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

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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.

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 & 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 &

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 & 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 & 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 & Jones 1973). Palm & 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 are 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 effect 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.

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 soil 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 & Ingram 1989). Lignin, cellulose and hemicellulose were determined by the acid detergent fiber method (Goering & 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 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-H_2O 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

Table 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})	
A. barteri[b e]	45.1	1.51	0.99	0.20	0.09	0.77	3.86	28.9	24.5	9.3	−1.8	0.93
L. leucocephala[c e]	45.5	5.87	1.77	0.36	0.20	1.82	4.90	10.3	7.1	5.6	4.2	0.95
G. sepium[c e]	47.3	5.04	1.31	0.34	0.23	2.14	2.12	10.9	8.6	6.8	6.4	0.97
C. siamea[d e]	44.0	2.62	2.76	0.18	0.14	1.11	1.57	18.0	6.5	21.6	2.8	0.65
P. santalinoides[c e]	45.4	3.01	1.39	0.38	0.11	1.23	2.63	20.5	24.1	19.2	0.8	0.56
D. guineense[c e]	43.8	1.80	0.72	0.13	0.14	0.51	4.84	18.9	14.5	15.7	−1.3	0.86
M. pruriens[c f]	45.5	6.05	0.59	0.23	0.40	1.88	4.00	17.3	16.8	4.2	5.4	0.94
C. pubescens[c f]	44.1	5.51	0.77	0.29	0.38	1.89	1.50	40.2	10.1	5.0	5.5	0.91
A. cordifolia[b e]	46.2	2.69	0.50	0.15	0.20	0.88	5.30	14.5	8.7	11.6	0.5	0.59
A. macrophylla[d e]	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: $R^2_{0.05} = 0.44$, $R^2_{0.01} = 0.62$
b: non leguminous species
c: N_2-fixing leguminous species
d: Non N_2-fixing leguminous species
e: woody species
f: herbaceous species

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).

Results and discussion

Chemical composition of fallow species

Table 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 ($<12\%$).

Pattern of nitrogen release of plant residues

Mineral N in the control treatment showed a small and gradual increase, from 11.2 to 36.4 μg 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* (Fig. 1). With addition of *A. barteri* and *D. guineense* leaves, soil mineral N was reduced to a very low level

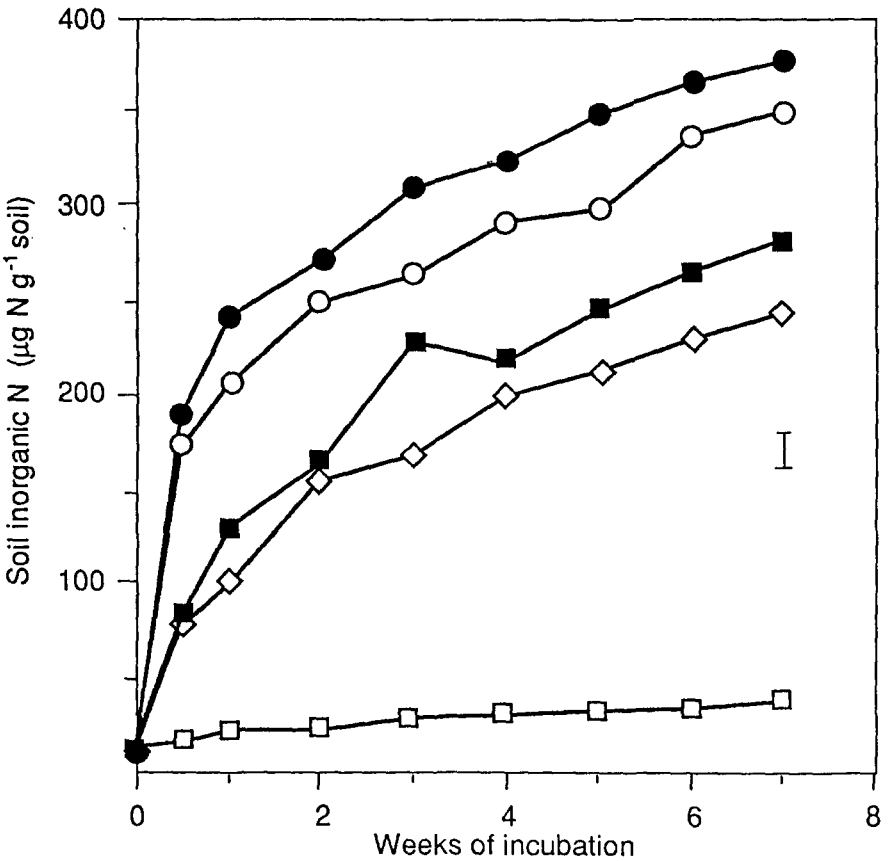

Fig. 1. Changes in soil inorganic N levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *L. leucocephala* (◇), *G. sepium* (○), *M. pruriens* (●), *C. pubescens* (■). Bar represents LSD. 05 at 7 weeks of incubation.

(2.2 μg N g^{-1} soil) (Fig. 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 (Fig. 3).

Net N mineralization after 7 weeks of incubation differed considerably from 3.3 μg N g^{-1} soil in *A. macrophylla* to 365.4 μg N g^{-1} soil in *M. pruriens* (Figs. 1, 2 and 3).

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 (Fig. 4).

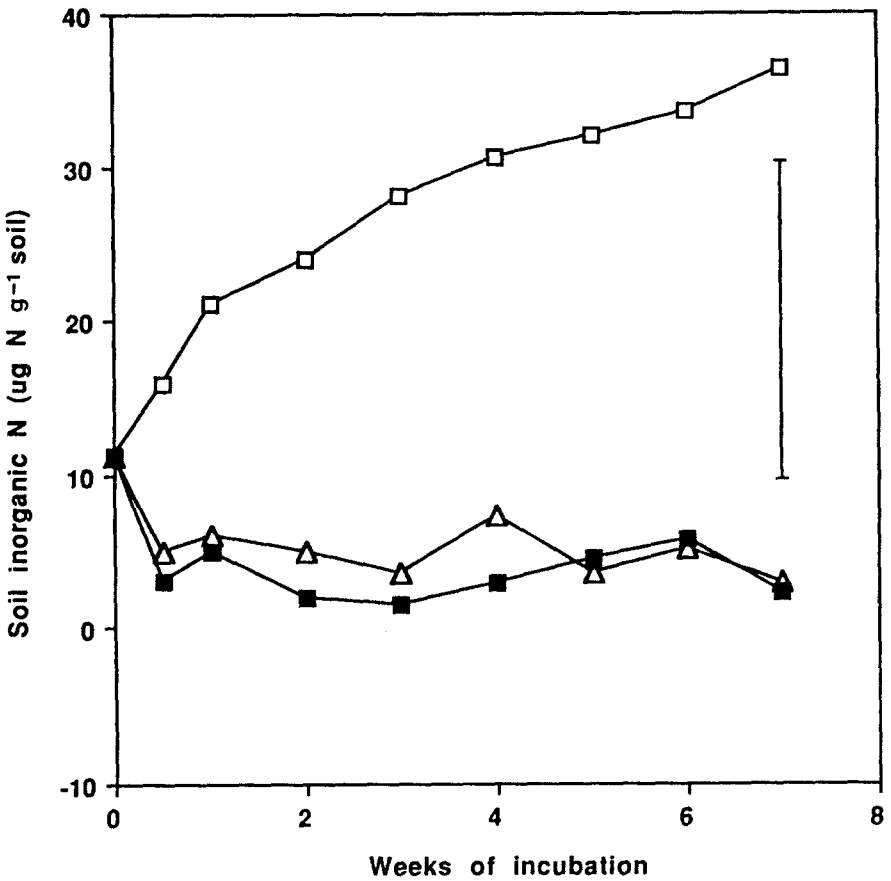

Fig. 2. Changes in soil inorganic N levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *A. barteri* (△), *D. guineense* (■). Bar represents LSD. 05 at 7 weeks of incubation.

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:

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

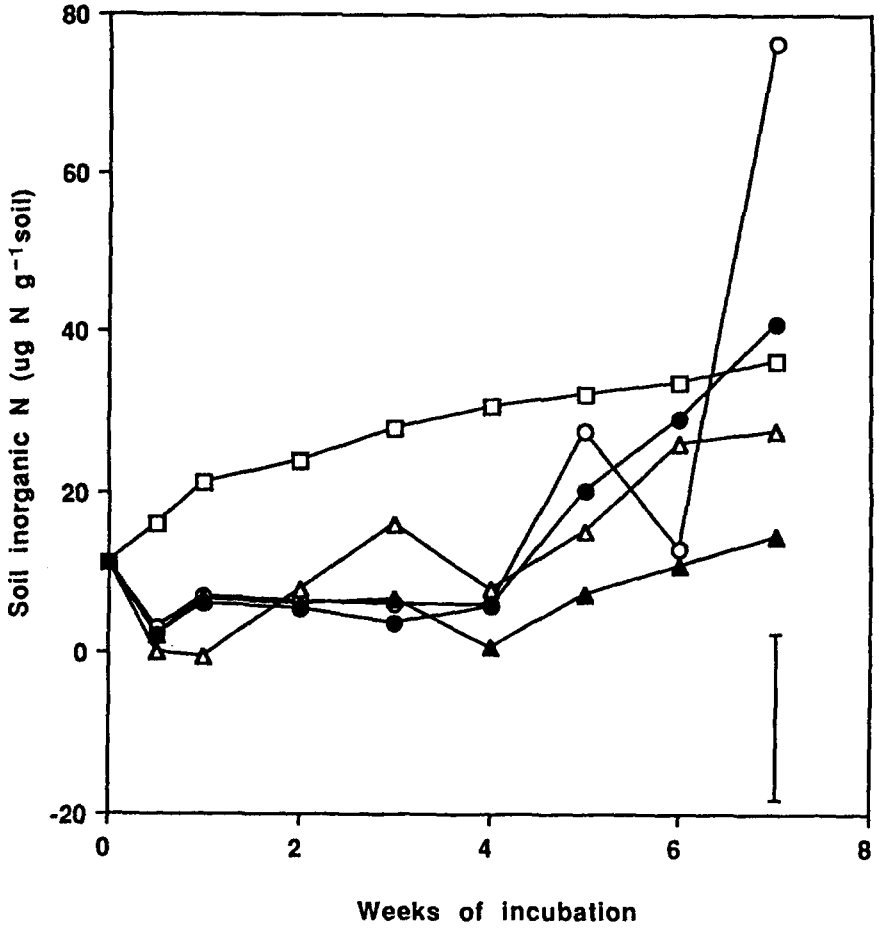

Fig. 3. Changes in soil inorganic N levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *C. siamea* (○), *P. santalinoides* (●), *A. cordifolia* (△), *A. macrophylla* (▲). Bar represents LSD. 05 at 7 weeks of incubation.

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 1 shows the calculated N release rate constants (k) of leaves from the ten fallow species. The N

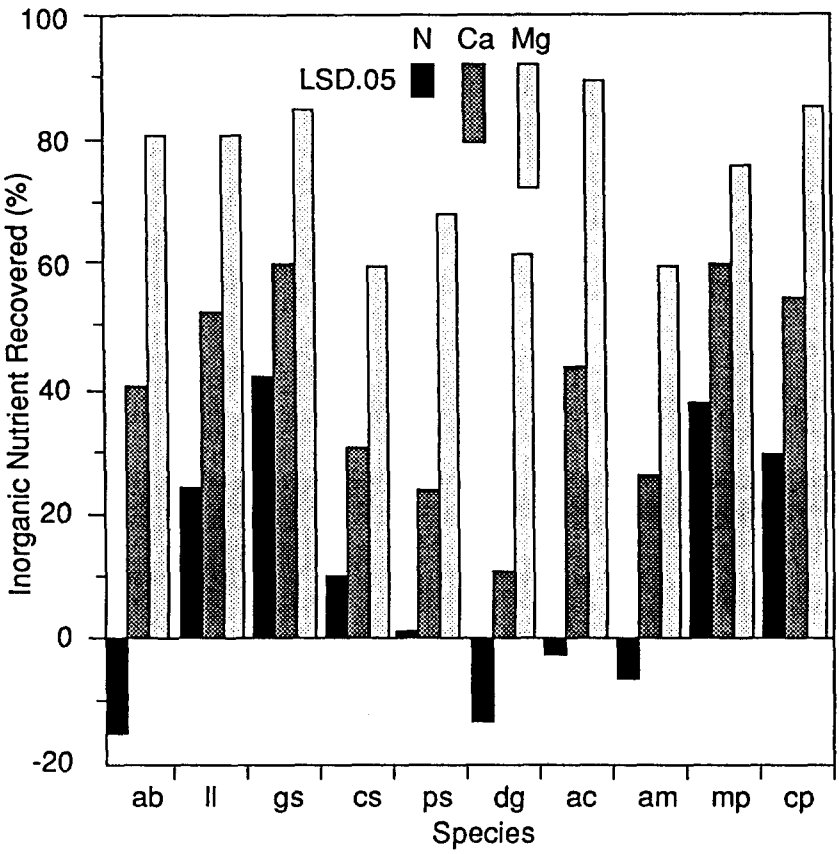

Fig. 4. Percentage nutrient release from leaves of fallow species following 7 weeks of incubation. ab: *A. barteri*, II: *L. leucocephala*, gs: *G. sepium*, cs: *Cassia siamea*, ps: *P. santalinoides*, dg: *D. guineense*, ac: *A. cordifolia*, am: *A. macrophylla*, mp: *M. pruriens*, cp: *C. pubescens*.

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 showed that N, polyphenol and lignin contents of leaves were significantly related to N release rate constants (k). Stepwise analysis (Table 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.

Table 2. Regression coefficient (n = 10) for N release rate constant (k) from leaves of different fallow species (Data from Table 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	−0.000837				0.97

Previous studies have stressed the importance of initial N content on N release (Herman et al. 1977). Frankenberger & 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).

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 mineralized 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.

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 & 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).

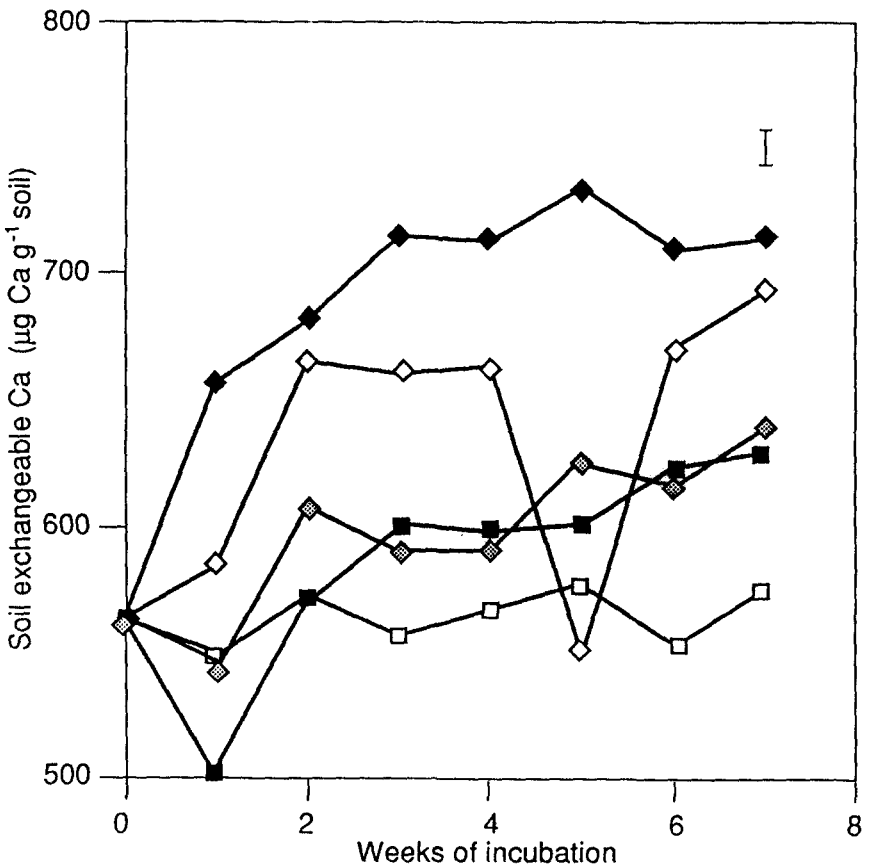

Fig. 5. Changes in soil exchangeable Ca levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *L. leucocephala* (◆), *G. sepium* (◇), *M. pruriens* (■), *C. pubescens* (◈). Bar represents LSD. 05 at 7 weeks of incubation.

Ca and Mg release

Addition of leaves from each of the different fallow species significantly increased the concentration of soil exchangeable Ca (Figs. 5 and 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* (Fig. 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 (Fig. 7).

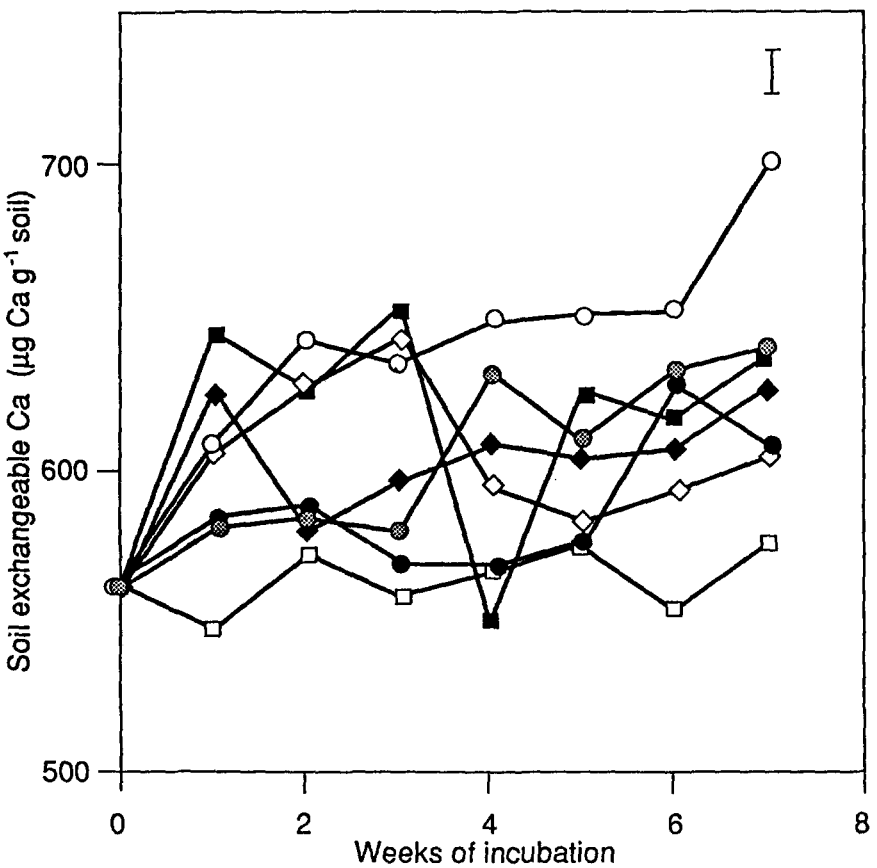

Fig. 6. Changes in soil exchangeable Ca levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (□), *A. barteri* (■), *C. siamea* (○), *P. santalinoides* (◆), *D. guineense* (◇), *A. cordifolia* (●), *A. macrophylla* (◍). Bar represents LSD. 05 at 7 weeks of incubation.

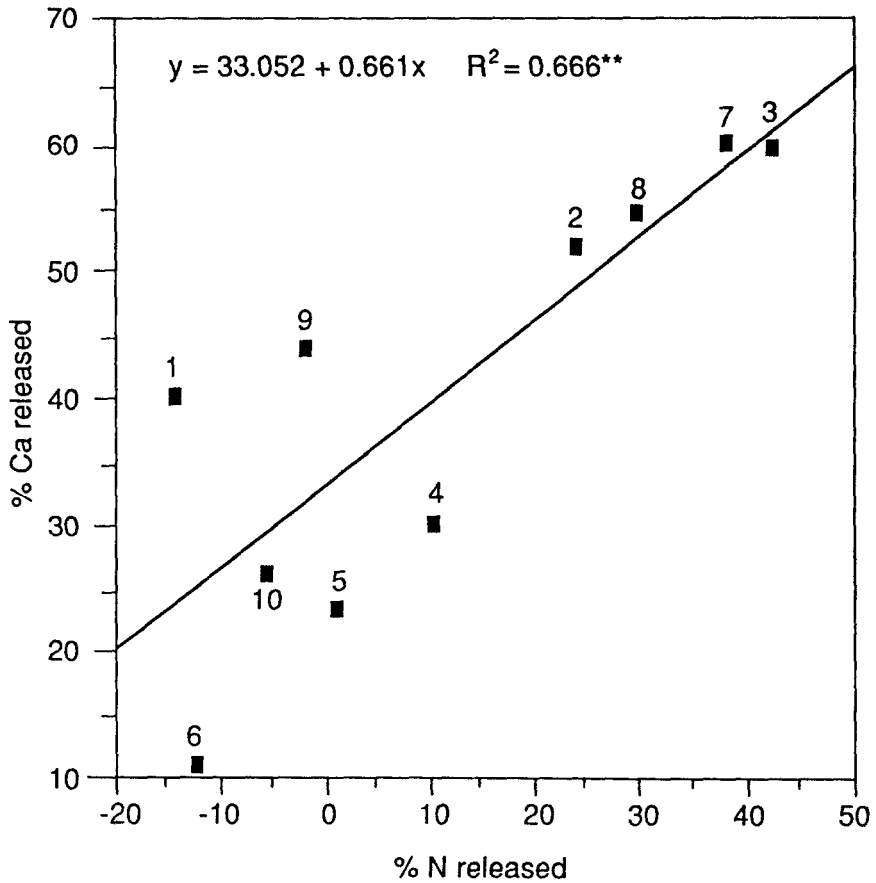

Fig. 7. Relationship between N and Ca releases from leaves of fallow species following 7 weeks of incubation (1: *A. barteri*, 2: *L. leucocephala*, 3: *G. sepium*, 4: *C. siamea*, 5: *P. santalinoides*, 6: *D. guineense*, 7: *M. pruriens*, 8: *C. pubescens*, 9: *A. cordifolia*, 10: *A. macrophylla*).

Addition of leaves from the different fallow species also resulted in increased exchangeable Mg concentration (Figs 8 and 9). Highest Mg release was obtained with addition of *L. leucocephala* and *G. sepium*, and lowest in *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* (Fig. 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

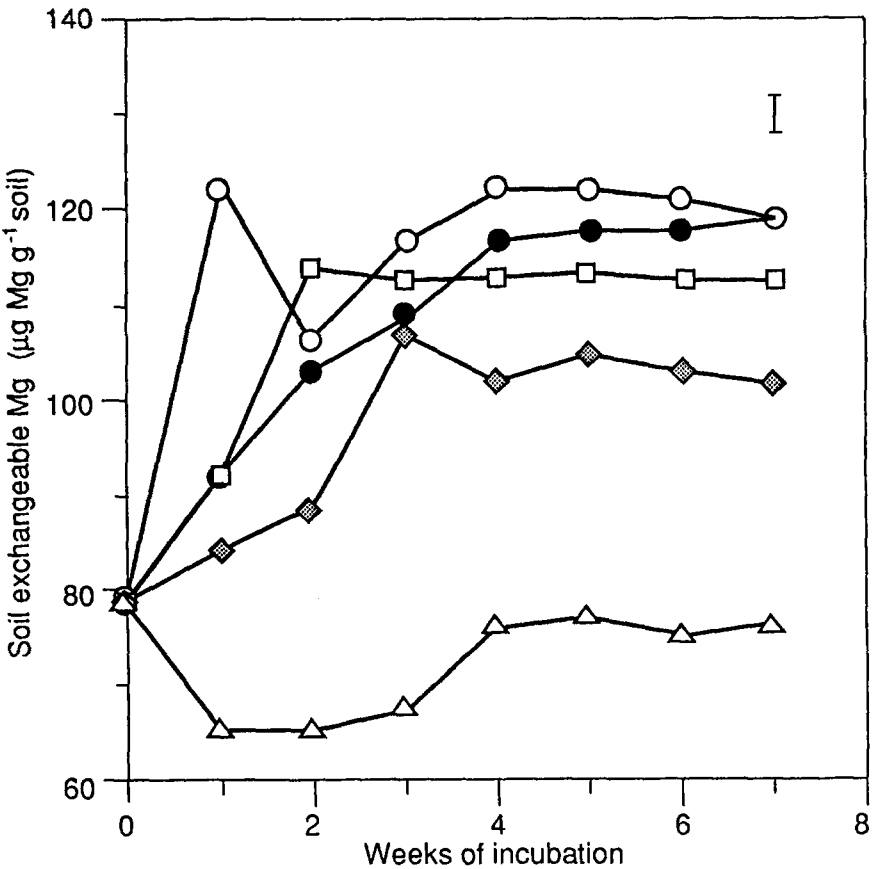

Fig. 8. Changes in soil exchangeable Mg levels during 7 weeks of incubation as affected by addition of leaves of different fallow species. Control (△), *L. leucocephala* (○), *G. sepium* (●), *M. pruriens* (◈), *C. pubescens* (□). Bar represents LSD. 05 at 7 weeks of incubation.

explanation can be given for the lack of relationship between initial Ca and Mg content of leaves and Ca and Mg release rates.

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 & 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.

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

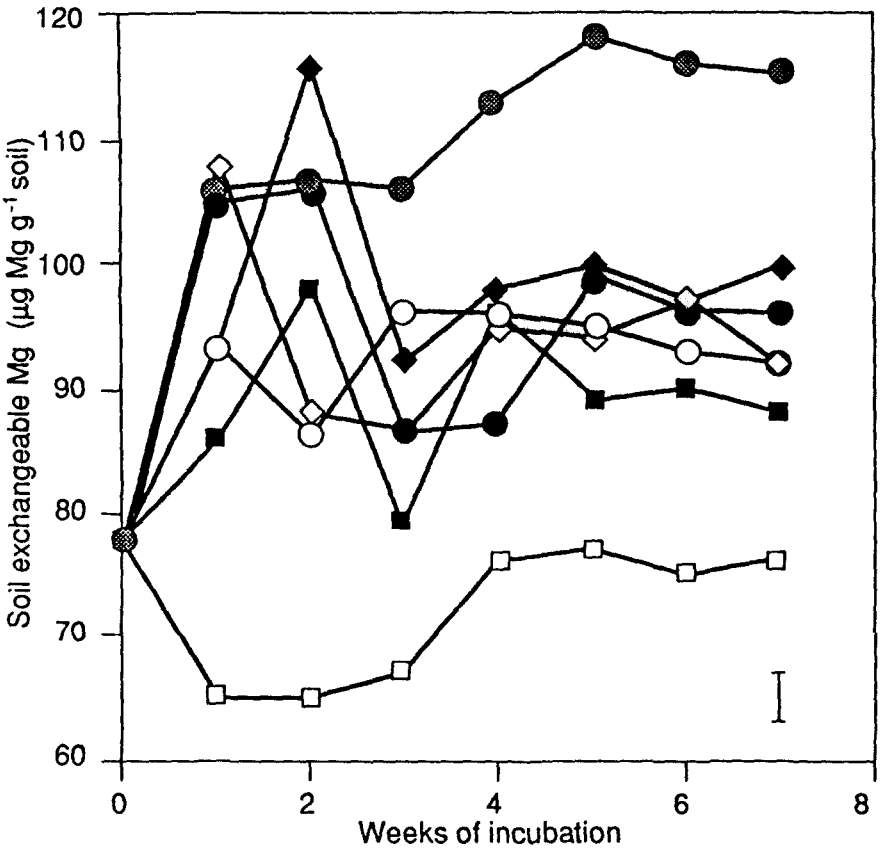

Fig. 9. Changes in soil exchangeable Mg levels during 7 weeks of incubation as affected by addition of different fallow species. Control (□), *A. barteri* (◆), *C. siamea* (○), *P. santalinoides* (◍), *D. guineense* (■), *A. cordifolia* (●), *A. macrophylla* (◇). Bar represents LSD. 05 at 7 weeks of incubation.

release rates (Verhoef & 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).

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 with food crops have been shown (Kang & Wilson 1987). Slower N releasing materials (*A. cordifolia*, *A. macrophylla*, *C. siamea* and *P. santaoloides*) 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.

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