Decomposition and nutrient release patterns of *Pueraria phaseoloides*, *Flemingia macrophylla* and *Chromolaena odorata* leaf residues in tropical land use systems

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ABSTRACT

The study determined the decomposition and nutrient release patterns of *Pueraria phaseoloides*, *Flemingia macrophylla* and *Chromolaena odorata* leaf residues in young secondary forest and bush land use systems at Mfou, southern Cameroon. Residue mass loss after incubating fresh leaves for 120 days was *C. odorata* > *P. phaseoloides* > *F. macrophylla*. Mean weekly loss rates were 4.5, 3.9 and 2.8 per cent for *C. odorata*, *P. phaseoloides* and *F. macrophylla*, respectively. Across residue types, leaf mass loss was greater in the young secondary forest than in the bush land use. Soil texture and soil chemical properties were not correlated to leaf mass loss. Except for N, releases of P, K, Ca and Mg were of the order *C. odorata* ≥ *P. phaseoloides* > *F. macrophylla*. Proportions of K released from the leaf residues were greater than those for the other nutrients. Half of the K was released within the first 7 weeks after incubation for *C. odorata* and *P. phaseoloides*. Among the land uses, release of K in the forest was 1.8 times faster than in the bush. The slowest releases, irrespective of type of leaf residue, were in Ca and Mg. The study concluded that among the planted fallows, *Pueraria phaseoloides* had the greatest rate of nutrient release. It could, therefore, ensure greater nutrient availability to associated crops. The leaves of *C. odorata* are rich in all nutrients; hence, short-season crops could benefit from this source of nutrients if the weed is well managed.

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RÉSUMÉ

BANFUL, B., OFORI, K., KUMAGA, F., HAUSER, S. & NDANGO, R.: *Décomposition et les schémas de dégagement de nutriment du résidu foliaire de* Pueraria phaseoloides, Flemingia macrophylla *et* Chromolaena odorata *dans les systèmes d'utilisation de terre tropicale*. Nous avons déterminé la décomposition et les schémas de dégagement de nutriment du résidu foliaire de *Pueraria phaseoloides, Flemingia macrophylla* et *Chromolaena odorata* dans les systèmes d'utilisation de forêt de jeunes arbres et de terre arbustive à Mfou, au sud du Cameroun. La perte de masse résiduaire après l'incubation de feuilles fraîches pour 120 jours était *C. odorata* > *P. phaseoloides* > *F. macrophylla.* Les taux de perte moyen par semaine étaient 4.5, 3.9 et 2.8% respectivement pour *C. odorata, P. phaseoloides* et *F. macrophylla*. En travers de types de residu, la perte de masse foliaire était plus élevée dans l'utilisation de forêt de jeunes arbres que dans la terre arbustive. La texture de sol et les propriétés chimiques de sol ne corrélaient pas à la perte de masse foliaire. Excepté A, les dégagements de P, K, Ca et Mg suivaient l'ordre *C. odorata* ≥ *P. phaseoloides* > *F. macrophylla*. Les proportions de K dégagées de résidu foliaire étaient plus élevées que celles des autres nutriments. La moitié de K était dégagée dans les 7 premières semaines après incubation pour *C. odorata* et *P. phaseoloides.* Parmi les utilisations de terre, le dégagement de K dans la forêt était 1.8 fois plus rapide que dans la terre arbustive. Les dégagements les plus lents, indépendamment de type de résidu foliaire, étaient en Ca et Mg. L'étude a tiré la conclusion que parmi les jachères plantées, *Pueraria phaseoloides*, avaient les taux de dégagement de nutriment les plus élevés. Elle pourra donc assurer la disponibilité de nutriment plus élevée aux cultures associées. Les feuilles de *C. odorata* sont riches en tous les nutriments donc les cultures de courte période pourraient tirer des bienfaits de cette source de nutriments si la mauvaise herbe est bien maîtrisée.

Introduction

In the humid tropics of West and Central Africa, the sustainability of “slash and burn”, the traditional farming system, relies on long fallow periods in-between the cropping phases (Henrot & Brussaard, 1997). As human population increases and land availability decreases, the fallows, traditionally used as weed-breaks (de Rouw, 1995) and for soil fertility regeneration, are shortened. Thus, soil fertility maintenance and management, rather than the avoidance of weeds, become crucial factors in any alternative system. Widely used alternatives to slash and burn involve the use of organic mulches; that is, tree and shrub pruning or leguminous cover crops for improved fallows.

The decomposition and nutrient release of these organic mulches are key processes by which nutrients locked up in the plant residue eventually become available to crops. Yet studies on residue decomposition of cover crops (Luna-Orea, Wagger & Gumpertz, 1996) and hedgerow pruning (Handayanto, Giller & Cadisch, 1997) have been confined to forest lands, neglecting the bush fallows. However, human population pressure on land has restricted most smallholder farmers to these degraded bush fallow lands. Moreover, shading, a consequence of the establishment of trees and cover crops, alters the species composition, biomass production (de Rouw, 1995) and above-ground partitioning (Saxena & Ramakrishnan, 1984) of tropical weeds. As weeds establish quickly after crop planting, they can also have a role in retaining nutrients in the agroecosystem (Lambert & Arnason, 1986), potentially important in systems in which fertilizer is not used for long-cycle crops. In West and Central Africa, *Chromolaena odorata* (L.) King and Robinson (Asteraceae) often dominates the weed flora in young fallows (Slaats *et al*., 1996) and open fields (de Rouw, 1991). In southern Cameroon, it is known as ‘kondengui’. Yet research on the decomposition of *C. odorata*, the most available and ‘investment-free’ residue, is very limited across the subregion.

This study was designed to determine the decomposition and nutrient release characteristics of leaf residues of *P. phaseoloides* as a cover crop, *F. macrophylla* as a hedgerow species, and *C. odorata* as weed species in bush and young secondary forest land use systems.

Materials and methods

Description of experimental locations

Experiments were carried out at Mfou (3° 57′ N, 11° 48′ E) in southern Cameroon. The predominant soil is clayey, kaolinitic, Typic Kandiudult (Hulugalle & Ndi, 1993). The site has a bimodal rainfall distribution, with peaks in June and September. The first and second growing seasons typically last from mid-March to mid-July, and from mid-August to end of November, respectively, separated by a short dry spell of about 4 weeks in July. The dry season starts in mid-November and lasts through end of February or mid-March. The experiments were laid out in two land use systems (LUS) comprising 4 to 5-year-old bush fallow dominated by *C. odorata* and > 20-year-old young secondary forest.

Experimental procedure

Fields were slashed in January and burned in mid to late February 2002. The experiment was laid out in a randomized complete block with three replications. The treatments comprised three fallow systems: *F. macrophylla* hedgerows, *P. phaseoloides* cover crop, and *C. odorata*-dominated natural regrowth.

Planting was done in mid-June 2002 on plots that measured 15 m × 12 m. The *F. macrophylla* hedgerows were planted by drilling seeds at 4 kg ha^{-1} in rows of 12 m length and 3 m apart. *Pueraria phaseoloides* was established from seed by drilling at 12 kg ha^{-1} in four double rows spaced 1 m between two rows and 2 m between adjacent double rows. This planting pattern was adopted to accommodate the establishment of plantain in the alleys of the hedgerows and the space between the adjacent double rows.

Soil chemical analyses

Nine soil cores of 0 to 10-cm depth were collected in a stratified pattern per plot before planting *F. macrophylla* and *P. phaseoloides*. One composite of the nine samples was also made to obtain one sample per plot. Soil samples were air-dried and ground, mixed thoroughly and sub-sampled for chemical analyses. The following procedures were adopted for the analyses : *p*H was determined in 1:2.5 (w/v) soil : water suspension. Exchangeable basic cations, Ca^{2+}, Mg^{2+} and K^+, and phosphorus were extracted by the Mehlich-3 procedure (Mehlich, 1984). Cations were determined by atomic absorption spectrophotometry, and phosphorus by the molybdate blue procedure described by Murphy & Riley (1962). Organic carbon was determined using improved Heanes digestion and spectrophotometric procedure (Heanes, 1984). Total nitrogen was determined from a wet acid digest (Buondonno, Rashad & Coppola, 1995) by colorimetric analysis (Anderson & Ingram, 1993).

Particle size distribution analysis

Soil samples were initially collected from each undisturbed plot before laying out the field for planting. Thirty-six core samples were collected per plot using a 100-cm^3 cylindrical soil core at depth of 0 to 10 cm. Soil particle size distribution was determined according to Day (1965).

Determination of chemical characteristics of the leaf materials

The leaves of *P. phaseoloides, F. macrophylla*, and *C. odorata* were harvested fresh, 11 months after planting (MAP) and air-dried. Sub-samples of the air-dried material were ground to pass through a 0.5-mm sieve and analysed for total N, P, K, Ca, and Mg. Total N was determined from a wet acid digest (Buondonno *et al*., 1995) and read colorimetrically (Anderson & Ingram, 1993). Calcium, Mg, and K were determined by atomic absorption spectrophotometry (Jones & Case, 1990), while total P was determined by the procedure of Murphy & Riley (1962).

Decomposition experiment

The litterbag technique was used to determine decomposition and nutrient release from the leaf materials in the field. The experiment was conducted from April to July 2003 in the young secondary forest and bush land use systems. Litterbags (30 cm × 30 cm) were constructed from aluminium netting with 2-mm mesh size. For each leaf residue, the bags were filled with 100 g of fresh leaves and sealed. The litterbags were placed flat at random on the surface of the soil in 5 m × 4 m plots. The plots were distributed in a randomised complete block with three replications and three leaf residue treatments: *F. macrophylla*, *P. phaseoloides*, and *C. odorata*. Each plot contained five litterbags of each residue treatment. A field map was drawn to identify the residues in each plot.

One litterbag was collected from each plot at 20, 40, 60, 90 and 120 days after placement to monitor dry matter and nutrient loss. The leaf materials remaining in the litterbags at each time were separated from soil and organic debris by hand and oven-dried at 65 °C to constant mass. The dry mass was recorded. Sub-samples were then ground to pass through a 0.5-mm sieve and analysed for total N, P, K, Ca, and Mg contents. The amount of nutrients remaining in the litterbag at each sampling time was determined by multiplying the mass of residue remaining by their respective concentrations. It was assumed that the amount of nutrients released or immobilized at each time was the difference between the amount of nutrients contained in the initial leaf materials and the amounts in the materials at the given sampling time.

The decomposition and nutrient loss constants, *k*, were determined for each type of leaf residue by the negative single exponential model:

$$m = m_o e^{-kt} \qquad (1)$$

where *m* is the mass of material or nutrient remaining at each time *t* in days, and m_o is the initial mass of material or nutrient (Wieder & Lang, 1982). Half-life (t_{50}), the time when 50 per cent of the material would have decomposed (or half of the nutrients would have been released), was calculated as:

$$t_{50} = \frac{-\ln(0.5)}{k} \qquad (2)$$

Statistical analysis

Data were analysed for variance (ANOVA) using the general linear model (GLM) procedure of SAS (SAS, 1997), and means separated by the Least Significant Difference (LSD). Differences were significant if $P < 0.05$.

Results

Soil physico-chemical characteristics

The soil of the young secondary forest was sandy clay whilst that of the bush fallow was sandy clay loam. No significant differences were observed in the particle size distribution of the soil in both land use systems. In contrast, soil chemical properties differed significantly between land use systems (Table 1). The forest soil was more acidic and also contained greater levels of N, C and P than the bush fallow. Conversely, the bush contained greater amounts of Ca and Mg than the forest.

Quality characteristics of leaf residues

The incubated *P. phaseoloides* leaf residue had the largest N content, while the largest amounts of P, K, Ca and Mg were present in *C. odorata* leaf residue (Table 2). All the three leaf residues had N concentrations greater than the critical level of 18 to 22 g kg^{-1} below which point net N immobilization from soil would be expected (Palm *et al*., 1997). As regards P, only *C. odorata* leaves contained concentration level above the critical value of 2.5 g kg^{-1} (Janssen, 1993; Palm, Myers & Nandwa, 1999). The C/N ratios of all the leaf residues were below 25, which indicated rapid release of mineral N during decomposition. Nutrient release constants were used as indices for estimating the mineralization rates. The bigger the constant, the faster the mineralization of the nutrient.

Residue mass loss

Decomposition of the different leaf residues fitted significantly to logarithmic functions (Fig. 1). At all retrieval periods, residue mass loss was *C. odorata* > *P. phaseoloides* > *F. macrophylla*. Mean weekly loss rates were 4.5 , 3.9 and 2.8 per cent for *C. odorata*, *P. phaseoloides* and *F. macrophylla*, respectively. Consequently, the half-lives ranged from 11.0 to 11.3 weeks for *C. odorata*, 9.7 to 15.7 weeks for *P. phaseoloides*, and 16.2 to 19.0 weeks for *F. macrophylla* (Table 3). Mass loss in both land uses also fitted significantly to logarithmic functions (Fig. 2). Across residue types, leaf mass loss was greater in the young secondary forest than in the bush fallow. Soil texture and none of the soil chemical properties were correlated to leaf mass loss.

TABLE 1

Initial Soil Physical and Chemical Properties at 0-10 cm Depth of the Two Land Use Systems at Mfou

	Bush	*Forest*	*t (prob.)*
% sand	54.35	49.89	ns
% clay	36.83	41.67	ns
% silt	8.82	8.45	ns
*p*H (H_20)	4.7	4.4	0.019
Total N (g kg^{-1})	1.72	2.08	0.003
Organic C (g kg^{-1})	27.75	33.10	0.007
Available P (mg kg^{-1})	16.17	24.34	0.002
Exch. K (cmol (+) kg^{-1})	0.31	0.34	ns
Exch. Mg (cmol (+) kg^{-1})	1.56	1.19	0.018
Exch. Ca (cmol (+) kg^{-1})	4.11	3.28	0.023

Nutrient release patterns

Release of N was significantly greater in *P. phaseoloides* and *C. odorata* leaf residues than in *F. macrophylla* (Fig. 3). Residue × land use interactions were not significant. The faster N

TABLE 2

Initial Nutrient Concentration of the Leaf Residues

	Nutrient concentration (g kg^{-1})						
Leaf residue	*N*	*P*	*K*	*Ca*	*Mg*	*C*	*C/N*
P. phaseoloides	40.61	2.05	12.31	8.54	3.16	457.17	11.30
F. macrophylla	36.11	1.96	8.90	6.43	1.76	472.65	13.09
C. odorata	32.80	2.59	16.91	12.58	6.58	473.18	14.43

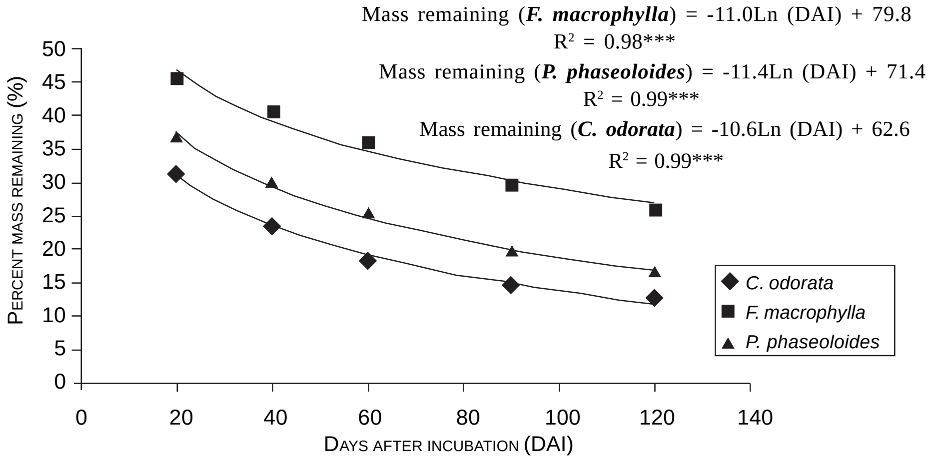

Fig. 1. Percent mass remaining after incubation of different leaf residues.

TABLE 3

Half-life of Leaf Residue Loss of C. odorata, P. phaseoloides *and* F. macrophylla *in Land Use Systems at Mfou*

Land use system	*Type of leaf residue*	*Rate constant, k week^{-1}*	*r^2*	*Half-life (weeks)*
Bush	*F. macrophylla*	- 0.0427	0.98 ***	16.2
	P. phaseoloides	- 0.0441	0.98 ***	15.7
	C. odorata	- 0.0616	0.98 ***	11.3
Forest	*F. macrophylla*	- 0.0052	0.97 ***	19.0
	P. phaseoloides	- 0.0102	0.99 ***	9.7
	C. odorata	- 0.0090	0.94 ***	11.0

*** : $P<0.001$

mineralization in *P. phaseoloides* (0.0693 week^{-1}) and *C. odorata* (0.0623 week^{-1}) resulted in the release of half of the constituent N in 10 and 11.1 weeks, respectively (Table 4). *Flemingia macrophylla* released the least amount of N (Fig. 3) during the study with a half-life of 18.3 weeks. The half-life of *F. macrophylla* was about 1.7 times slower than those of *P. phaseoloides* and *C.*

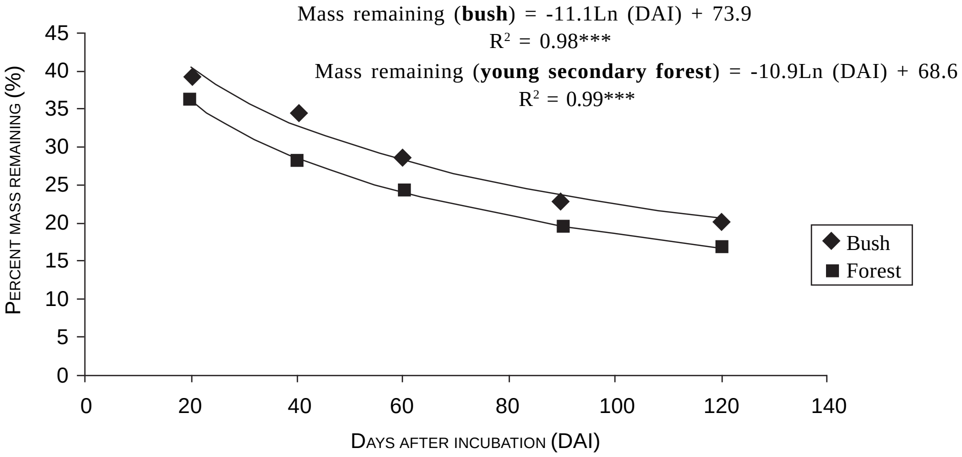

Fig. 2. Percent mass remaining after incubation of leaf residue in two land use systems.

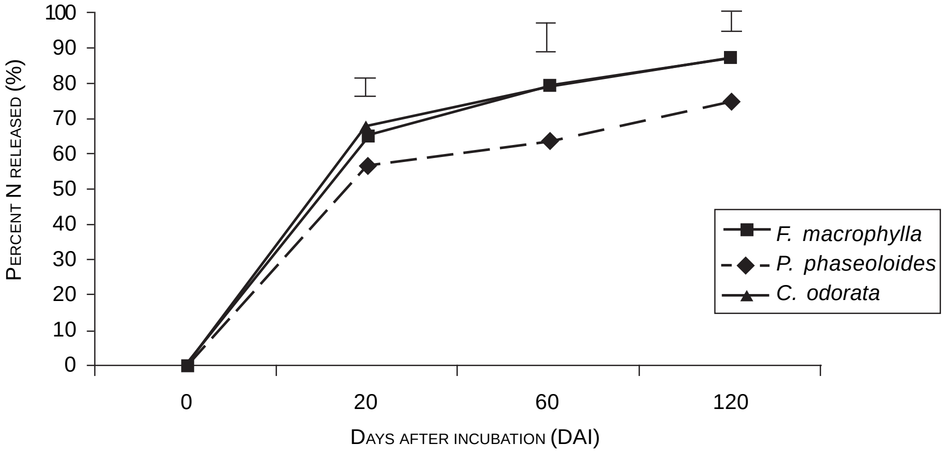

Fig. 3. Nitrogen release pattern of different leaf residues.

TABLE 4

Half-life of Nutrients Released from the Different Leaf Residues

Leaf residue	*N*	*P*	*Half-life (weeks)* *K*	*Ca*	*Mg*
P. phaseoloides	10.0	9.7	6.7	17.4	13.8
F. macrophylla	18.3	10.9	10.9	19.8	23.6
C. odorata	11.1	9.1	5.1	15.0	11.9
Land use system					
Bush	14.4	11.9	10.1	19.0	18.3
Secondary forest	11.8	8.3	5.9	15.9	14.4

odorata. The release of N was faster in the young secondary forest with a half-life of 11.8 weeks compared with 14.4 weeks in the bush (Table 4).

Phosphorus release patterns

Chromolaena odorata released more phosphorus ($P < 0.05$) at all retrieval periods than *F. macrophylla* (Fig. 4). Residue × land use interactions were not significant. Phosphorus releases from the leaf residues were generally greater and faster than N releases. Thus, the half-lives of P releases were smaller than those of N releases (Table 4). By 120 DAI, over 82 per cent of phosphorus was released from all the leaf residues, with that of *C. odorata* reaching 89 per cent. The forest recorded faster rate of P release than the bush, similar to that of N release (Table 4).

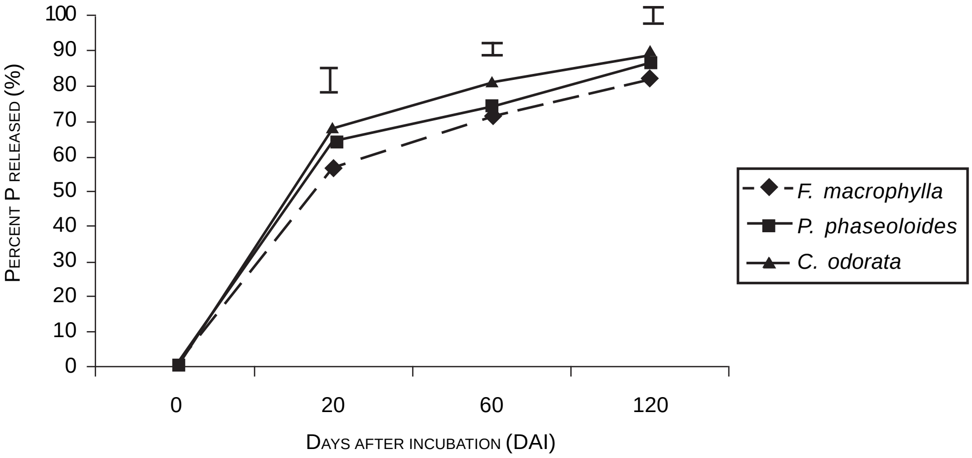

Fig. 4. Phosphorus release pattern of different leaf residues.

Potassium release patterns

Proportions of K released from the leaf residues were greater than those for the other nutrients. *Chromolaena odorata* leaf residue consistently released the largest K at each retrieval period (Fig. 5), culminating in a 97.2 per cent release of total K by 120 DAI. Residue × land use interactions were not significant. In just about 5 weeks, *C. odorata* had released 50 per cent of its K. Potassium release was slowest in *F. macrophylla* (0.0637 week^{-1}), although the time required to release half of the K (10.9 weeks) was still less than that for N (Table 4). Among the land uses, K release was significantly greater in the forest than in the bush after 20 DAI (Fig. 6). The release in the forest was 1.7 times faster than in the bush (Table 4).

Calcium release patterns

Chromolaena odorata leaf residue released greater ($P < 0.05$) Ca at all retrieval periods, while the least was released by *F. macrophylla* (Fig. 7). Residue × land use interactions were not significant. Calcium releases from the leaf residues were the slowest among all the nutrients, with half-lives ranging from 15 weeks (*C. odorata*) to 19.8 weeks (*F. macrophylla*). The difference in the pattern of Ca release was not significant between the land uses. However, compared to the other nutrients, Ca releases in the land uses were very slow, with half of releases occurring between 15.9 weeks (forest) and 19.0 weeks (bush) (Table 4).

Magnesium release patterns

Chromolaena odorata released the largest ($P < 0.05$) amount of Mg up to 60 DAI; thereafter, the

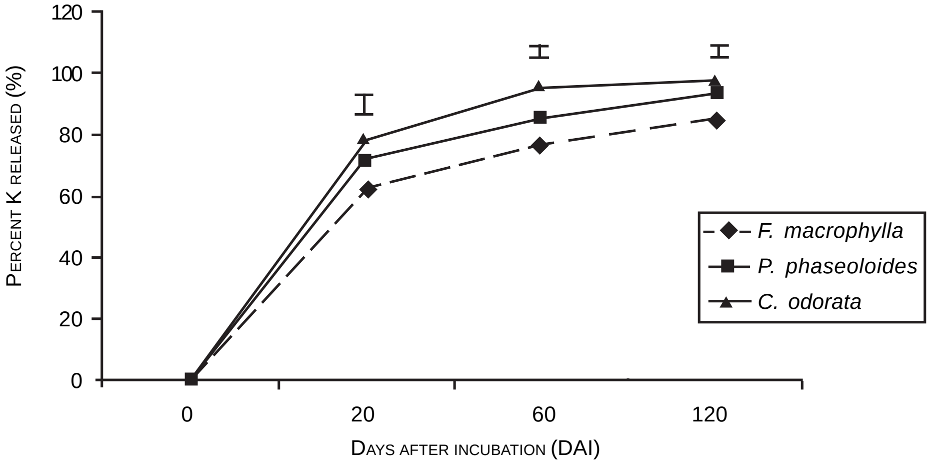

Fig. 5. Potassium release pattern of different leaf residues.

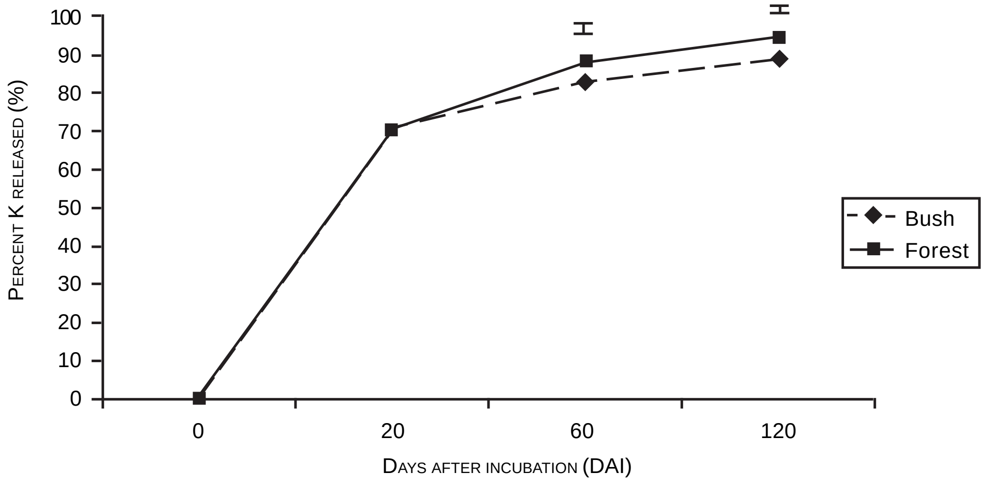

Fig. 6. Potassium release pattern in two land use systems.

pattern of release was similar to that of *P. phaseoloides* (Fig. 8). Between *P. phaseoloides* and *F. macrophylla* leaf residues, Mg releases were significantly different only at 120 DAI such that release was greater from residue of *P. phaseoloides* compared to *F. macrophylla*. Residue × land use interactions were not significant. The half-lives of Mg and N releases from *C. odorata* were similar (Table 4), indicating that half of both nutrients were lost at the same time. The slowest Mg release was from *F. macrophylla* (0.0294 week^{-1}) with a half-life of 23.6 weeks. The release of Mg from *F. macrophylla* was even slower than the release of Ca from the same leaf residue, contrary to that observed in *P. phaseoloides* and *C. odorata*. However, half of the constituent Mg from the leaf residues was released faster in the forest compared to the bush (Table 4).

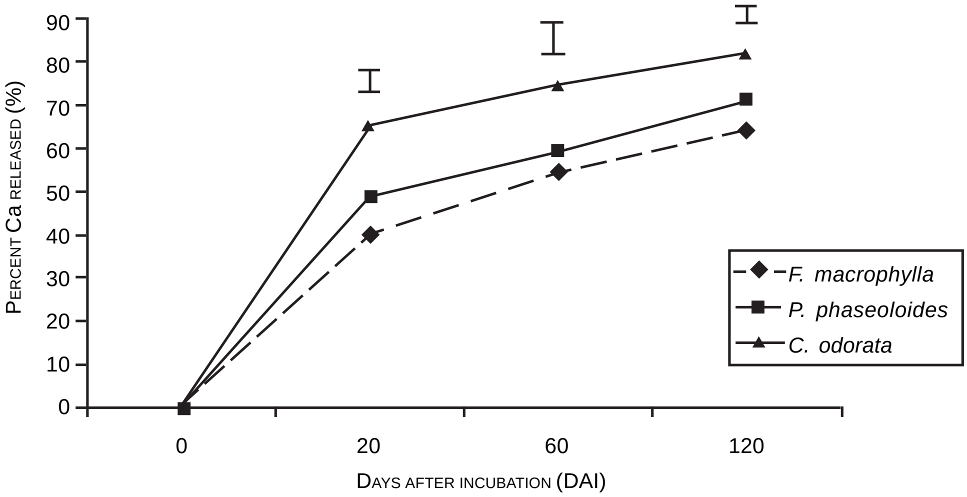

Fig. 7. Calcium release pattern of different leaf residues.

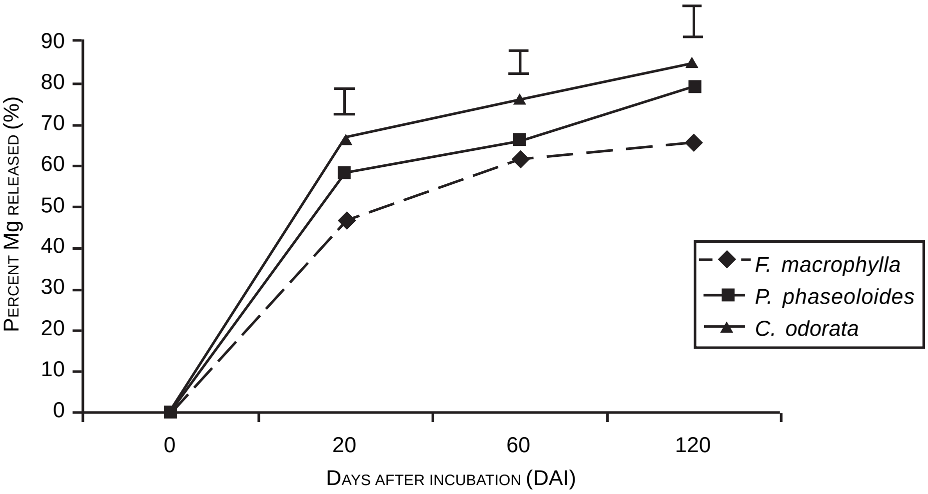

Fig. 8. Magnesium release pattern of different leaf residues.

Discussion

Mass loss of residue

The mean weekly mass loss of *P. phaseoloides*, *F. macrophylla* and *C. odorata* clearly indicated that decomposition was fastest in *C. odorata* leaves. However, these findings contrasted McDonagh *et al*. (1995) who reported that crop residues with greater N contents, as in *P. phaseoloides* and *F. macrophylla*, decomposed faster. But Norgrove, Hauser & Weise (2000) suggested that the overall high leaf nutrient concentrations in *C. odorata* could be the likely reason for its high decomposition, an assertion corroborated in this study. The half-life values for *C. odorata* and *F. macrophylla* in this study are comparable to those of earlier studies in southern Cameroon (Norgrove *et al*., 2000) and south-eastern Nigeria (Henrot & Brussaard, 1997), respectively. The (Polyphenol + Lignin) / Nitrogen ratio is regarded as the most robust index determining the decomposition rate of a residue (Mafongoya, Nair & Dwowela, 1998). This study, thus, speculates that the slower decomposition of *F. macrophylla* leaves could be due to its high (Polyphenol + Lignin) / Nitrogen ratio of 8.2 (Zingore *et al*., 2003) compared with 3.1 (Tian *et al*., 2001) for *P. phaseoloides*.

The consequence of the slow decomposition of *F. macrophylla* would be prolonged soil cover which could enhance infiltration of rainwater and subsequently increase moisture retention (Bhattacharyya & Rao, 1985) for the benefit of the associated crop. This study found no correlations among percent mass remaining of leaves and soil chemical properties and texture, implying that soil chemical and physical properties might not play crucial roles in residue decomposition. Hauser *et al.* (2005) and Motavalli *et al.* (1995) recorded similar observations regarding soil chemical properties and soil texture, respectively. Furthermore, Bremer, van Houtum & van Kessel (1991) reported that for residues rich in N, the presence of soil did not accelerate decomposition. Across residue types, leaf mass loss was greater in the young secondary forest than in the bush, probably because of increased soil microbial activity in the forest as a result of the greater soil organic matter as reported by Ayanaba, Tuckwell & Jenkinson (1976).

Nutrient release from residue

The faster mineralization of N from leaf residues of *P. phaseoloides* and *C. odorata* was expected because nutrient release rates are generally dependent on mass loss rates. Such rapid release of N might be vital, as it could be in synchrony with crop demand; particularly short-season crops such as maize and vegetables, thereby boosting growth. The slow N release from *F. macrophylla* might be explained by the high (Polyphenol + Lignin) / Nitrogen ratio of *F. macrophylla,* because Fox, Myers & Vallis (1990) reported that this index was highly correlated ($r = 0.93$) with mineralization of N in legumes. Except for N, releases of P, K, Ca and Mg were in the order *C. odorata* ≥ *P. phaseoloides* > *F. macrophylla*.

Phosphorus releases from the leaf residues were generally greater and faster than N releases, and could be beneficial to an associated crop for the rapid development of roots to anchor and absorb moisture and nutrients. Proportions of K released from the leaf residues were greater than those of all the other nutrients such that over half of K release was within the first 7 weeks for most of the leaf residues. Potassium is highly mobile and has high solubility (Marschner, 1995); so such rapid loss was expected. The slowest releases were Ca and Mg which, apart from their importance in crop nutrition, play crucial roles in the stability of surface soil aggregates (Salako & Hauser, 2001) that results in good soil tilth. Such good soil structure directly improves water infiltration and aeration, and indirectly increases nutrient uptake by crop roots. Between the planted fallows, the high nutrient release patterns of *P. phaseoloides* compared to *F. macrophylla* implied that crops might have a better nutrient synchrony with *P. phaseoloides* than *F. macrophylla*. Consequently, the incorporation of *P. phaseoloides* as nutrient source in the production systems of short-duration crops should be encouraged. Releases of N, P, and K from the leaf residues were faster in the young secondary forest than in the bush, probably due to the linear relationship between rates of mass loss and nutrient release. Yet, the slow nutrient releases in the bush land use could benefit long-duration crops, if weeds are effectively managed to limit competition for nutrients.

Conclusion

The study clearly established that among the planted fallows, *Pueraria phaseoloides* had the largest rates of nutrient release and, therefore, could ensure greater nutrient availability to associated crops, particularly short-duration crops. It was also shown that *C. odorata* leaves are a nutrient-rich source, which could also provide nutrients for short-duration crops, if well managed.

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