have contributed to the low fertilizer use, including scarcity of resources and the economics of its use. Furthermore, continuous use of high nitrogen fertilizer rates results in soil acidification (Jones, 1976). Integrated low chemical input soil fertility management systems are therefore needed, by combining the use of plant residues and chemical fertilizers (Sanchez and Salinas, 1981; Kang and Spain, 1986).

Apart from their direct nutrient contribution, plant residues are known to affect soil physical properties (Hulugalle et al., 1986), availability of soil nutrients (Wade and Sanchez, 1983), and soil faunal populations. The effects of woody plant residues on arable crops have been widely studied in recent years (Kang et al., 1981; Swarup, 1987; Yamoah et al., 1986). Most investigations are, however, concerned with the nutritional effect of addition of legume plant residues. Plant residues with different chemical compositions, are expected to have differential effects on crops. Plant residues with high C/N ratio, lignin and polyphenol contents decompose and release nutrients slowly (Tian et al., 1992), resulting in low direct nutrient effect and high indirect mulching effect on crops. Those with low C/N ratio, lignin and polyphenol contents decompose rapidly, resulting in high direct nutrient effect and low indirect mulching effect. To verify this hypothesis, a field experiment was carried out to determine the comparative effects of plant residues with contrasting chemical compositions on maize crop.

6.2 Materials and methods

The field experiment was carried out on an Egbeda series soil (Oxic paleustalf) at the main station of the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria (3°54'E longitude, 7°30'N latitude, 213 m altitude). The area has a bimodal rainfall pattern with an annual mean of 1278 mm and a mean annual temperature of 26.2°C. The experiment was conducted during the 1990 and 1991 rainy seasons. Prior to the experiment the land had been under grass fallow dominated by *Pinnisetum purpureum* for six years. The surface (0-15 cm) soil of the experimental site has the following properties: Organic C, 1.99%; pH-H₂O, 6.52; ECEC, 6.22 cmol kg⁻¹ and a sandy loam texture.

A randomized complete block design with four replications was used for the trial. The treatments were: (1) control + 45N (45 kg N ha⁻¹), (2) control + 90N, (3) control + 135N, (4) *Acioa barteri* prunings + 45N, (5) *Gliricidia sepium* prunings + 45N, (6) *Leucaena leucocephala* prunings + 45N, (7) maize (*Zea mays* L.) stover + 45N, and (8) rice (*Oryza sativa* L.) straw + 45N.

Table 6.1 Amount of nutrients added (kg ha⁻¹) with 5 tons ha⁻¹ of dry plant residues and different fertilizer rates

Treatments	N		P		K		Ca		Mg	
	I*	O**	I	O	I	O	I	O	I	O
45N	45	0	20	0	37	0	69	0	0	0
90N	90	0	20	0	37	0	88	0	0	0
135N	135	0	20	0	37	0	107	0	0	0
<i>Acioa</i> + 45N	45	80.5	20	3.45	37	40.0	69	37.0	0	15.5
<i>Gliricidia</i> + 45N	45	180.0	20	6.46	37	137.0	69	81.5	0	22.5
<i>Leucaena</i> + 45N	45	177.5	20	4.60	37	139.5	69	79.5	0	20.0
Maize stover + 45N	45	50.0	20	6.65	37	103.0	69	21.0	0	14.5
Rice straw + 45N	45	42.0	20	2.65	37	117.0	69	29.0	0	15.5
LSD (.05)		6.0		0.12		12.5		3.0		1.0

*I - Inorganic sources

**O - mulch

Plant residues were air-dried and applied as mulch at a rate of 5 t dry weight ha⁻¹, 5 days after planting maize in 1990 and 1 day after planting maize in 1991. Nitrogen was split-applied as calcium ammonium nitrate, 1/3 N at 1 week after planting (WAP) and 2/3 N at 5 WAP. Nitrogen was added to all treatments at rates shown above, as it was known that maize will not perform well on this plot without some N application. All plots received basal dressings of 20 kg P ha⁻¹ as single superphosphate, and 37 kg K ha⁻¹ as muriate of potassium. Maize cultivar TZSRW was planted as

test crop at a population of 40,000 plants ha^{-1} . Plots were hand-hoed and manually weeded at 1, 6 and 11 WAP.

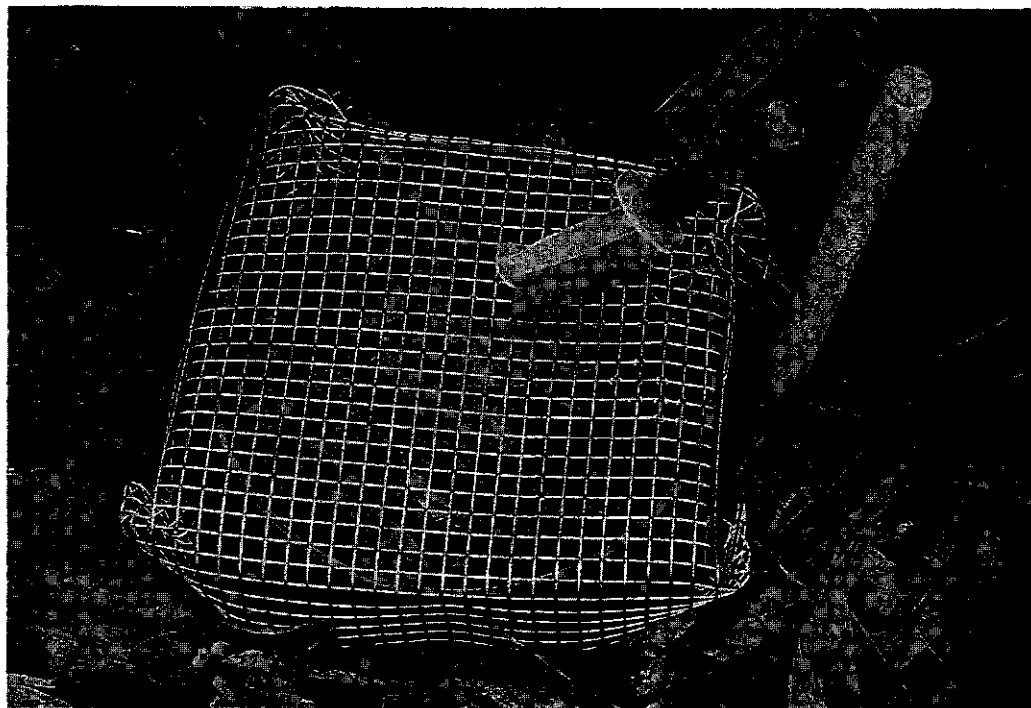


Plate 6.1 Mini-lysimeter system

For determination of maize dry matter yield and nutrient uptake, maize plants were sampled at 2, 5, 10 and 15 WAP. At harvest maize stover and grain yields were determined. Plot size was 6 m x 8 m. Subsamples were dried at 65°C and weighed for dry matter measurement. Samples of maize stover and grain were also taken, ground to pass 20 mesh sieve for nutrient (N, P, K, Ca and Mg) analysis (IITA, 1983).

Nutrient contents of mulch materials added are shown in Table 6.1. It can be derived from Table 6.1 that the amount of nitrogen added with mulch materials was approximately 90 kg N ha^{-1} for the maize stover and rice straw treatments, 135 kg N ha^{-1} in the *Acioa* treatment and 220 kg N

ha⁻¹ in the *Gliricidia* and *Leucaena* treatments. Detailed chemical compositions of the plant residues were given by Tian et al. (1992).

Soil temperature measurements were made at bi-weekly intervals at 15:00 hours during the period of maize growth in 1990 using a LCD thermo-probe set at 10 cm depth. Bi-weekly surface soil moisture measurements were also carried out using tensiometers installed at 10 cm depth, at the same time as that for soil temperature. To determine the water retention characteristics of the soil, ten soil core samples were taken from the top 10 cm layer of the experimental plot. The water retention characteristic of the soil was determined according to method used by Hillel (1971). The water retention curve fitted the equation: $Y = 59.99X - 0.22$ ($r^2 = 0.95$), in which X stands for soil water retention (mbar), and Y represents soil moisture content (v/v %).

Dynamics of the mineral N (NO_3^- and NH_4^+) concentrations in the soil solution following mulching with plant residues were monitored using a mini-lysimeter system (Plate 6.1). This system consists of a PVC column with a length of 30 cm and a diameter of 20 cm that was inserted to 28 cm depth into the undisturbed soil in the field. A microporous soil solution sampler with an external diameter of 2 mm, length of 18 cm and pore size of 0.2 μm was placed horizontally inside the PVC column just above the bottom. The soil solution sampler was connected with a collecting syringe of 10 ml volume. At bi-weekly intervals soil solution was collected by creating a vacuum inside the syringe before sunset, and soil solution was collected after sunrise the next day. No crop was planted inside the PVC columns. Concentrations of NO_3^- and NH_4^+ in the soil solution were determined by auto-analyzer (IITA, 1981). Using data of mineral N concentrations in the soil solution and rainfall received during the two weeks before sampling the soil solution, the total amount of the mineral N in the soil solution over the cropping season (15 weeks) was estimated using the formula: $Y = k \cdot C \cdot R \cdot S$, where C = mineral N concentration, R = rainfall, S = surface area of PVC column and k = constant.

Tensiometer and soil solution data were collected in 1990 only, because drought periods which occurred during the first five weeks of maize growth severely affected the tensiometer and mini-lysimeter measurements in 1991.

6.3 Results

Temperature

A comparison of data on soil temperature measurements showed mulching of plant residues significantly reduced soil temperature. Average soil temperature during the period of maize growth was lower in the plant residue-mulched plots than in the unmulched plots (Table 6.2). Temperature averages with mulching with *Gliricidia* and *Leucaena* prunings were not significantly different from the control. Mulching with *Acioa* prunings significantly reduced soil temperature as compared to the control. The effects of mulching with maize stover and rice straw were less than with *Acioa* prunings.

The reduction in soil temperature by mulching with plant residues was higher initially and declined with the decomposition of plant residues. To better assess the temporal effect of plant residue mulching, two parameters are used: "Prime Effect" and "Duration of Effect". The "Prime Effect" is the mean of soil temperature reduction over the first month following the application of plant residues. This period is of extreme importance for the development of the crop canopy. The "Duration of Effect" is the time period during which soil temperature reduction exceeds the mean of $LSD_{.05}$ over the entire experimental period. Using this criteria, *Acioa* prunings had the highest "Prime Effect" and the longest "Duration of Effect". *Leucaena* and *Gliricidia* prunings showed lower "Prime Effects" and shorter "Duration of Effect" (Table 6.3).

Moisture

Mean soil moisture content during the period of maize growth was higher with the application of plant residues (Table 6.2). The highest soil moisture content was associated with application of *Acioa* prunings. On average, it was 2.8% higher than in the unmulched plot for the whole season. *Gliricidia* and *Leucaena* prunings did not significantly affect the soil moisture reserve. Rice straw and maize stover followed *Acioa* in influencing soil moisture reserve.

For all of the plant residues, the mulching effect on soil moisture like that on soil temperature was more pronounced initially, and decreased drastically with decomposition of plant residues. Similar to the temperature effect, the "Prime Effect" and "Duration of Effect" on soil moisture were also estimated. The "Prime Effect" of mulching with *Acioa* pruning was on average 2.4 times higher than that of addition of *Gliricidia* and *Leucaena*

prunings. The "Duration of Effect" of *Acioa* prunings was on average 2.6 times longer than that of *Gliricidia* and *Leucaena* prunings (Table 6.3).

Table 6.2 Average soil temperature and moisture content over a period of 14 weeks in 1990 as a function of mulching with plant residues.

Plant materials	Temperature(°C)	Moisture content(% v/v)
Control (unmulched)	28.4	21.2
<i>Acioa</i> prunings	26.9	24.0
<i>Gliricidia</i> prunings	28.2	22.0
<i>Leucaena</i> prunings	28.1	22.1
Maize stover	27.5	22.7
Rice straw	27.5	23.2
LSD _{.05}	0.6	2.1

Soil mineral N

Mineral N in the soil solution was dominated by NO_3^- during the period of maize growth, and NH_4^+ concentration was not significantly different between treatments. Hence total mineral N ($\text{NO}_3^- + \text{NH}_4^+$) concentration in the soil solution is presented (Figure 6.1). Although mineral N in the soil solution changed considerably in the control, ranging from 3.1 to 54.4 $\mu\text{g g}^{-1}$ throughout the experimental period, application of plant residues affected the mineral N concentration. The mineral N concentration was increased by an average of 84% with addition of *Leucaena* pruning and by 73% with addition of *Gliricidia* prunings during the experimental period. With addition of *Acioa* prunings, mineral N concentration was higher than in the control during the first four weeks after application. From 4 to 8 weeks after mulching, the N concentration drastically decreased to a level which was lower than the control, and subsequently increased again to above-control level. Mulching with maize stover and rice straw increased

mineral N in the soil solution during the first two weeks. During the following two weeks, the mineral N concentration rapidly declined to below-control value, and gradually returned to control level thereafter.

Table 6.3 "Prime effect" and "Duration of effect" of mulching on soil temperature and moisture during the cropping season of 1990.

Plant materials	Prime effect	Duration of effect
	Temperature ($^{\circ}\text{C}$)	(days)
<i>Acioa</i> prunings	-2.6	90
<i>Gliricidia</i> prunings	-0.6	20
<i>Leucaena</i> prunings	-0.8	22
Maize stover	-1.7	60
Rice straw	-2.2	38
	Moisture (% v/v)	(days)
<i>Acioa</i> prunings	5.5	63
<i>Gliricidia</i> prunings	2.1	21
<i>Leucaena</i> prunings	2.5	28
Maize stover	3.6	37
Rice straw	4.9	38

The calculated total amount of mineral N was higher in the plots mulched with *Leucaena*, *Gliricidia* and *Acioa* prunings than in the control (Table 6.4). *Leucaena* prunings were estimated to increase the total soil mineral N by 84%, *Gliricidia* by 72% and *Acioa* by 39% during the cropping season. The effects of maize stover and rice straw were not significantly different from the control.

Maize dry matter

Weight of total maize dry matter in all treatments increased gradually until

5 WAP, and rapidly after that time till 10 WAP in 1990 and 15 WAP in 1991 (Figure 6.2). Maize dry matter production responded to application of fertilizer N both in 1990 and 1991. There was no significant fertilizer N response with application over 90 kg N ha⁻¹.

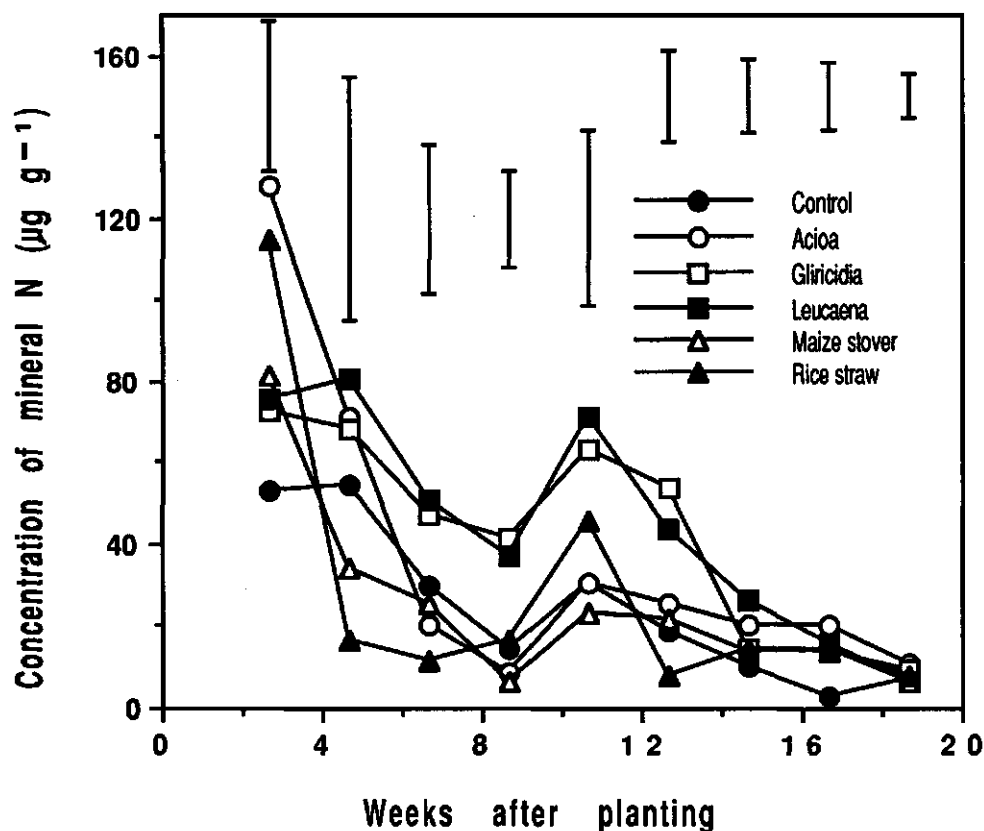


Fig. 6.1 Concentration dynamics of mineral N ($\text{NO}_3^- + \text{NH}_4^+$) in the soil solution through the experimental period, as affected by application of various plant residues (All treatments received 45 kg N ha⁻¹). Bar represents $\text{LSD}_{.05}$.

The effects of applications of plant residues on maize dry matter production was significant in both years. In 1990, the highest effect was observed in the plot mulched with *Leucaena* prunings, followed by *Gliricidia* and *Acioa* prunings. The treatments with addition of maize stover or rice straw, supplemented with 45 kg N ha⁻¹ produced about as

much dry matter yield as that with application of 90 kg N ha⁻¹.

Table 6.4 Cumulative amount of the mineral N (NO₃⁻ + NH₄⁺) in the soil solution over the 1990 maize growth season (15 weeks) as affected by application of plant residues

Plant materials	(kg N ha ⁻¹)
Control (unmulched)	122.0
<i>Acioa</i> prunings	169.8
<i>Gliricidia</i> prunings	209.8
<i>Leucaena</i> prunings	225.1
Maize stover	112.1
Rice straw	94.4
LSD _{.05}	46.8

In 1991, lower dry matter yield was observed mainly due to the drought occurring during the first five weeks of maize growth. Overall, however, dry matter yield increased with application of plant residues and was slightly higher in 1991 (43.1%) than in 1990 (37.4%), mainly due to the mulching effect on the microclimate by *Acioa* prunings in 1991. Unlike the prunings from the three woody species, maize stover and rice straw did not significantly increase maize dry matter weight.

Grain yield

There was a decline in maize grain yield in 1991 compared to 1990 (Figure 6.3). Fertilizer N and mulching increased maize grain yield in both years, however, compared to control. Significant yield increases were only observed with *Acioa*, *Gliricidia* and *Leucaena* prunings in both years and with maize stover mulch in 1990. The effect of mulching on grain yield was more pronounced in 1991 than in 1990. There were also differences due to the plant residue treatments on maize grain yield. Highest grain yields, observed with the *Leucaena* prunings in combination with 45 kg

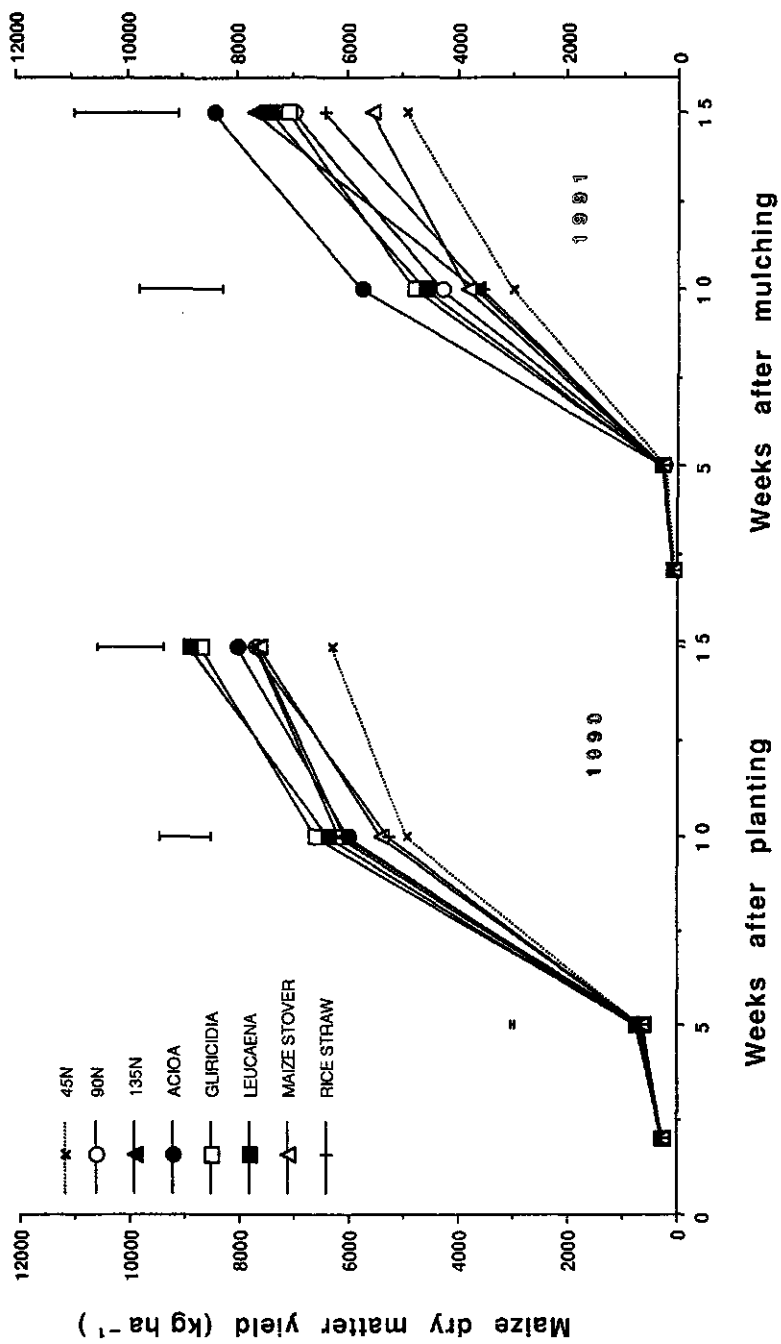


Fig. 6.2 Maize dry matter weight in 1990 and 1991 as affected by application of various plant residues and N fertilizer rates. Bars represent LSD₀₅. (Mulched plots received 45 kg N ha⁻¹).

ha^{-1} , were 1284 and 1655 kg ha^{-1} higher than the control treatments in 1990 and 1991, respectively. There were no significant effects of rice straw on grain yield. Treatments mulched with *Acioa* prunings in combination with 45 kg N ha^{-1} showed the least decrease in maize grain yield in 1991 as compared to 1990. Increased nitrogen application gave higher maize grain yield, but the effect was significant only up to a rate of 90 kg N ha^{-1} .

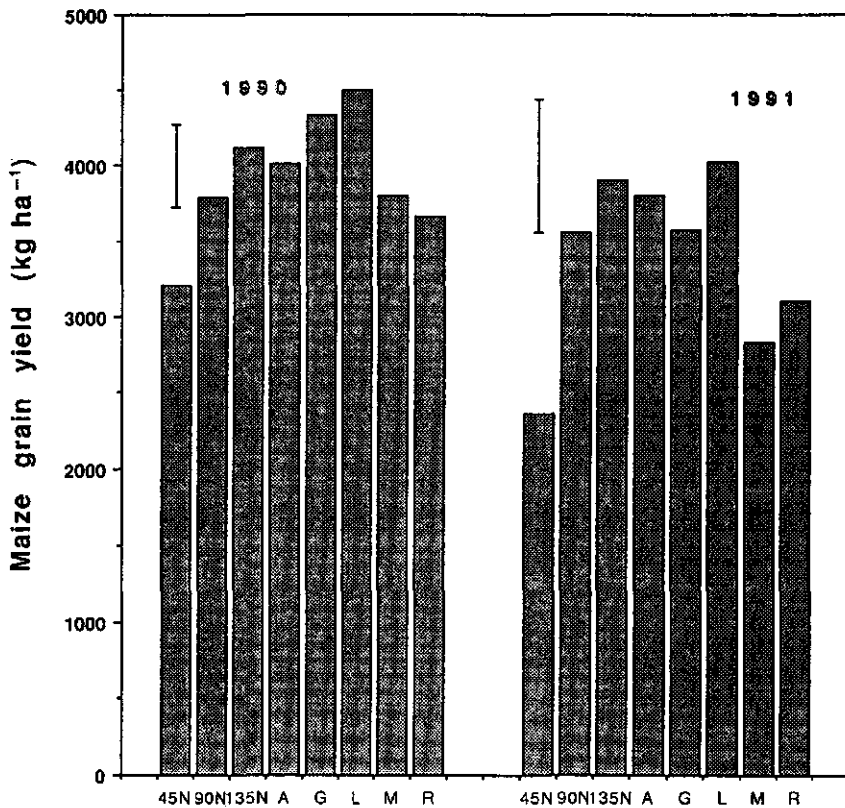


Fig. 6.3 Maize grain yield in 1990 and 1991 as affected by application of various plant residues and N fertilizer rates. Bars represent $\text{LSD}_{0.05}$ (mulched plots received 45 kg N ha^{-1}).

Nutrient uptake

Nitrogen uptake by maize was improved by applications of N and various

plant residues. Nitrogen uptake responded to N fertilizer rates up to 90 kg N ha⁻¹. Maize plants mulched with *Leucaena* prunings, supplemented with 45 kg N ha⁻¹ absorbed the highest amount of N, which was 73.8% and 118.6% higher in 1990 and 1991 respectively, than those with only the 45 kg mineral N ha⁻¹. Applications of prunings of all woody species had higher effects on N uptake than those of crop residues (Table 6.5).

Table 6.5 Effect of application of various plant residues and nitrogen fertilizer rates on nutrient uptake by maize plant (kg ha⁻¹).

Treatments (kg N ha ⁻¹)	N		P		K		Ca		Mg	
	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Control + 45N	61.0	46.7	20.2	15.2	82.2	45.8	10.8	6.9	14.2	7.1
+ 90 N	81.0	75.4	24.5	22.6	109.8	55.9	16.0	10.2	15.9	10.5
+ 135 N	78.2	79.4	20.8	21.0	100.4	64.1	14.9	11.1	16.2	9.1
<i>Acioa</i> + 45N	84.1	91.4	29.0	28.6	115.0	88.8	19.5	14.1	18.6	13.0
<i>Gliricidia</i> + 45N	99.0	76.9	29.0	24.6	116.0	77.0	19.7	13.5	18.6	9.1
<i>Leucaena</i> + 45N	106.6	102.1	34.0	30.5	111.6	72.4	19.4	10.8	20.2	11.8
Maize stover + 45N	80.3	54.8	26.0	19.8	99.8	58.6	14.3	7.7	16.0	7.1
Rice straw + 45N	75.5	63.4	25.4	21.5	113.8	70.6	16.2	10.9	16.2	8.4
LSD (.05)	19.2	18.6	4.6	6.3	19.9	19.7	3.0	3.3	2.6	2.6

The responses of P uptake by maize to application of plant residues and N fertilizer were very similar to those of N uptake. Addition of crop residues had a higher effect on P uptake than on N uptake by maize (Table 6.5).

It appears that N fertilizer application does not significantly improve K uptake, unlike plant residues. Compared to the control, treatments with *Acioa*, *Gliricidia* and *Leucaena* prunings, maize stover and rice straw, averaged over 1990 and 1991, increased K uptake by 59%, 51%, 44%, 24% and 43% respectively (Table 6.5).

Calcium uptake by maize was also enhanced by applications of all

plant residues and N fertilizer. Mulching with *Acioa* prunings in combination with 45 kg N ha⁻¹ resulted in the highest Ca uptake, which was on average 92% more than the treatment with only the 45 kg N ha⁻¹ (Table 6.5).

Table 6.6 Apparent efficiency* of utilization of added nutrients from chemical fertilizer and released from plant residues under different mulches

Plant residues	N		P		K		Ca		Mg	
	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
<i>Acioa</i>	1.78	1.93	1.44	1.42	1.64	1.26	0.32	0.23	5.26	3.68
<i>Gliricidia</i>	0.45	0.35	1.11	0.94	0.67	0.44	0.13	0.09	0.85	0.41
<i>Leucaena</i>	0.52	0.50	1.41	1.27	0.63	0.41	0.14	0.08	1.13	0.66
Maize stover	0.95	0.65	0.99	0.76	0.72	0.42	0.17	0.09	1.27	0.56
Rice straw	1.05	0.88	1.15	0.97	0.98	0.61	0.18	0.12	1.30	0.68

* Apparent efficiency = maize nutrient uptake : (nutrient-A + nutrient-B)

Maize nutrient uptake: from Table 5;

Nutrient-A: from inorganic sources in Table 1;

Nutrient-B: released from plant residues (calculated from the results of litterbag trial by Tian et al (1992)).

The effects of additions of plant residues and N fertilizer on Mg uptake were significant, though less pronounced than the effects on the other nutrients. The highest Mg uptake by maize was recorded in the treatment with *Leucaena* prunings in 1990 and *Acioa* prunings in 1991 (Table 6.5).

Apparent utilization efficiency of nutrients from added plant residues was high for *Acioa* prunings and low for the other plant residues. Phosphorus recovery in maize was generally higher than that of the other nutrients (Table 6.6).

Grain protein concentration

Protein concentration of maize grain was calculated using its nitrogen content, assuming protein content is $6.25 \times$ nitrogen content. Results in Table 6.7 show that application of plant residues and N fertilizer increased concentrations of protein in maize grain both in 1990 and 1991. The change in the *Leucaena* mulched plot with addition of 45 kg N ha^{-1} was most conspicuous. Compared to the control, protein concentration in that plot increased by 17% in 1990 and 15% in 1991. *Acioa* and *Gliricidia* prunings with addition of 45 kg N ha^{-1} also achieved higher effects than 135 kg N ha^{-1} . The average effect of maize stover and rice straw in combination with 45 kg N ha^{-1} was approximately equal to 90 kg N ha^{-1} .

Table 6.7 Effect of application of N and plant residues on protein concentration in maize grain

Plant residues	N fertilizer (kg ha^{-1})	Protein concentration (%)		
		1990	1991	Mean
Control (unmulched)	45	9.2	8.9	9.0
	90	9.8	9.5	9.6
	135	9.9	9.6	9.8
<i>Acioa</i> prunings	45	10.1	10.0	10.0
<i>Gliricidia</i> prunings	45	9.7	10.0	9.8
<i>Leucaena</i> prunings	45	10.8	10.2	10.5
Maize stover	45	10.0	8.8	9.4
Rice straw	45	9.9	9.4	9.6
LSD(.05)		1.2	0.9	1.0

6.4 Discussion

Increases in maize biomass, grain yield and nutrient uptake with applications of plant residues, indicate the important role that plant residues

can play in enhancing crop production. This study which included plant residues with a wide range of chemical compositions, provides evidence that additions of organic materials are important for sustaining crop production.

Different mechanisms influence the impact of plant residues on maize yield and N uptake. *Leucaena* and *Gliricidia* prunings contributed significant amount of nutrients through their high nutrient levels (Table 6.1) and fast nutrient release (Tian et al., 1992), although the apparent nutrient utilization efficiencies from these prunings were low (Table 6.6). Nitrogen uptake and grain yield of the crop responded to higher added nitrogen level when partially applied as prunings (Table 6.5, Figure 6.3) than when added as fertilizer N alone. No significant responses above 90 kg ha⁻¹ were observed with only N fertilizer addition.

Acioa prunings added lower amount of nutrients (Table 6.1) and direct nutrient supply was low due to the slow nutrient release from *Acioa* prunings (Tian et al., 1992), apparently, which did not explain the improvement in nutrient uptake with addition of *Acioa* mulch. This can be explained from their indirect mulching effect. Table 6.3 shows, that *Acioa* prunings had the highest "Prime effect" and the longest "Duration of effect" on both surface soil temperature and moisture level. Mulching may have the following two agronomic effects in improving crop production: (1) Mulch induced-lower temperature and -higher moisture increase root density (Lal, 1978; Maurya and Lal, 1981) and enhance the lateral spread of roots and abundance under the mulch (Allmaras and Nelson, 1971; Chaudhary and Prihar, 1974), which may result in high utilization efficiency of nutrients from the surface soil (Russell, 1977) and, (2) Mulching with slow decomposing materials such as *Acioa* prunings may have significant indirect supply of the mineral N. As shown in Table 6.4 mineral N in the soil solution in the plot mulched with *Acioa* was significantly higher than that in the control. The high amount of N in the soil solution presumably resulted from higher rate of decomposition of soil organic matter, enhanced by an improved microclimate induced by the mulching. This phenomenon probably resulted in the high apparent nutrient utilization efficiencies with *Acioa* mulch (> 1.0) (Table 6.6).

The experiment was carried out in plots which had been under grass fallow for six years, during which time organic matter would have accumulated. Mulching effects on microclimate could favour the decomposition of the readily decomposable part of the accumulated organic matter, resulting in high N concentrations in the soil solution. In continuous

cropping system, this effect may become less obvious over time. However, the mulching effect on root development still will enhance the use of soil nutrients and water.

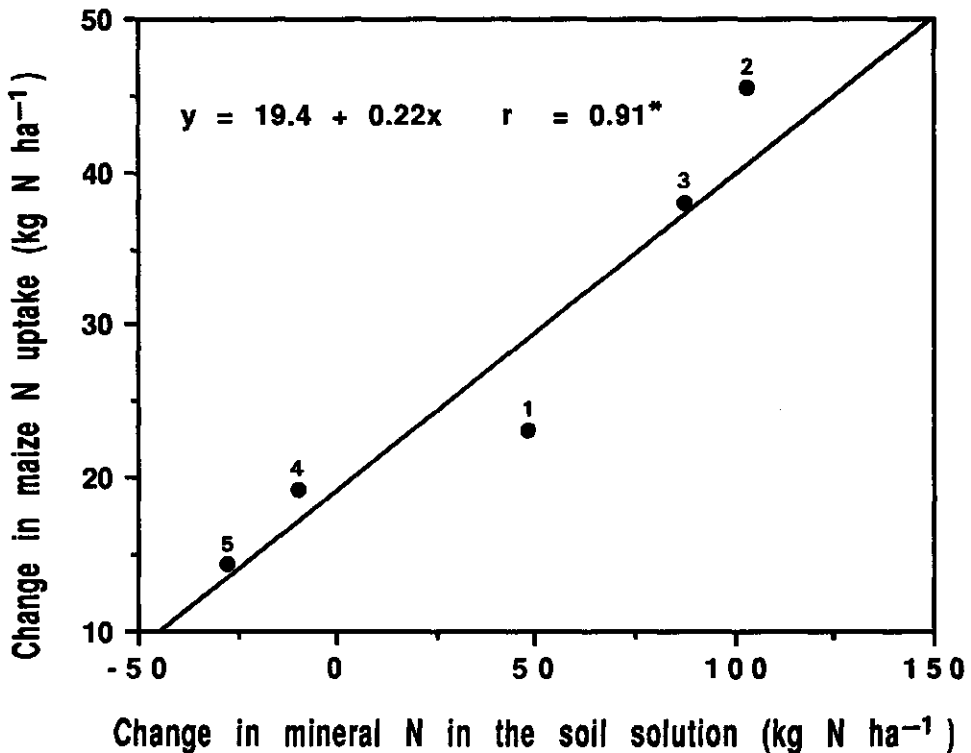


Fig. 6.4 Relationship between changes in maize N uptake (calculated from Table 6.5) and cumulative mineral N in the soil solution (calculated from Table 6.4), both due to application of plant residues in 1990 (1. *Acioa*, 2. *Gliricidia*, 3. *Leucaena*, 4. maize stover and 5. rice straw).

Compared to prunings of woody species, maize stover and rice straw seem to have less impact on maize performance. This is attributed to their strong N immobilization (Tian et al., 1992) and intermediate mulching effects on microclimate (Table 6.2 and 6.3). If plant residues like *Leucaena* and *Gliricidia* prunings, low in C/N ratio lignin content or polyphenol level are considered to have "high quality", and those like *Acioa* prunings, high in C/N ratio, lignin content or polyphenol level to have "low quality", it

appears that applications of plant residues with "high or low quality" will have significant effects on crop performance due to their direct and indirect effects, respectively. Plant residues with "intermediate quality", such as maize stover and rice straw have less clear effects on crop performance, due to their poor direct and indirect effects.

As shown in figure 6.4, with application of plant residues, change in the N recovery in the maize is correlated with change in the mineral N amount in the soil solution. This indicates that determination of N levels in the soil solution even in the absence of the plant can be used as a useful tool for evaluating the possible N contribution of plant residues.

6.5 Conclusions

Introduction of plant residues in tropical farming is a promising management of soil for improvement of crop production. The chemical compositions of plant residues markedly influence their effects on crop performance. Plant residues with extremely "high or low quality" will have higher effects on crop performance, but through different mechanisms. Efficiency of nutrient utilization from the applied plant residues is high for the "low quality" materials and low for the "high quality" materials. Determination of N in the soil solution in the absence of plants will be a useful tool to predict the N contribution of plant residues and N uptake by crop.

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7. General discussion and concluding remarks

Results presented in chapters 2 and 3 confirm that the chemical compositions of substrates affect decomposition and nutrient release. The study adds new information on integrated effects of chemical components (nutrients, recalcitrant components such as lignin and repellent components such as polyphenols) on decomposition. The regression models developed in chapter 3 can be used for the prediction of decomposition and nutrient release from selected agroforestry species and crop residues, but further research is needed to validate the models in other ecological zones.

The source from which plant material of the same agroforestry species was obtained considerably affected its chemical composition. Inclusion of small twigs and leaves resulted in higher contents of lignin and cellulose (chapter 3), compared to the leaves only (chapter 2). However, the differences in chemical compositions between species remained in the same order.

C/N ratio and contents of lignin and polyphenols were correlated with decomposition under laboratory, growth chamber and field conditions, indicating their importance for decomposition and nutrient release. The decomposition and nutrient release models developed from laboratory and field trial data, showed the highest effect of C/N ratio to the decomposition pattern (chapters 2 and 3). Approximate decomposition characteristics can thus be identified through analysis of C/N ratios in plant residues.

The influence of polyphenols was different under laboratory and field conditions. Polyphenols had more influence on decomposition rate constants in laboratory than field experiments. This is presumably due to the rapid leaching of soluble polyphenols under field conditions and stimulation of decomposition and N release by the soil fauna under field conditions.

Nitrogen release rate was lower in the laboratory trial (chapter 2) than in the field experiment (chapter 3). This may well be associated with the lack of leaching of polyphenols and the absence of soil fauna during the laboratory experiment. Laboratory trials on decomposition may therefore underestimate the rate of nutrient release.

In the presence of soil fauna, decomposition of plant residues and

nutrient release were enhanced. The increase in decomposition rate by soil faunal activity may be mainly through their effect on the microbial degradation of plant residues rather than through comminution (chapter 5).

The correlation of fauna-enhanced degradation with chemical compositions of plant residues is the result of influence of chemical compositions on palatability for the fauna. Millipedes had a strong effect on the degradation of "low quality" substrates, whereas low lignin content favoured the consumption of substrates by earthworms (chapter 5). The interplay between substrate quality and contributions of termites and ants to degradation of substrates was not analysed, as these animals were too difficult to deal with experimentally.

The contributions of decomposing plant residues to improving and sustaining of crop production and faunal activity are not only connected with their nutrient contents but also with mulching effects on the microclimate. "High quality" plant residues such as *Leucaena* and *Gliricidia* prunings mainly enhance crop performance (chapter 6) and populations of earthworms and ants (chapter 4) through direct nutritional effects, whereas "low quality" plant residues such as *Acioa* prunings mainly enhance crop production (chapter 6) and populations of termites (chapter 4) through mulching effects on the microclimate and, probably, the associated enhanced decomposition of soil organic matter (chapter 6). Mulching-induced microclimate enhanced the contributions of earthworms and millipedes to the degradation of plant residues.

One of the most important questions in the use of plant residues for improving and sustaining of crop productivity is what species should be introduced. By investigating the effects of plant residues with different chemical compositions an attempt was made to answer this question.

Although the regression models in chapter 3 can predict decomposition and nutrient release rates, they may not work out well for the estimation of nutrient uptake by a crop, as these models do not consider nutrient transformations such as volatilization and denitrification or the impact of mulching-induced microclimate on element transformations. This is exemplified by the study of N uptake by maize (chapter 6), which showed that "high quality" materials and "low quality" materials contributed more to maize production than "intermediate quality" materials. For "high quality" mulches, a large amount of N can be lost from the surface due to their fast decomposition, whereas a strong mulching effect on the microclimate of "low quality" mulches can enhance N mineralization from the soil organic matter. Since the regression models do

not account for such effects, using the models would result in overestimation of the N contribution from "high quality" plant residues and underestimation of the N contribution from "low quality" plant residues to crop uptake. Determination of the N level in the soil solution was shown to be a better tool for evaluating the possible N contribution of plant residues, as N uptake of maize is correlated with the inorganic N in the soil solution (chapter 6).

It can be concluded that a keen choice of plant residues in terms of nutritional effects and mulching-induced effects on soil microclimate is a prerequisite for the application of fauna-mediated decomposition towards synchronization of soil nutrient supply and crop nutrient demand.

Further studies should consider the effects of plant residues on soil organic matter pools and their contributions to physical soil properties.

Simulation modelling of the interplay between plant residue quality, soil fauna, decomposition, nutrient release, crop nutrient uptake and mulching-induced microclimate, as established in this thesis, would seem to be a useful next step in rendering the results applicable in recommendations for the management of tropical crop production systems.

Summary

A study on plant residues with contrasting chemical compositions was conducted under laboratory, growth chamber and humid tropical field conditions to understand the function of the soil fauna in the breakdown of plant residues, the cycling of nutrients, in particular nitrogen, and the performance of maize as a test crop. Leaves from ten agroforestry and fallow plant species with a wide range of chemical compositions (different C/N ratios and contents of lignin and polyphenols) were selected for laboratory incubations. Of the ten species, prunings from *Acioa barteri*, *Gliricidia sepium* and *Leucaena leucocephala*, maize (*Zea mays*) stover and rice (*Oryza sativa*) straw were selected for field and growth chamber experiments.

Laboratory incubation showed that N mineralization was significantly correlated with initial N, polyphenol and lignin content of plant residues. Litterbag studies in the field showed that decomposition was also correlated with the activity of soil fauna. In the field the effect of polyphenols on the degradation of plant residues was less prominent than in the laboratory. In both growth chamber and field trials the breakdown of plant residues and nutrient release were enhanced in the presence of earthworms and millipedes.

Application of plant residues increased populations of earthworms and ants. Stepwise regression illustrated populations of earthworms were negatively correlated with lignin:N ratio; populations of ants were positively correlated with N content of plant residues. Application of high C/N ratio and lignin content plant residues attracted termites. Millipedes were not influenced by the quality of plant residues.

Addition of plant residues as mulch ameliorated the soil microclimate by lowering soil temperature and maintaining soil moisture. A strong mulching effect on the soil microclimate was associated with application of plant residues with high C/N ratio and lignin content.

Increase in the amount of mineral N in the soil solution was recorded with application of plant residues with "high" or "low quality", but probably caused by different mechanisms. The N contribution of "high quality" materials mainly originated from their decomposition, whereas

mulching effects on microclimate, which presumably promoted the degradation of soil organic matter, mainly accounted for the N contribution of "low quality" materials. There is a need to both consider the direct and indirect contributions of plant residues applied as mulch.

Markedly improved crop performance was achieved with the application of plant residues with "high" or "low quality". Materials with "intermediate quality" had no significant impacts.

Results of the study indicate the possibility to influence nutrient cycling by manipulation of soil faunal activity.

It is concluded that a keen choice of plant residues in terms of nutritional effects and mulching-induced effects on soil microclimate is a prerequisite for the application of soil fauna-mediated decomposition towards synchronization of soil nutrient supply and crop nutrient demand.

Samenvatting

Een onderzoek naar plantaardige resten met sterk verschillende chemische samenstelling werd uitgevoerd onder laboratorium- en groeikameromstandigheden en in het veld in de natte tropen teneinde licht te werpen op de functie van de bodemfauna in de afbraak van plantenresten, de kringloop van plantevoedende stoffen, in het bijzonder stikstof, en de ontwikkeling van maïs als toetsgewas. Bladeren van tien soorten planten die als bomen worden aangeplant tussen voedselgewassen of die in de braakfase tussen opeenvolgende gewassen groeien en die sterk in chemische samenstelling verschillen (verschillende C/N-verhouding en gehalte aan lignine en polyfenolen) werden geselecteerd voor incubatie in het laboratorium. Van de tien soorten werd het snoeisel van *Acioa barteri*, *Gliricidia sepium* en *Leucaena leucocephala*, maïsstengels (*Zea mays*) en rijststro (*Oryza sativa*) voor veld- en groeikamerexperimenten geselecteerd.

Incubaties in het laboratorium toonden aan dat de stikstofmineralisatie significant gecorreleerd was met het aanvankelijke stikstofgehalte en het gehalte aan polyfenolen en lignine van de plantenresten. Onderzoek met strooiselzakjes in het veld toonde aan dat de decompositie ook gecorreleerd was met de activiteit van de bodemfauna. In het veld trad het effect van de polyfenolen op de afbraak van plantenresten minder op de voorgrond dan in het laboratorium. Zowel in groeikamer- als in veldexperimenten werd de afbraak van plantenresten en de vrijmaking van nutriënten vergroot in aanwezigheid van regenwormen en miljoenpoten.

Toepassing van plantenresten leidde tot een toename van regenwormen en mieren. Stapsgewijze regressie liet zien dat de regenwormenpopulaties negatief gecorreleerd waren met de lignine:N verhouding van de plantenresten; de mierenpopulaties waren positief gecorreleerd met het stikstofgehalte van de plantenresten. Plantenresten met een hoge C/N-verhouding en een hoog ligninegehalte bleken termieten aan te trekken. Miljoenpoten werden niet beïnvloed door de kwaliteit van de plantenresten.

Toediening van de plantenresten als mulch leidde tot verbetering van het bodemmicroklimaat doordat de bodemtemperatuur werd verlaagd en het bodemvochtgehalte op peil bleef. Een sterk effect van mulchen op het

bodemmicroklimaat ging samen met de toediening van plantenresten met een hoge C/N-verhouding en een hoog ligninegehalte.

Toename van de hoeveelheid minerale stikstof in de bodemoplossing werd vastgesteld na de toediening van plantenresten van "hoge" of "lage" kwaliteit, maar dit werd vermoedelijk veroorzaakt door verschillende mechanismen. De stikstof van materiaal met een "hoge" kwaliteit was hoofdzakelijk afkomstig uit de afbraak van het materiaal zelf, terwijl de stikstof, aangetroffen na toediening van materiaal met een "lage" kwaliteit, hoofdzakelijk tot stand kwam door het effect van mulchen op het microklimaat, waardoor vermoedelijk de afbraak van bodem-organische stof werd bevorderd. Het is noodzakelijk om zowel de directe als de indirecte bijdragen van plantenresten, die worden toegepast als mulch, in beschouwing te nemen.

Door toediening van plantenresten van "hoge" of "lage" kwaliteit werd een duidelijke verbetering in de ontwikkeling van het gewas bewerkstelligd. Materialen met een "gemiddelde" kwaliteit hadden geen significante effecten.

De resultaten van het onderzoek wijzen erop dat het mogelijk is de kringloop van plantevoedende stoffen te beïnvloeden door manipulatie van de bodemfauna.

Geconcludeerd wordt dat een uitgekiende keuze van plantaardige resten ten aanzien van hun plantevoedende effecten en hun met mulchen samenhangende effecten op het bodemmicroklimaat een voorwaarde is voor de toepassing van door de fauna beïnvloede decompositie in de richting van synchronisatie van de levering van nutriënten door de bodem en de behoefte daaraan van het gewas.

Curriculum vitae

Guanglong Tian was born on January 14, 1963 in ShuangLiu, Chengdu, Sichuan province, China. He began his undergraduate study at Sichuan Agricultural University, China in September 1978, receiving his BSc in Soil Science and Agrochemistry in June 1982. He continued his study as graduate student and Research Assistant at the Institute of Soil Science, Chengdu, Academia Sinica in September 1982 and obtained his MSc in Soil Geography in July 1985. Thereafter, he worked as Research Associate until November 1987 and as Research Assistant Professor from December 1987 to November 1988 both at the Institute of Soil Science, Chengdu, Academia Sinica. In December 1988 he joined the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria as Research Fellow and Wageningen Agricultural University as PhD student and Research Fellow.