Forage legumes for improved fallows in agropastoral systems of subhumid West Africa. II. Green manure production and decomposition after incorporation into the soil

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Abstract

A short-term improved fallow system based on forage legumes for enhancing crop and livestock components of mixed farming systems was tested in the subhumid zone of West Africa. As part of the evaluation, the ability of 11 legume species (*Centrosema macrocarpum, C. pubescens, Stylosanthes guianensis, Pueraria phaseoloides, Mucuna pruriens, Zornia glabra, Dioclea guianensis, Arachis pintoi, Aeschynomene histrix, Calopogonium caeruleum, Flemingia macrophylla*) to accumulate biomass and nitrogen after dry season harvest of herbage was assessed at 2 sites in south-west Nigeria. Litter bags were subsequently used to study the potential nutrient contribution to maize from decomposing green manure for 6 of the 11 species in comparison with natural fallow vegetation.

Accumulation of green manure biomass and nitrogen was related to the regeneration potential of the legumes in the absence of rainfall and their apparent ability to fix atmospheric nitrogen. Following 4-month regrowth after a dry season harvest, *F. macrophylla* yielded the highest amounts of green manure dry matter (4.0–5.7 t/ha) and nitrogen (102–144 kg/ha N) at the 2 sites, followed by *P. phaseoloides, C. pubescens* and the other species. Decomposition of green manure was governed by initial concentrations of cellulose, hemicellulose, lignin, lignin:nitrogen ratio and amounts of green manure incorporated, with nitrogen disappearing more slowly than dry matter. Highest loss rates were observed for potassium followed by phosphorus and nitrogen. Half-life values for undecomposed residue dry matter were in the range of 2–8 weeks. Nitrogen release after 3 months ranged between 26–88 kg/ha N and 19–52 kg/ha N at the 2 sites. The tested green manures can contribute significantly to subsequent crops as well as to the mineralisable nitrogen pool of the soil. Rapid decay rates of dry matter and nutrients indicate the need to synchronise nutrient release from green manure residues with crop requirements.

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Introduction

For improved fallow management to be adopted by crop-livestock farmers, the practice must enhance both dry season feed supply and soil fertility for subsequent cropping. Testing of suitable legumes for both cattle rearing and cropping purposes has been attempted in few cases, *e.g.* in Thailand (Gibson 1987), Sri Lanka (Sangakkara 1989) and Syria (Thomson *et al.* 1992). In subhumid West Africa, where Tarawali and Peters (1996) measured effects of fodder bank pastures on subsequent crops, strategic research on improved fallow or ley systems for crop-livestock systems started only recently. In a short-term improved fallow system, a range of forage legumes was tested in rotation with maize at 2 sites in the derived savanna of subhumid south-west Nigeria (Muhr *et al.* 1999). Among the 11 species tested, *Stylosanthes guianensis* and *Aeschynomene histrix* were the most promising forage alternatives to native pasture in terms of biomass yield in the year of establishment. However, *Centrosema pubescens* and *Pueraria phaseoloides* were higher in forage quality. In this paper, the potential of the same legume species, after harvesting in the dry season, to contribute nutrients to a subsequent crop was investigated. In particular, the study focused on: i) the green manure production between the dry season harvest and maize sowing; and ii) decomposition and nutrient release of green manure residues after incorporation into the soil immediately prior to sowing maize.

Materials and methods

Sites and experimental design

The experiments were carried out at 2 sites in the derived savanna of south-west Nigeria: on an Oxic Paleustalf (USDA classification) at Ibadan (7°30′ N, 3°54′ E) and on a farmer's field, a Plinthic Oxic Haplustoll (USDA classification), at Fashola (8°7′ N, 3°20′ E). Overall soil fertility was higher at the first site with total N (0.12%) and organic carbon (1.4%) concentrations about double those at Fashola (Muhr *et al.* 1999). Annual rainfall is 1200 mm with a distinct dry season from November to March.

After the onset of the rains in May 1994, 11 herbaceous (*Centrosema macrocarpum* CIAT 5713, *C. pubescens* ILRI 512 [CIAT 5126], *Stylosanthes guianensis* ILRI 164 [CIAT 184 cv. Pucallpa], *Pueraria phaseoloides*, *Mucuna pruriens* [both locally used varieties], *Desmodium ovalifolium* CIAT 13089, *Zornia glabra* CIAT 8279, *Dioclea guianensis* CIAT 7801, *Arachis pintoi* CIAT 17434 [cv. Amarillo], *Aeschynomene histrix* CIAT 9690 [ILRI 12463], *Calopogonium caeruleum* CIAT 8123) and 2 shrubby (*Flemingia macrophylla* CIAT 17403, *Cratylia argentea* CIAT 18516) legumes were established alongside a natural fallow control on 4 × 5 m plots. The experimental design was a randomised complete block design with 4 replications. Since *D. ovalifolium* and *C. argentea* needed to be resown completely, they had less time to establish than the other species. Results for these species were therefore not considered further in this study. Site conditions and methods of establishment were described in more detail by Muhr *et al.* (1999).

Pre-incorporation sampling

Extent of nodulation was determined from 4 plants per legume treatment 10 weeks after sowing by excavating an area of 25 × 25 cm around each plant to a depth of 20 cm. Nodule size (small, medium, large) and activity (based on the colour [grey, red-grey, red] of nodule contents) were classified according to Sarrantonio (1991). All herbage was cut at 5 cm above the soil surface (at 50 cm stem height for shrubs) and removed from the plots in the mid dry season (January) 1995 (Muhr *et al.* 1999). Once the rains had stabilised at the end of May, green manure biomass (sown legumes and associated vegetation) accumulated between dry season harvest and maize sowing (May) was measured by cutting two 1 m^2 quadrats per plot 5 cm above the soil surface (at 50 cm stem height for shrubs). Green manure was then incorporated into the soil by rotor-tiller at Ibadan and traditional hoe at Fashola (depth of tillage: 20 cm). Subsamples of green manure were analysed for dry matter (DM) and initial chemical composition (methods below).

Green manure decomposition

Of 13 legume species established in the field trials, 6 species (see Table 1) and the natural fallow vegetation as a control were selected for a litter bag study, which was similar to that used by Tian *et al.* (1992). Air-dried green manure samples at quantities corresponding with the actual biomass yields were cut into 10 cm pieces and buried in nylon litter bags of 30 × 30 cm and 2 mm mesh size at 10 cm soil depth. In order to avoid compaction of green manure residues inside the bags, a wooden cross was inserted. Six litter bags were buried on each plot and recovered in sequence after 13, 22, 30, 42, 61 and 95 days at Ibadan and 8, 15, 22, 34, 55 and 90 days at Fashola. Owing to the small amount of biomass available from *A. histrix* at Fashola, the quantity in litter bags had to be doubled in order to reduce errors during sample processing. As a consequence, only 3 litter bags (sampling dates: 8, 15 and 34 days) could be filled for this species at Fashola. Undecomposed residues were cleaned of adhering soil by brief flotation in water and the remaining litter decanted through a 2 mm sieve. After DM determination, subsamples were analysed for macronutrients and ash-free dry matter as specified below.

Plant analyses

Dry matter concentration in plant samples was determined by drying at 60°C for 48 h. Subsamples

Table 1. Chemical composition of leguminous green manure before incorporation into the soil at Ibadan and Fashola.

Species	N	C	C:N	Lignin	Cellulose	Hemicellulose	Polyphenols
Ibadan	(%)	(%)		(%)	(%)	(%)	(%)
C. macrocarpum	1.4	40.4	28.7	15.4	35.5	11.0	0.88
S. guianensis	2.0	38.7	19.0	14.7	38.3	5.8	0.67
C. pubescens	2.5	40.8	16.1	18.8	34.7	11.9	0.69
A. histrix	2.3	41.5	18.2	16.5	34.6	7.9	1.14
F. macrophylla	2.5	42.7	17.1	23.1	36.6	8.7	0.60
C. caeruleum	2.2	39.6	18.0	12.8	39.7	15.9	0.68
Natural fallow	2.3	38.2	16.6	12.6	36.6	8.9	0.75
Fashola	(%)	(%)		(%)	(%)	(%)	(%)
C. macrocarpum	1.5	40.3	26.3	18.6	37.5	5.8	0.93
S. guianensis	2.0	39.8	19.8	10.8	39.9	12.5	0.69
C. pubescens	2.1	40.4	19.2	12.5	33.2	17.2	0.68
A. histrix	2.3	39.4	16.9	9.0	27.3	11.0	1.09
F. macrophylla	2.5	41.8	16.7	18.7	35.0	12.8	0.60
C. caeruleum	1.9	41.5	21.3	12.7	36.4	15.6	0.66
Natural fallow	1.5	39.4	25.7	11.8	32.8	19.0	0.75

of the dry material were milled through a 1.0 mm mesh for nutrient analyses. One green manure subsample per treatment was analysed for initial concentrations of N, P (phosphorus), K (potassium), C (total carbon), cellulose, hemicellulose, lignin and polyphenols. Subsamples of green manure residues from the 1st, 3rd and 5th sampling dates were analysed for N, P and K. N was analysed by the micro-Kjeldahl method followed by colorimetric determination in a continuous-flow analyser (Technicon). For analysis of P and K, plant samples were wet-digested with a mixture of $HClO_4$-HNO_3. P was then determined colorimetrically by the Vanado-Molybdate method in a continuous-flow analyser (Technicon) and K by flame photometry (IITA 1979). C was analysed according to Amato (1983). Lignin, cellulose and hemicellulose were determined by the acid detergent fibre method (Goering and van Soest 1970) and polyphenols by the Folin-Denis method in hot 50% methanol, thus extracting hydrolysable tannins, condensed tannins and non-tannin polyphenols (Anderson and Ingram 1993).

Since the nutrient concentrations of the 1st, 3rd and 5th sampling dates decreased steadily, the 2nd and 4th dates were not analysed but extrapolated linearly with constancy of nutrient concentrations assumed after the 5th sampling date. Ash-free mass was determined by ashing subsamples for 3 h in a muffle furnace at 550°C.

Statistics

Dry matter decomposition of green manure residues was modelled by a single exponential decay function with a fixed intercept, assuming that at time = 0 all of the initial material was present (Wieder and Lang 1982). Simple linear correlation and multiple regression analyses were calculated for means of decay rates and parameters of chemical composition. Multiple comparisons of means were made according to either Ryan-Einot-Gabriel-Welsch's Multiple F-test ($P<0.05$) or Tukey-Kramer (HSD; $P<0.05$).

Results

Green manure biomass

Six weeks after the onset of the rains (May), highest yields of green manure were obtained for *F. macrophylla* at both sites with *C. macrocarpum*, *C. pubescens*, *P. phaseoloides* and *C. caeruleum* also producing good yields (Figures 1A; 1B). Although *S. guianensis* started to regrow only with onset of the rains, this species showed a remarkable potential to recover within this short period of rainfall. Generally, sown legumes and associated vegetation (herbs, grasses and naturalised legumes) produced higher yields at Ibadan than at Fashola. The fallow vegetation at Ibadan contained a large proportion of naturalised legumes (mostly *Desmodium scorpiurus*), whereas the proportion of grasses was higher at Fashola.

The N accumulated in green manure largely followed the trend of biomass yields and was higher at Ibadan (44–144 kg/ha N) than at Fashola (22–102 kg/ha N; Figures 1C; 1D). When sown legumes produced less green manure

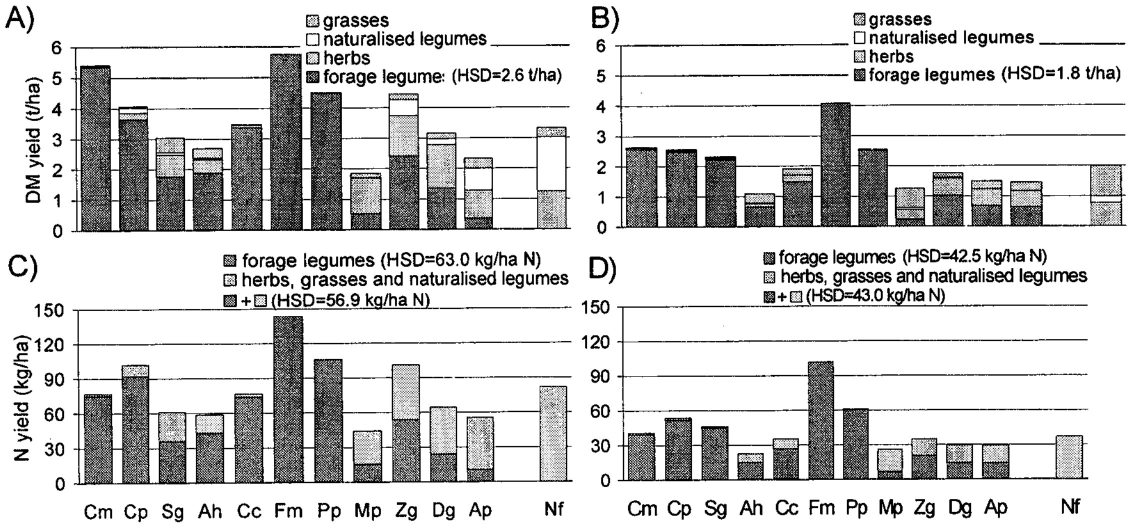

Figure 1. Accumulation of green manure biomass (A, B) and green manure N (C, D) by forage legumes and associated vegetation between dry season harvest and green manure incorporation (4-month regrowth) at Ibadan (A, C) and Fashola (B, D). (HSD according to Tukey at $P<0.05$. Cm = *C. macrocarpum*, Cp = *C. pubescens*, Sg = *S. guianensis*, Ah = *A. histrix*, Cc = *C. caeruleum*, Fm = *F. macrophylla*, Pp = *P. phaseoloides*, Mp = *M. pruriens*, Zg = *Z. glabra*, Dg = *D. guianensis*, Ap = *A. pintoi*, Nf = natural fallow).

bio-mass, the associated vegetation contributed higher amounts of biomass N. Due to the higher proportion of naturalised legumes, N accumulation was considerable (82 kg/ha N) in the natural fallow regrowth at Ibadan.

Chemical composition of green manure residues

N concentrations ranged from 2.0 to 2.5% (of DM) for most legumes, but *C. macrocarpum* did not exceed 1.5% at either site (Table 1). The natural fallow vegetation at Ibadan with its high content of naturalised legumes (cf. Figure 1A) showed a high herbage N concentration. The proportions of structural constituents in the green manure material such as carbon, lignin, cellulose and hemicellulose were similar at both sites with some variation between species especially for lignin and hemicellulose (Table 1). C:N ratios were highest for *C. macrocarpum* at both sites and natural fallow at Fashola. The concentration of polyphenols was low and exceeded 1.0% only for *A. histrix*.

Nodulation potential

All species except *C. macrocarpum* in some replications nodulated with native root nodule bacteria (Table 2). Most species nodulated better at Ibadan, with the exception of *S. guianensis*.

Table 2. Nodulation parameters of selected forage legumes 10 weeks after planting at Ibadan (I) and Fashola (F).

Species	No. of nodules per plant		Nodule size	Plant top (g DM)	
site	I	F	I + F	I	F
F. macrophylla	133 b[1]	47 b	small	1.4 b	3.4 b
C. macrocarpum	8 c	4 b	large	13.0 b	9.1 b
P. phaseoloides	29 c	14 b	large	8.0 b	14.4 b
C. pubescens	23 c	7 b	large	14.0 b	6.8 b
C. caeruleum	135 b	75 b	medium	8.7 b	21.9 ab
Z. glabra	284 a	15 b	small	2.8 b	3.0 b
A. histrix	134 b	6 b	small	10.3 b	9.5 b
S. guianensis	195 ab	437 a	small	5.0 b	12.1 b
D. guianensis	17 c	5 b	medium	1.6 b	2.3 b
M. pruriens	14 c	7 b	multiple	52.3 a	40.2 a
A. pintoi	256 a	86 b	medium	13.0 b	12.7 b

[1] Means within columns followed by the same letter are not significantly different according to Ryan-Einot-Gabriel-Welsch's Multiple F-test ($P<0.05$).

Decomposition and nutrient release

When a single exponential decay function ($y = e^{-kt}$) was fitted to the data for dry matter residues, decay rates (k_{DM}) and half-life values ($t50\%_{DM}$) were shown to differ significantly ($P<0.05$) between treatments (Table 3). Decay rates increased in the order: *F. macrophylla* < *C. pubescens*, *C. caeruleum*, *C. macrocarpum* < *A. histrix*, *S. guianensis* and natural fallow at both sites, and half-life values decreased in the same order.

Table 3. Half-life values ($t50\%_{DM}$) and relative decomposition rates (k_{DM}) of a single exponential decay function ($y = e^{-kt}$) of green manure residue dry matter at Ibadan (I) and Fashola (F), with coefficient of determination (r^2; n = 4).

Species	$t50\%_{DM}$		k_{DM}		r^2	
	I	F	I	F	I	F
	(days)		(per day)			
C. macrocarpum	23.2 b[1]	26.4 b	0.030 b	0.027 b	0.85	0.77
S. guianensis	14.2 c	17.3 c	0.049 c	0.041 d	0.83	0.85
C. pubescens	23.7 b	20.5 bc	0.029 b	0.034 c	0.76	0.49
A. histrix	15.6 c	14.1 c	0.045 c	0.049 e	0.92	0.72
F. macrophylla	33.4 a	55.6 a	0.021 a	0.013 a	0.85	0.71
C. caeruleum	23.4 b	21.8 bc	0.030 b	0.032 bc	0.75	0.72
natural fallow	14.1 c	20.3 bc	0.049 c	0.034 cd	0.86	0.84

[1] Means within columns followed by the same letter are not significantly different according to Ryan-Einot-Gabriel-Welsch's Multiple F-test ($P<0.05$).

N retention (k_N and $t50\%_N$) in *F. macrophylla* and *Centrosema* spp. was greater than in the remaining species at both sites (Table 4). Disappearance of N (k_N) was slower than that for dry matter except for *A. histrix* and natural fallow at Ibadan, and for *A. histrix* and *C. caeruleum* at Fashola.

Table 4. Half-life values ($t50\%_N$) and relative decomposition rates (k_N) of a single exponential decay function ($y = e^{-kt}$) of green manure residue nitrogen at Ibadan (I) and Fashola (F), with coefficient of determination (r^2; n = 4).

Species	$t50\%_N$		k_N		r^2	
	I	F	I	F	I	F
	(days)		(per day)			
C. macrocarpum	44.5 a[1]	31.9 b	0.016 a	0.022 ab	0.91	0.30
S. guianensis	15.6 d	19.2 d	0.045 b	0.037 bc	0.91	0.73
C. pubescens	33.6 bc	28.4 bc	0.021 a	0.025 abc	0.42	nc
A. histrix	14.3 d	8.3 e	0.049 b	0.085 d	0.75	nc
F. macrophylla	40.9 ab	66.7 a	0.017 a	0.010 a	0.93	nc
C. caeruleum	25.8 c	18.7 d	0.027 a	0.037 c	0.57	0.16
natural fallow	12.4 d	22.8 cd	0.057 b	0.031 bc	0.65	0.66

[1] Means within columns followed by the same letter are not significantly different according to Ryan-Einot-Gabriel-Welsch's Multiple F-test at ($P<0.05$); nc = not computable, indicating poor fit of the model.

Disappearance of residue P and K was clearly faster than that of N, with up to 55% gone after about 15 days at both sites (Figure 2). At Fashola, *F. macrophylla* and *C. macrocarpum* had a short phase of P immobilisation between 8 and 22 days. The same species retained significantly ($P<0.05$) more K than the other species at the first two sampling dates at Ibadan.

Effects of initial chemical composition on relative decomposition rates of residual dry matter (k_{DM}) and N (k_N) were significant ($P<0.05$) for C and lignin (k_{DM}) and lignin and lignin:N ratio (k_N) when single linear relationships were assumed (Table 5). Both rate constants were also related to the initial amounts in the litter bags (DM_i) with smaller initial dry weights decaying faster. Using multiple regression analysis, DM_i plus lignin and hemicellulose concentrations could significantly explain k_{DM} ($r^2 = 0.86$; Table 6), whereas DM_i, lignin:N ratio plus hemicellulose and cellulose concentrations could be used to predict N disappearance ($r^2 = 0.89$).

Table 6. Multiple regression of decomposition rates for dry matter (k_{DM}) and nitrogen (k_N) against initial amount of dry matter (DM_i), lignin concentration, lignin:N ratio, cellulose and hemicellulose concentrations of legume green manure at two sites before incorporation into the soil (n = 14), with coefficient of determination (r^2).

	k_{DM} ($r^2 = 0.86$)		k_N ($r^2 = 0.89$)	
	Regression coefficient	Probability >F	Regression coefficient	Probability >F
DM_i	−0.0005	0.0325	−0.0009	0.0080
% lignin	−0.0017	0.0159	—	—
Lignin:N	—	—	−0.0042	0.0099
% hemicellulose	−0.0016	0.0016	−0.0025	0.0020
% cellulose	—	—	−0.0019	0.0235
Intercept	0.0888	0.0001	0.1828	0.0001

Discussion

Green manure production

In contrast to typical green manure systems without a livestock component, such as the 'tapado' system in central America (Buckles *et al.* 1994), the short-term improved fallow or ley system of the present study faces two important constraints. Firstly, considerable amounts of nutrients are likely to be exported from the field, depending on the quantity of forage removed in the dry season and the proportion of nutrients recycled by excretions of grazing animals. Secondly, there is only a short time after dry season forage utilisation to accumulate leguminous green manure for a subsequent crop (Mohamed Saleem and Fisher 1993).

Due to the very harsh dry season of 1994–95, the ability of the legumes to recover after the dry season forage harvest depended solely on regrowth from surviving plants rather than from seedling recruitment. Those species with the ability, before the onset of the rainy season, to build up dense canopies from the stubble remaining after the dry season harvest had the highest green manure yields 6 weeks after the onset of rains (*e.g. F. macrophylla*). Yields were similar to those recorded for similar regrowth periods by Cobbina (1992) for accessions of *C. macrocarpum*, *C. pubescens*, *S. guianensis*, *P. phaseoloides* and *Calopogonium* spp.

Since the sown legumes were not inoculated with *Rhizobium*, to fix atmospheric N_2 they would have to nodulate with native rhizobia. Considerable N_2 fixation with limited nodulation has been shown before for *M. pruriens* (Sanginga *et al.* 1996). The low numbers of nodules and modest N levels in plant tissue of *C. macrocarpum* may be due to inefficiency of native rhizobia (*Bradyrhizobium*) (Sylvester-Bradley *et al.* 1990), although large numbers of nodules and high N levels in plant tops of the same species were found by Cobbina (1992) very close to the Fashola site of the present study. In Cobbina's study, a different field history including legumes might have induced more favourable rhizobium strains for *C. macrocarpum*. Poor presence of arbuscular mycorrhiza, however, is another possible factor contributing to poor nodulation

Table 5. Linear correlation coefficients between relative decomposition rates (dry matter k_{DM} and nitrogen k_N) and initial amounts of dry matter (DM_i) plus selected parameters of initial chemical composition of legume residues at Ibadan and Fashola (n=14).

	C	N	C:N	Lignin	Lignin:N	Polyphenols	Cellulose:N	DM_i
k_{DM}	−0.71**	−0.05	−0.13	−0.66*	−0.52	0.48	−0.28	−0.78**
k_N	−0.52	0.17	−0.31	−0.64*	−0.65*	0.58	−0.51	−0.73**

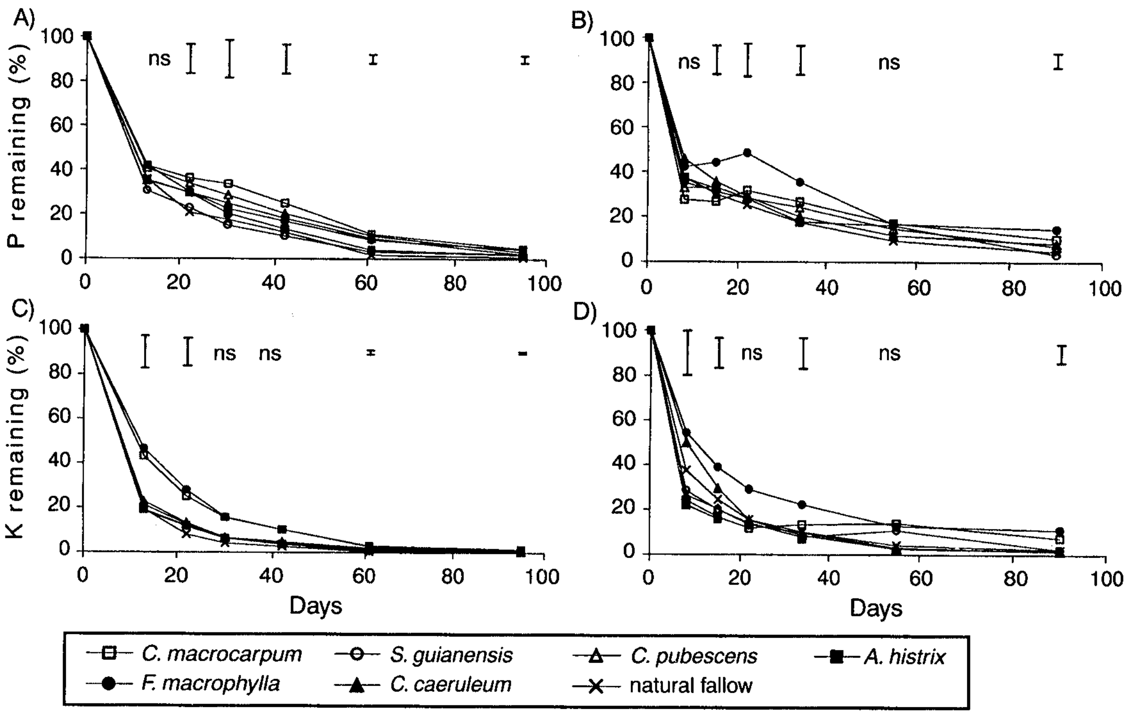

Figure 2. Proportions of phosphorus (A, B) and potassium (C, D) remaining in green manure residues during 90 days of decomposition at Ibadan (A, C) and Fashola (B, D); bars indicate HSD according to Tukey at $P<0.05$ between legume species at each sampling date.

and lack of N_2 fixation (Mosse *et al.* 1976), particularly in low phosphorus soils.

Despite these constraints, N accumulation of most species (range 43.9–143.7 kg/ha N) at Ibadan compared well with data on leguminous green manures collated by Peoples *et al.* (1995). The lower regrowth rates at Fashola than at Ibadan, where rainfall was higher during this period, produced lower green manure N (22.4–101.9 kg/ha N). However, the green manuring potential at both sites may have been drastically underestimated, since the contribution of below-ground biomass has been ignored. Although Peoples *et al.* (1995) concluded that roots and nodules contributed <15% of total legume N, Hairiah and van Noordwijk (1989) reported shoot:root ratios as low as 2.2:1 (DM basis) for herbaceous legumes 14 weeks after sowing. This suggests that root systems of legumes may contribute considerable amounts of N (Vanlauwe *et al.* 1996).

Decomposition and nutrient release

The potential nutrient contribution of green manure to a subsequent crop depends on both the amount of nutrients accumulated and the decomposition rate after incorporation in the soil. Initial chemical composition largely determines this process (Thomas and Asakawa 1993; Constantinides and Fownes 1994) for equal amounts of residues in litter bags or laboratory incubation studies. If soil fertility effects associated with actual amounts of applied green manure residues are to be quantified, however, the impact of initial dry weight (DM_i) on the decomposition rate has to be considered. In the present study, initial amounts were determined by legume regrowth after dry season forage utilisation and significantly affected decomposition rates (Table 5). Higher initial DM amounts resulted in slower decomposition rates, which may be due to compaction (Lousier and Parkinson 1976), reduced contact with the soil or N limitation at high C:N ratios (Jensen 1994).

As a consequence, correlations of decomposition rates with parameters of initial chemical composition were weak when compared with results in the above-mentioned studies of Thomas and Asakawa (1993) and Constantinides and Fownes (1994). Another reason for the relatively low linear correlation coefficients is the heterogeneity of the residue material within legume treatments. Consideration of separate decomposition patterns for leaves and stems might improve the significance of relationships between decay rates and chemical parameters (McDonagh *et al.* 1995). Similarly, different leaf size and form have been shown to influence the mineralisation of residues mixed with soil (Jensen 1994). The negative relationship between % C and dry matter decay rate (k_{DM}) found at Ibadan has to be interpreted with caution, since C levels in green manure were very similar. In contrast, the significant ($P<0.05$) role of lignin in delaying the decomposition process agrees with findings of Thomas and Asakawa (1993) and Vanlauwe *et al.* (1996).

Similarly, the protein-binding capacity of polyphenols slows down decomposition and N mineralisation (Palm and Sanchez 1991; Handayanto *et al.* 1994). In our study, polyphenols did not affect the decomposition process but were present at extremely low levels comparable with those obtained with leaf litter of some of the same herbaceous species (Thomas and Asakawa 1993). The polyphenol concentrations in *F. macrophylla* were particularly low when compared with results for the same species by Vanlauwe *et al.* (1996) who used the same analytical method. In our study, no explanation for these low polyphenol levels could be found and the low dry matter decay rates of *F. macrophylla* seemed to be related to high lignin contents rather than to polyphenols. Lignin might also be involved in the higher retention of N relative to dry weight for most of the species, but especially for the *Centrosema* spp. and *F. macrophylla*. In *C. macrocarpum*, a high C:N ratio could have further contributed to the lower N release from its residues (Jensen 1994).

Potential nutrient contribution to crops

The cumulative N release (Figure 3) was generally higher at Ibadan, where more green manure was incorporated into the soil. *F. macrophylla* showed great potential as N source for a subsequent crop, because it released large amounts of N over 90 days. By contrast, availability of K to the following crop is likely to be limited as it was released very quickly and is readily leached on light soils (Swift *et al.* 1981). The rapid release of P and K during decomposition is in agreement with other studies on similar species (Tian *et al.* 1992; Thomas and Asakawa 1993).

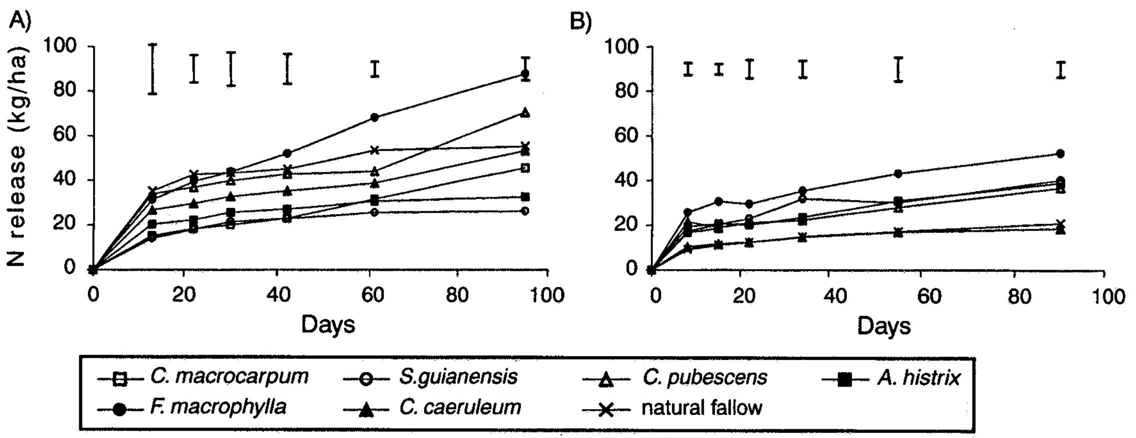

Figure 3. N release (kg/ha) from decomposing green manure residues at Ibadan (A) and Fashola (B); bars indicate HSD according to Tukey at $P<0.05$ between legume species at each sampling date.

Modelling the decomposition process using the single exponential model ($y = e^{-kt}$) gave a consistent lack of fit, underestimating decomposition rates during the first 30 days, and overestimating them thereafter. The phenomenon that a rapid dry matter loss at the beginning of the decomposition process is slowing down at later stages, has been addressed by fitting double exponential models: $y = ae^{-k_a t} + (1-a)e^{-k_{(1-a)} t}$, assigning different decay rates (k_a, $k_{(1-a)}$) to a more labile (a) and a more recalcitrant fraction (1–a) (Bunnell and Tait 1974). Studies with tropical tree legumes, however, showed that the resulting parameters were poorly related to the residue quality (Vanlauwe *et al.* 1996). Therefore, it is uncertain whether the improved model actually enhances understanding of the decomposition process or just improves the mathematical fit of data. Nevertheless, a period of rapid decay immediately after incorporation has important implications for the management of green manure systems. Planting must be done as soon as possible after incorporation of residues for maximum exploitation of released nutrients. The recalcitrant fraction, on the other hand, plays an important role in enhancing continuous N supply to subsequent crops and may also contribute to the build-up of the soil organic matter reserve of mineralisable organic N (Haggar *et al.* 1993).

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