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MINERALIZATION OF CARBON AND NITROGEN OF ORGANIC RESIDUES FROM SELECTED PLANTS IN A TROPICAL CROPPING SYSTEM

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ABSTRACT

Aerobic incubation experiments were conducted with residues of four plant species, to determine C and N mineralization, and their relationships with chemical composition of the residues. The residues were grouped into three distinct classes, based on their chemical characteristics. The shoot of mucuna (Mucuna pruriens (L) DC. Var. utilis (Wright) Bruck and lablab (Lablab purpureus (L.) Sweet) with such characteristics as >3% N contents and C: N ratios < 12 were high quality. Residues of medium quality include the roots of mucuna and lablab; mixtures of mucuna or lablab with imperata (Imperata cylindrica (L.) Raueschel) or maize (Zea mays L.) shoots with characteristics such as 1.5 to 2.4% N contents and C: N ratios of 17 to 22. The residues of imperata and maize with N contents < 1% and C: N ratios > 30 were classified as low quality. The proportion of residue-C mineralized after 42 days ranged from 15% in imperata leaf to 35% in the mixture of mucuna or lablab with maize shoots. Three patterns of N mineralization were observed, each closely related to the residue classes distinguished. Carbon mineralization from the residues was significantly ($p<0.05$) correlated with the C: N ratio, (lignin + polyphenol): N ratio, polyphenol: N ratio and lignin content. Labile C correlated with (lignin + polyphenol): N ratio, C: N ratio, Lignin: N ratio and polyphenol: N ratio. However, no measured quality parameters correlated with the decomposition rate constants of either the labile or resistant C fractions. The ratio of (lignin + polyphenol): N, N content and C: N ratio appeared to be good predictors of the proportion of residue-N mineralized. Nitrogen mineralization rate constant was significantly ($p < 0.05$) correlated with the (lignin + polyphenol): N ratio, N content, C: N ratio and lignin: N ratio.

Key words: *herbaceous legumes, N dynamics, SOM, rate constants, residue quality, root*

INTRODUCTION

Low-external input agriculture depends on the use of plant residues to maintain and increase soil fertility during cropping. In the derived savanna zone of West Africa, systems such as cover cropping have been developed to maximize the use of plant residues. In addition to soil fertility improvement, herbaceous legumes used in cover cropping systems such as mucuna (*Mucuna pruriens* (L) DC. Var. *utilis* (Wright) Bruck) and lablab (*Lablab purpureus* (L.) Sweet), control imperata (*Imperata cylindrica* (L.) Raueschel). Maize (*Zea mays* L.) is a major crop grown in cover cropping system. Organic residues from such plants as mucuna, lablab, are expected to supply significant amounts of nitrogen (N) to the soil and build-up the soil organic matter content.

Residue quality is the intrinsic factor that affect residue decomposition rate (Swift *et al.*, 1979). High quality materials are known to decompose fast whereas low quality materials have characteristics that inhibit decomposition. The impact of mixing fast and slow decomposing plant residues on N availability to crops would be a result of an interaction between the residue quality and factors affecting N uptake by crops. Both high and low quality materials are produced in leguminous cover cropping systems in the derived

savanna zone of West and Central Africa. Proper management of these residues is of prime importance especially when considering their role as major input into the systems.

Determination of N release from plant residues is often included in decomposition studies. Most studies with tree legumes have determined N, lignin and polyphenol levels and C: N ratio, lignin: N, polyphenol: N and (light + polyphenol): N ratios as good indicators for predicting N mineralization or immobilization (Palm and Sanchez 1991; Vanlauwe *et al.*, 1997). However, there is dearth of information on the effect of residue quality on the mineralization of C and N from cover crop residues used in the derived savanna of West and Central Africa. Quantitative knowledge on the impact of residue quality on decomposition and N mineralization is essential to maximize their benefits. Another aspect of N turnover related to cover cropping systems is the mineralization of N from belowground biomass. Despite the availability of data on the yield and contributions of above –ground biomass of cover crops (Tian *et al.*, 1992), information on the contribution of roots is still limited. However, roots can be an important nutrient reserve for low-external input agriculture that is prevalent in the tropics especially considering that above-ground biomass are often removed from the field at plant harvest for other purposes (Magdoff *et al.* 1997; Ibewiro *et al.* 1998).

The objectives of this study are; to determine the chemical composition of above- and below- ground residues of mucuna, lablab, imperata and maize, to describe C and N mineralization from above- and below-ground residues of mucuna, lablab, imperata and maize; and from their mixtures under aerobic incubation conditions and to relate C and N mineralization with the residue quality.

MATERIAL AND METHODS

Surface soil samples (0 – 10cm) were collected from farmer-abandoned, imperata infested fields at Ijaiye, southwestern Nigeria ($7^0 36'$ N, $3^0 52'$ E, altitude 250m), and used for the incubation experiment. The soil (Haplic Lixisol), was air dried, sieved through a 2 mm screen and had the following properties; pH (1:1 H_2O) 6.50; organic carbon, 5.12g kg^{-1}; total N, 0.48 g kg^{-1}; available P (Bray-1), 1.30 mg kg^{-1}; ECEC, 2.22 cmol kg^{-1} and was sandy loam in texture with 6% clay, 10% silt and 84% sand. The soil samples were rewetted to 40% water holding capacity and pre-incubated in a closed polyethylene bag at $25^0C \pm 0.5$ for one month, to exclude drying/rewetting phenomena prior to incubation.

At the time of collection for use in the experiment mucuna, lablab and imperata were 20 weeks old while maize was 8 weeks. Roots were washed over a 0.5 mm screen to remove adhering soil. Residues were dried at 65^0C for 36hours, ground to pass a 0.5mm screen and subsamples were used for the following analysis: organic carbon (Amato 1983), total N (Bremmer and Mulvaney 1982), ash content (550^0C for 2hours), polyphenol concentrations (Anderson and Ingram 1993) and lignin content (van Soest, 1963). Residue treatment combinations for the incubation studies were:

1. mucuna shoots
2. lablab shoots
3. imperata leaves
4. maize shoots
5. mucuna roots
6. lablab roots
7. imperata roots
8. maize roots
9. mucuna shoots + imperata leaves
10. mucuna shoots + maize shoots
11. lablab shoots + imperata leaves
12. lablab shoots + maize shoots
13. unamended soil (control)

The Mucuna, lablab, imperata and maize shoots were mixed in the various combinations in a ratio of 1:1. All residues were mixed with the pre-incubated soil at a rate of 6g (ash-free) kg-[1] soil. Incubation experiments were conducted at $25^0C \pm 0.5$, using hermetically sealed one-litre jars, each containing three 100 ml pots with 50g of pre-incubated soil and a vial containing 10ml 2N NaOH to trap evolving CO_2 from the sample. The experiment was arranged in a completely randomized design with three replicates of each treatment combination.

The jars were aerated at 2,3,5,7,14,28 and 42 days, NaOH in all jars was collected for the determination of CO_2.C evolved and replaced with freshly prepared NaOH. The amount of CO_2.C absorbed in the NaOH solution was determined by titration with 0.05N HCL between pH 8.3 and 3.7 (Underwood, 1961). At 3, 7, 14, 28 and 42 days of incubation, three pots with 50g soil were sampled for each treatment. Forty grams of the soil were extracted with 120ml 2N KCI, while the remaining soil samples were used to determine the soil moisture content. Soil extracts were analyzed for NO_3-N using a Technicon Autoanalyzer (IITA, 1982).

Calculations and statistical analysis

The amount of C mineralized from the residues (Cmin) was calculated as follow:

$$\% \quad C_{min} = \left(\frac{CO_2\text{-}C}{\text{Added C}}\right) * 100 \qquad (1)$$

Where; CO_2-C was the CO_2 evolved from residue-amended soil minus the CO_2-C evolved from unamended soil. Net N mineralization/immobilization (min) was estimated using the equation:

$$N_{min} = (NO_3 - N)_t - (NO_3\text{-}N)_t = 0 \qquad (2)$$

Where t = 3, 7, 14, 28 and 42 days. The proportion of net N mineralized/immobilized from the residues was calculated as follows:

$$\%N_{min} = \left(\frac{NO_3\text{-}C}{\text{Added N}}\right) * 100 \qquad (3)$$

Where $NO_3 - N$ is N_{min} values of residue-amended soil minus N_{min} of unamended soil. This assumes that the residue additions caused no "priming action" on the decomposition of

indigenous soil organic matter. Data on C mineralization were fitted to combine a first-and zero-order kinetic functions with the model:

$C_m = C_l * (1-e^{-kl*t}) + C_r * e^{-kr*t}$ ..... (4)

Where C_m is the cumulative amount of CO_2-C released at time t (the amount of residue-C added at time =0 minus $\%C_{min}$ at time = t), C_l referred to the size of labile C fraction, k_l is the mineralization rate constant of labile C while C_r is the recalcitrant C fraction ($100 - C_l$) and K_r refers to the mineralization rate constant of the slowly decomposing fraction and t is time in days. Curve fittings were performed using SAS non-linear regression procedure (SAS, 1990).

Mineralization of residue N from the soil was represented by a single compartment model:

$N_m = N_0 - N_0 * e^{-k*t}$ ..... (5)

Where N_m is the cumulative amount of N mineralized at time = t. N_0 referred to the mineralizable part of soil N, k is the N-mineralization rate constant. Measured variables and estimated parameters were analyzed by an analysis of variance (ANOVA) using PROC GLM procedures of SAS statistical software (SAS, 1990) based on a completely randomized design.

RESULTS AND DISCUSSION

The initial chemical characteristics of plant residues used in this study varied substantially (Table 1) and can be grouped into three major classes in terms of their chemical composition. High quality residues, comprise mucuna and lablab shoots that have such characteristics as high N content (> 3%N), low lignin content (<5%) and low C: N ration (< 12). Mucuna roots, lablab roots and the shoot mixtures of either of the herbaceous legumes with imperata or maize with 1.5 to 2.5% N content, 6 to 11% lignin content and C-to-N ration of 17 to 22 are in the second class of medium quality materials. The third group, are low quality residues, which include roots and shoots of imperata or maize, with such chemical characteristics as low N content (<1% N) and high C-to-N ration (>30). The total N content of mucuna and lablab shoots obtained in this study is comparable to previously reported values (Lathwell, 1990), but lower than values for mucuna shoots N, lignin and polyphenol contents reported by Tian *et al.*, (1992). Tjitrosoedirjo *et al.*, (1986) reported similar N and lignin contents for field grown imperata to values presented in this study. Calculated values of N contents for mucuna roots based on the data of Lathwell, (1990) were higher than the N contents of mucuna roots presented in this study. Variations in soil, environmental and management factors however, may cause a change in the chemical composition of plant residues.

Carbon and nitrogen mineralization

The proportion of added residue-C mineralized ranged from 15% for imperata shoots to 35% for either of the mixture of lablab with maize shoots (Figure 1). After 42 days, significantly higher fractions of the added residue-C were mineralized from mucuna and maize shoot mixtures than from mucuna shoots incubated separately. Lablab shoots lost

comparable proportions of added C to lablab and maize mixtures, which were significantly higher than values of C mineralized from lablab roots or lablab-imperata mixtures. At the end of incubation, imperata roots had lost 19% of its C as CO_2-C compared to 15% lost from imperata shoots. Both imperata shoots and roots lost significantly lower proportions of their residue-C than the corresponding mixture of imperata shoots with either mucuna or lablab. In contrast, the proportion of maize shoot-C mineralized, as CO_2-C was higher than the C mineralized from maize roots. However, maize shoot and maize mixtures with either mucuna or lablab shoots evolved similar amounts of CO_2-C. Vanlauwe et al., (1997) reported 8 to 29% mineralization of added C from roots and leaves of three agroforestry species after 56 days of incubation. Carbon availability is influenced by the quality of the material, duration of incubation and soil type. This often makes it difficult to compare results.

Mineralization of N from the added residues showed three patterns (Figure 2). Mucuna and lablab shoots immobilized N only in the first 7 days, followed by N mineralization until the end of incubation. Shoot mixtures of imperata or maize with mucuna or lablab shoots showed the second pattern of comparable N mineralization to the unamended soil in the first 3 days and subsequent N immobilization from the remaining period of incubation. The third pattern, was N immobilization without any period of net N release during the 42 days incubation shown by imperata shoots, maize shoots and roots of all the studied plant species. Mineralization of N in this study was closely related to the distinguished residue quality classes. The amount of N mineralized by mucuna shoots ranged from 4 mg Nkg-^{1} soil at 7 days to 45 mg N kg^{-1} soil at 14 days representing 2 to 21% of the added residue N. Soil amendment with lablab shoots resulted in a net N mineralization 8 to 12% of the residue-N amounting to 11 to 24 mg N kg^{-1} soil. Net immobilization of soil N due to the addition of roots, mixture of the legumes with imperata or maize shoots, imperata and maize shoots varied at 42 days and represents 3 to 51% of the added residue N. After 42 day, apparent mineralization of residue – N, ranged from a 52% immobilization for imperata shoots to 10% mineralization for mucuna shoots (Table 2). Mineralization rate constants for each of the residue treatments were higher for mucuna and lablab shoots that for the other plant residues. Net N mineralization from shoot residues of mucuna and lablab can be related to their high quality. The apparently higher N immobilization by imperata or maize shoots incubated separately than the mixtures with legumes could be related to low quality of imperata or maize shoots. Net N immobilization, of legume shoot-N in the mixture with either imperata or maize shoots may be due to reduced N mineralization as a result of reduced microbial activity or due to more N immobilized in the presence of the medium quality mixed residues. Rapidly released N from the legume shoots was immobilized in the presence of imperata or maize shoots. In the field, this immobilized N could be re-mineralized later in synchrony with crop demand, especially considering the reduce rate of net N immobilization at the later periods of the study.

Relationships between C and N mineralization and initial residue quality

The proportion of added residue-C mineralized (% C_{min}) as CO_2-C was significantly ($p < 0.05$) correlated with the C: N ratio throughout the incubation period and with the (lignin +

polyphenol): N ratio in the first 28 days (Table 3). The % C_{min} was significantly ($p < 0.05$) correlated with polyphenol: N ratio in the first 10 days and lignin content from 10 to 42 days. Residue N concentrations were positively correlated with % C_{min} in the first 7 days, whereas polyphenol content of the residues correlated with % C_{min} only at 2, 3 and 5 days. The labile C fraction was negatively correlated with the (lignin + polyphenol): N ratio, C: N ratio, lignin-to-N ratio and polyphenol: N ratio (Table 4). Matmbanegwe and Kirchmann (1995) had previously observed similar relationships, for forest litters. None of the measured residue quality parameters correlated significantly ($P < 0.05$) with the decomposition rate constants of either the labile or resistant C fractions and implies that variations in both k values of the residues cannot be attributed to only differences in their qualities.

The ratio of (lignin + polyphenol): N and N content of the residues correlated significantly ($P < 0.05$) with the proportion of residue-N mineralized (% N_{min}) throughout the incubation period (Table 5). The % N_{min} correlated with the C-to-N ratio in the first 14 days, whereas the polyphenol content and polyphenol-N ratio correlated significantly ($P < 0.05$) with % N_{min} only at 3 days. Nitrogen mineralization rate constant was significantly ($p < 0.05$) correlated with the (lignin + polyphenol): N ratio, N content, C: N ratio, and lignin: N ratio of the residues. The importance of initial N, lignin and polyphenol contents of plant residues on decomposition had been reported (Palm and Sanchez 1991; Vanlauwe *et al.*, 1997). Lignin decomposers require a C source other than lignin; the addition of legume residues (with high N) may reduce the decomposition of lignin as a result of competition by non-lignin decomposers. Consequently, the relative proportion of lignin increases during decomposition and its impact on decomposition, increases with time. Fox *et al.*, (1990) noted the formation of recalcitrant N-compounds when plant lignin degrades to polyphenols in the soil. The above processes could be responsible for the higher relevance of parameters integrating lignin and polyphenol as determinants of C and N mineralization in this study. Strong, negative correlations between % C_{min} and C: N ratio throughout the study indicates that N was limiting for C mineralization during the study period. Conversely, non-significant correlations between N mineralization and C: N ratio from 28 days implies that N was no longer limiting for N mineralization from the residues at the later periods. The abundance of C relative to N in the residues at the initial periods accounts for this observed pattern.

Fig. 1

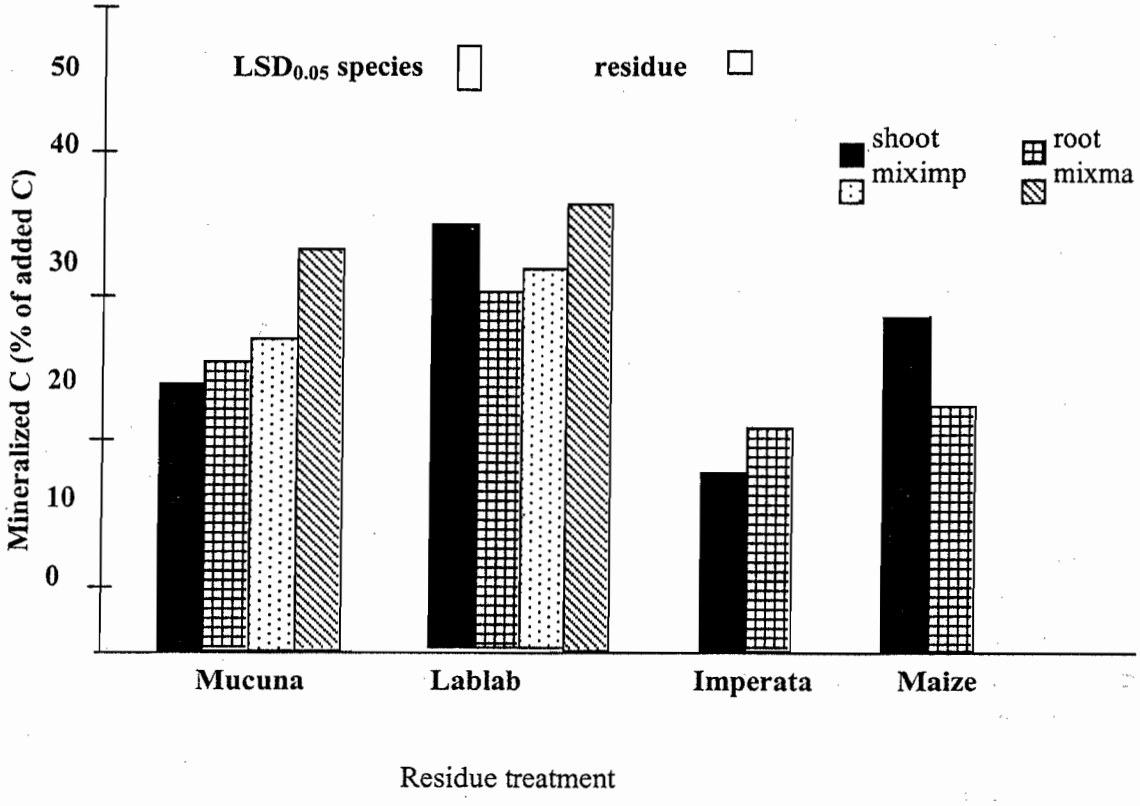
LSD0.05 species
residue
shoot
mixima
root
mixma
Mineralized C (% of added C)
50
40
30
20
10
0
Mucuna
Lablab
Imperata
Maize
Residue treatment

Table 1. Initial chemical characteristics of shoots and roots of mucuna, lablab, imperata and maize[a]

Residue	N	lignin (L)	PP[b] %	ash	C: N	L: N	PP: N	L+PP: N
					Shoot			
Mucuna	3.7d	5.3ab	3.4d	6.4a	11.0	1.4	0.9	2.3
Lablab	3.4d	4.9ab	1.8ab	7.2b	12.0	1.4	0.5	1.9
Imperata	0.9ab	17.9c	4.6e	7.5b	42.2	19.0	4.9	23.9
Maize	1.2b	6.9b	1.7a	6.4a				
					Root			
Mucuna	2.0c	6.5ab	2.7c	9.6c	18.3	3.2	1.4	4.6
Lablab	1.7c	6.6ab	2.0ab	10.8d	21.8	4.0	1.2	5.2
Imperata	0.7a	7.1b	2.8c	7.1ab	59.4	10.3	4.1	14.4
Maize	1.0ab	4.3a	2.3bc	7.8b	37.3	4.3	2.3	6.6

[a]Values for shoot mixtures the legumes and imperata or maize were means of the individual components [b]soluble polyphenols; [c]means followed by the same letter in a column are not different using DMRT

Table 2. Proportion of residue-N mineralized after 42 d incubating mucuna, lablab, imperata, maize and their respective mixtures in soil; and their N mineralization rate constants (kN)

Residue	N mineralized at day 42[a] (% of added N)	Mineralization rate constant[a] KN (mgN kg^{-1} soil d^{-1})
	Shoot	
Mucuna (muc)	10.49	0.39
Lablab (lab)	5.63	0.38
Imperata (imp)	-52.11	-0.09
Maize (mz)	-38.43	-0.11
	Root	
Mucuna	-19.35	-0.08
Lablab	-18.80	-0.07
Imperata	-68.00	-0.10
Maize	-48.27	-0.07
	Shoot mixtures	
Mucuna	-13.13	-0.10
Lablab	-9.86	0.01
Imperata	-9.56	-0.10
Maize	-6.30	0.02

[a]negative values indicate N immobilization.

Table 3. Correlation coefficients for the relationship between initial chemical characteristics of plant residues and the proportion of C mineralized (% C_{min})

-	C	N	Lignin (L)	PP[a]	Ash	C: N	L: N	PP: N	(L+PP): N
Time (days)			%						
2	0.70*	0.86**	-0.62	-0.76*	-0.51	-0.69*	-0.62	-0.83**	-0.73*
3	0.63	0.81*	-0.65	-0.75*	-0.56	-0.73*	-0.64	-0.85**	-0.78*
5	0.50	0.77*	-0.65	-0.67	-0.46	-0.78*	-0.65	-0.83**	-0.84**
7	0.37	0.69*	-0.68	-0.62	-0.28	-0.83*	-0.64	-0.76*	-0.87**
10	0.30	0.67	-0.72*	-0.62	-0.22	-0.88**	-0.68	-0.70*	-0.87**
14	0.34	0.66	-0.75*	-0.65	-0.16	-0.90**	-0.73	-0.65	-0.82*
20	0.17	0.66	-0.78*	-0.63	-0.12	-0.91**	-0.74*	-0.64	-0.77*
28	0.20	0.63	-0.85**	-0.60	-0.16	-0.84**	-0.71*	-0.65	-0.72*
42	0.11	0.52	-0.84**	-0.62	-0.06	-0.87**	-0.69*	-0.61	-0.67

[a]solution polyphenols; *significantly correlated at $p<0.05$; **significantly corrected at $p<0.01$

Table 4. Correlation coefficients for the relationship between initial chemical characteristics of plant residues and labile C fraction, mineralization rate constants of labile (K_l) and resistant (K_r) C fractions

-	C	N	Lignin (L)	PP[a]	Ash	C: N	L: N	PP: N	(L+PP): N
Parameter			%						
C1 (mg C kg-1 soil)	0.30	0.66	-0.68	-0.32	-0.22	-0.78*	-0.78*	-0.70	-0.81*
K1 (mg C kg-1 soil d-1)	0.30	0.57	-0.55	-0.57	-0.23	-0.57	-0.26	-0.57	-0.50
Kr (mg C kg-1 soil d-1)	0.45	0.43	-0.64	-0.29	-0.58	-0.52	-0.49	-0.52	-0.57

[a]solution polyphenols; *significantly correlated at $p<0.05$

Table 5. Correlation coefficients for the relationship between initial chemical characteristics of plant residues and the proportion of C mineralized (% C_{min})

-	N	Lignin (L)	PP[a]	C: N	L: N	PP: N	(L+PP): N
Time (days)		%					
3	0.91**	-0.58	-0.78*	-0.84**	-0.66	-0.75*	-0.97**
7	0.94**	-0.59	-0.68	-0.80*	-0.72*	-0.68	-0.96**
14	09.87**	-0.64	-0.67	-0.73*	-0.73*	-0.65	-0.92**
28	0.83*	-0.68	-0.60	-0.68	-0.68	-0.63	-0.88*
42	0.82*	-0.71*	-0.57	-0.68	-0.67	-0.58	-0.81*
KN (mg N kg^{-1} soil d^{-1})	0.83*	-0.64	-0.43	-0.76	-0.71*	-0.59	-0.89**

[a]solution polyphenols; *significantly correlated at $p<0.05$; **significantly corrected at $p<0.01$

REFERENCES

Amato, M., 1983. Determination of carbon ^{12}C and ^{13}C in plant and soil. Soil Biology & Biochemistry 5, 611-612.

Anderson, J.M., Ingram, J.S., 1993. Tropical soil Biology and fertility: a handbook of methods CAB International, Wallington, UK, 221 pp.

Bremmer, J.N., Mulvaney, C. S., 1982. Nitrogen – total. Methods of soil analysis. Part 2. Agronomy Monograph no. 9: 595-624.

Fox, R.H., Myers, R.J.K., Vallis, I., 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polyphenol, lignin and nitrogen contents. Plant & soil 129, 251-259. Honeycutt, C. W., Potraro, L., Avila, K., Halteman, W., 1993. Residue quality, loading rate and soil temperature relations with hairy vetch (Vicia villosa roth) residue carbon, nitrogen and phosphorus mineralization. Biological Agriculture & Horticulture 9, 181 – 199.

Ibewiro, B., Vanlauwe, B., Sanginga, N., Merckx, R., 1998. Nitrogen contributions of roots to succeeding maize in herbaceous legume cover cropping systems in a tropical derived savanna. In: G. Renard, A. Neef, K. Becker, M. Von Oppen (Eds). Soil Fertility Management in West African land use Systems. Margraf Verlay, Weikersheim, Germany, Pp. 123 – 128.

IITA, International Institute of Tropical Agriculture, 1982. automated and semiautomated methods for plant and soil analysis soil analysis. Manual Series No. 7, (IITA), Ibadan, Nigeria, 56 pp.

Lathwell, D. J., 1990. Legume Green manures: Principles for management. Tropsoil Bulletin no. 90-01. Cornell University, New York, 29 pp.

Magdoff, F. Lanyon, L., Liebbhardt, B., 1997. Nutrient cycling transformations and flows: implications for a more sustainable agriculture. Advance in Agronomy 60, 1 – 73.

Matmbanegwe, F., Kirchmann, H., 1995. litter from a tropical woodland (Miombo): chemical composition and C and N mineralization. Soil biology & Biochemistry 12, 1639-1651.

Myers, R. J. K., Palm, C.A. Curevas, E., Gunatillekel, U. N., Brossard, M., 1994. the synchronisaiton of nutrient mineralization and plant nutrient demand. In: P. L. Woomer, M. J. Swife (Eds). The Biological Management of Tropical Soil Fertility. John Wiley & Sons, Chichester, UK, Pp 81 – 116.

Palm, C. A. Sanchez, P. A., 1991. Nitrogen release from the leaves of tropical legumes as affected by their lignin and polyphenol contents. Soil Biology & Biochemistry 23, 83-88.

SAS, 1990. SAS Procedures Guide, version 6, 3rd education. Statistical Analytical System (SAS) Institute, Caryn., NC, USA, 705 pp.

Swift, M., Heal, O.W., Anderson, J. M., 1979. decomposition in terrestrial ecosystems. Blackwell Scientific. Oxford, 372 pp.

Tian, G., Kang, B. T., Brussard, L., 1992. effects of chemical composition on N, Ca and Mg release during incubation of leaves from selected agroforestry and fallow plant species Biogeochemistry 16 103 – 119.

Tjitrosoedirjo, S., Hanum, L., Wiroatmodjo, J., 1986. Decomposition aspects of Imperata cylindrical biomass in relation to zero tillage technique. Biotrop Special Publication 24, 220-224.

Underwood, A. L., 1961. Carbonic anhydrase in the titration of carbon dioxide solutions. Analytical Chemistry 33, 955-956.

Van Soest, P. J., 1963. use of detergents in the analysis of fibrous feed. II. A rapid method for the determination of fibre and lignin. Journal of Association of Official & Analytical Chemist 46, 929 – 935.

Vanlauwe, V., Nwoke, O. C., Sanginga, N., Merckx, R., 1997. Impact of residue quality on the C and N mineralization of leaf and root residues of three agroforestry species. Plant & Soil 183, 121 – 131.