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Decomposition and nitrogen release by green manure legume residues in different soil types

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A laboratory incubation experiment was conducted over a 16-week period to determine decomposition and N release by three green manure legume species, Mucuna (*Mucuna pruriens*), Lablab (*Lablab purpureus* cv. Rongai) and Sunhemp (*Crotalaria juncea*), in three soil types from South Africa. The amount of N mineralized from the residues was determined at 2, 4, 8 and 16 weeks from the onset of incubation. Nitrogen release pattern of the three legume residues followed a similar pattern in all the three soils, with sunhemp treated soil having the highest amount of mineral N after 16 weeks of incubation in all the three soils, followed by lablab and then mucuna. The amount of mineral N ranged from 121 to170, 96 to 134 and 92 to 108 mg kg^{-1} in the sunhemp, lablab and mucuna treated soils, respectively. The cumulative amounts of N from the legume residues mineralized recovered as mineral N in soil after 16 weeks of incubation ranged from 21 - 41% (92 - 121 mg kg^{-1}), 30 - 68% (108 - 170 mg kg^{-1}) and 26 - 60% (93 - 147 mg kg^{-1}) of the initial added N contained in the residues in the soils with 62, 20 and 12% clay contents, respectively. Less than 50% of the initial added N was mineralized in the high clay content soil. Mineralization rate constant, *k,* was significantly correlated to the residue N content, net mineralized N, C/N ratio and Lignin/N ratio. Results from this study indicated that all the three legumes could contribute significant amounts of N for uptake by plants, with sunhemp tending to release N at a faster rate, followed by lablab and then mucuna. High clay content in soil slowed down N mineralization.

Key words: Green manure legumes, incubation, decomposition, N release, soil type.

INTRODUCTION

Most of the smallholder farms in Limpopo province of South Africa are located in soils of inherently low fertility and intensive cropping combined with shorter or no fallow periods and lack of addition of inputs has caused significant loss of organic matter and depletion of nutrient reserves in soils overtime. Consequently, crop yields are often low. Organic matter input to the soil has been shown to be critical for improving soil quality and optimizing nutrient and water efficiencies and ultimately crop productivity in such degraded agro-ecosystems (Woomer et al., 1994; Sanchez et al., 1997; Sinaj et al., 2001; Tschakert et al., 2004). One of the key limiting nutrients in these soils is nitrogen. The integration of green manure legumes as cover crops into the smallholder farming systems has the potential to enhance yields of subsequent crops, an effect which can be largely attributed to increase in plant available N in the soil as a result of N release from the decomposition of the legume residues.

In addition, with regard to soil amelioration, legumes are thought to be superior to non-legume green manure crops because they show an exceptional ability to utilize rather inaccessible soil phosphorus (P) and potassium (K) fractions (Yadvinder-Singh et al., 1992), hence improving availability of P and K to subsequent crops. However, understanding the nitrogen (N) mineralization patterns of green manure legume residues is crucial in the synchronization of N release from plant residue and uptake by subsequent crops. Green Manure decomposition and subsequent N release depend largely on residue quality and quantity, soil moisture and temperature and specific soil factors such as texture, mineralogy and acidity, biological activity and the presence of other nutrients (Myers et al., 1994). Studies on litter mineralization have linked rate of nutrient release to biochemical properties, especially lignin, polyphenols and N content (Palm and Sanchez, 1991; Palm et al., 2001; Wang et al.,

Table 1. Some physical and chemical properties of the soil samples used in the incubation study.

Parameter measured	Site		
	UNIVEN	Dzwerani	Bloodriver
pH	5.17	5.65	5.95
Sand (%)	10.6	57.8	82.3
Silt (%)	27.4	22.2	5.7
Clay (%)	62	20	12
Total N (%)	0.048	0.029	0.017
C (%)	1.52	0.56	0.37
Na (cmol$_{(c)}$/kg)	0.117	0.115	0.113
K (cmol$_{(c)}$/kg)	0.095	0.232	0.234
Ca (cmol$_{(c)}$/kg)	2.334	2.2	0.98
Mg (cmol$_{(c)}$/kg)	1.337	1.45	0.756
CEC (cmol$_{(c)}$/kg)	13.02	7.45	3.97

2004; Nziguheba et al., 2005).

Soil incorporated legume residues become useful to the succeeding crop when the nutrient release pattern from the decaying matter and the nutrient needs of the succeeding crop occur simultaneously (Myers et al., 1994). Despite the widespread use of green manure legume cover crops by smallholder farmers in most tropical areas to improve soil fertility, this practice is yet to take root amongst smallholder farmers in Limpopo province in South Africa. The objective of this study, which was part of an overall effort to investigate options for green manure legume integration into the farming systems, was to determine N mineralization patterns of three green manure legumes [(Mucuna (*Mucuna pruriens*), Lablab (*Lablab purpureus* cv. Rongai) and Sunhemp (*Crotalaria juncea*)] in three soils of varying texture (62, 20 and 12% clay), from the semi-arid smallholder farming areas of Limpopo province of South Africa.

MATERIALS AND METHODS

Soil characterization

Soils were sampled from the surface 20 cm layer at University of Venda (UNIVEN), Dzwerani and Bloodriver (Table 1). Soil pH was determined in water (1:2.5 soil:water ratio). Particle size analysis was performed using the hydrometer method (Gee and Bauder, 1986). Total Nitrogen (N) was determined by the Kjeldahl method while organic carbon (C) was determined by the Walkley Black method. Exchangeable cations and CEC were determined by the ammonium acetate extraction procedure (Thomas, 1982; Rhoades, 1982).

Plant material characterization

Above-ground tissue of Mucuna (*M. pruriens*), Lablab (*L. purpureus* cv. Rongai) and Sunhemp (*C. juncea*) were collected from the field when the crops were at vegetative stage. The material was oven dried at 65°C for three days (72 h), ground to pass through 0.5 mm sieve and analyzed for total C (Dumas dry oxidation method),

Kjeldhal N, cellulose, hemicellulose and lignin (Van Soest and Wine, 1968). (Table 2).

Nitrogen mineralization

The N mineralization experiment was carried out by the method as described by Kuo and Sainju (1998) with slight modification. The soil samples were air-dried, ground and passed through a 2-mm sieve. The mixed cover crop residues were added to the soil at the rate of 10 g kg^{-1} soil on a dry weight basis. A 300 g soil was placed in a plastic bag (50 μ thickness) and mixed thoroughly and the moisture content brought to about 70% of field capacity with distilled water before incubating the soil in the dark at room temperature (temperature was recorded regularly). A polyethylene "breather tube" (0.5 cm in diameter) was placed in the opening of each bag and the top of the bag was wrapped around the tube to allow air to diffuse in and out of the bag. A control without residue addition was included. Each residue treatment was replicated twice. After 2, 4, 8 and 16 weeks of incubation, the soil was weighed and distilled water was added to bring the soil moisture to its original level and the soil was mixed well. Ten grams of soil from each bag was removed and extracted with 100 mL of 1N KCL. The NH_4^+-N and NO_3^--N was then analyzed by auto-analyzer (Automated Segment flow analyzer).

Nitrogen mineralization from the residues, expressed in percent, was calculated from the difference in cumulative amount of mineral N between residue and control treatments at each sampling time, divided by the initial N in applied as residue material. The rate constant of N mineralization (k) was estimated using a single exponential equation $Y = \exp(-kt)$ (Wieder and Lang, 1982); where Y is the percentage N remaining of the residue mixtures at time t. To calculate k value, linear regressions of ln Y vs t were performed and the slope of the linear regression is the k value.

Statistical analysis

Data at each sampling time was analyzed as a randomized complete block using the General Linear Model (GLM) procedure of the Statistical Analysis Software (SAS Institute). Linear regressions were fitted between each of the substrate variables and the mineralization rate constants (k) values in order to determine the significance of the residue quality variables in determining rates of N release.
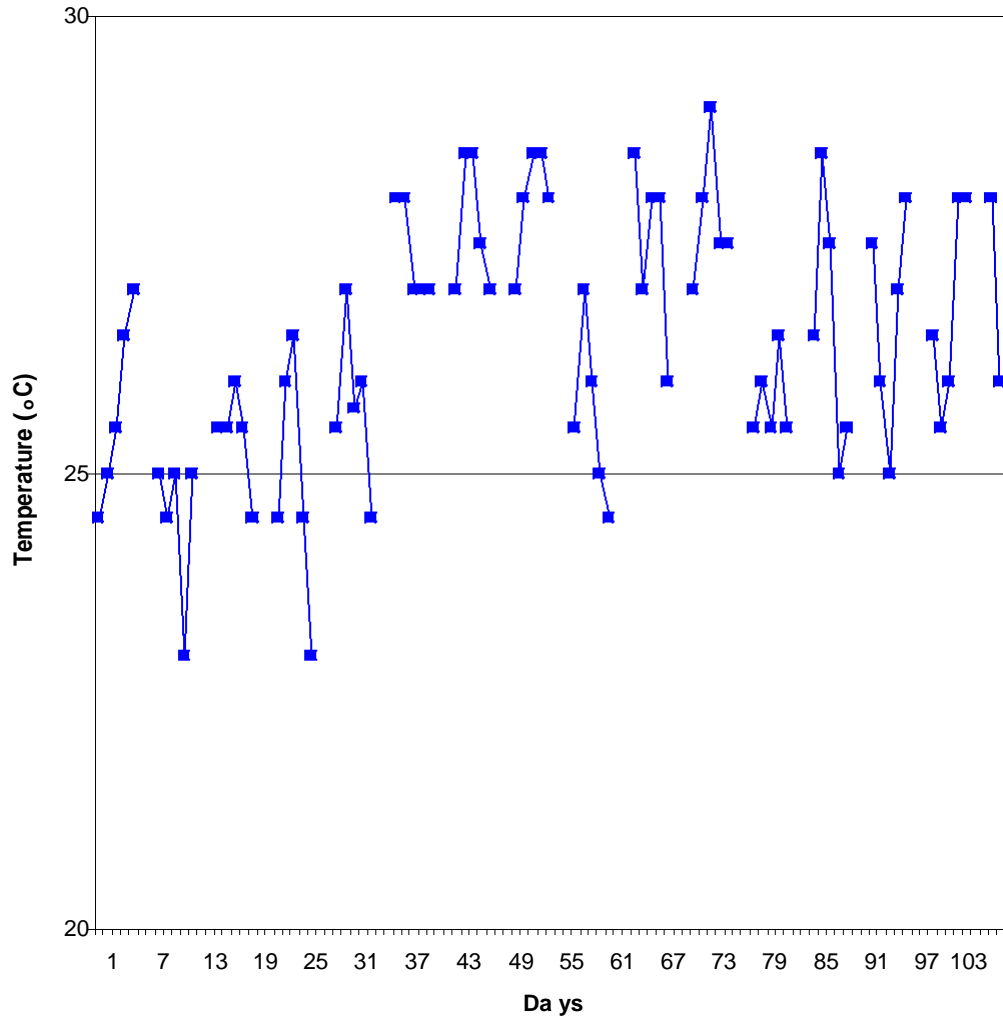
Figure 1. Temperature during incubation.

RESULTS

Temperature during incubation

The daily average temperature varied between 23 to 28.5^{o}C with an overall average of 26.42^{o}C over the 16 week incubation period (Figure 1).

Crop residue effects on N release

Mineral N release pattern by all residues throughout the 16 weeks incubation period followed a similar trend across all the soils (Figures 2a, b and c). At 2 weeks after the onset of incubation, N recovered as mineral N in soil ranged from 22 - 32, 5 - 10 and 11 - 22% of the initial added N contained in the sunhemp, mucuna and lablab residues, respectively, across all the soils. Between 2 to 16 weeks after the onset of incubation, N recovered as mineral N in the soil increased consistently by between

18.6 and 38.5, 15.9 and 22.1 and 17.1 and 30.3% of the initial added N contained in the sunhemp, mucuna and lablab residues, respectively, across all the soils. Sunhemp treated soil consistently had the highest amount of mineral N throughout the 16 week incubation period, followed by lablab and mucuna. At the end of 16 weeks of incubation, the amount of mineral N ranged from 121 to 170, 96 to 134 and 92 to 108 mg kg^{-1} in the sunhemp, lablab and mucuna treated soils respectively, across all the soils.

Soil effects on N release

After 16 weeks of incubation, N recovered as mineral N in Bloodriver soil was 60% (131 mg kg^{-1}), 26% (77 mg kg^{-1}) and 52% (119 mg kg^{-1}) of the initial added N contained in the sunhemp, mucuna and lablab residues, respectively (Figures 2a, b and c). In Dzwerani soil, the amount of N recovered as mineral N was 68% (148 mg kg^{-1}), 30% (86
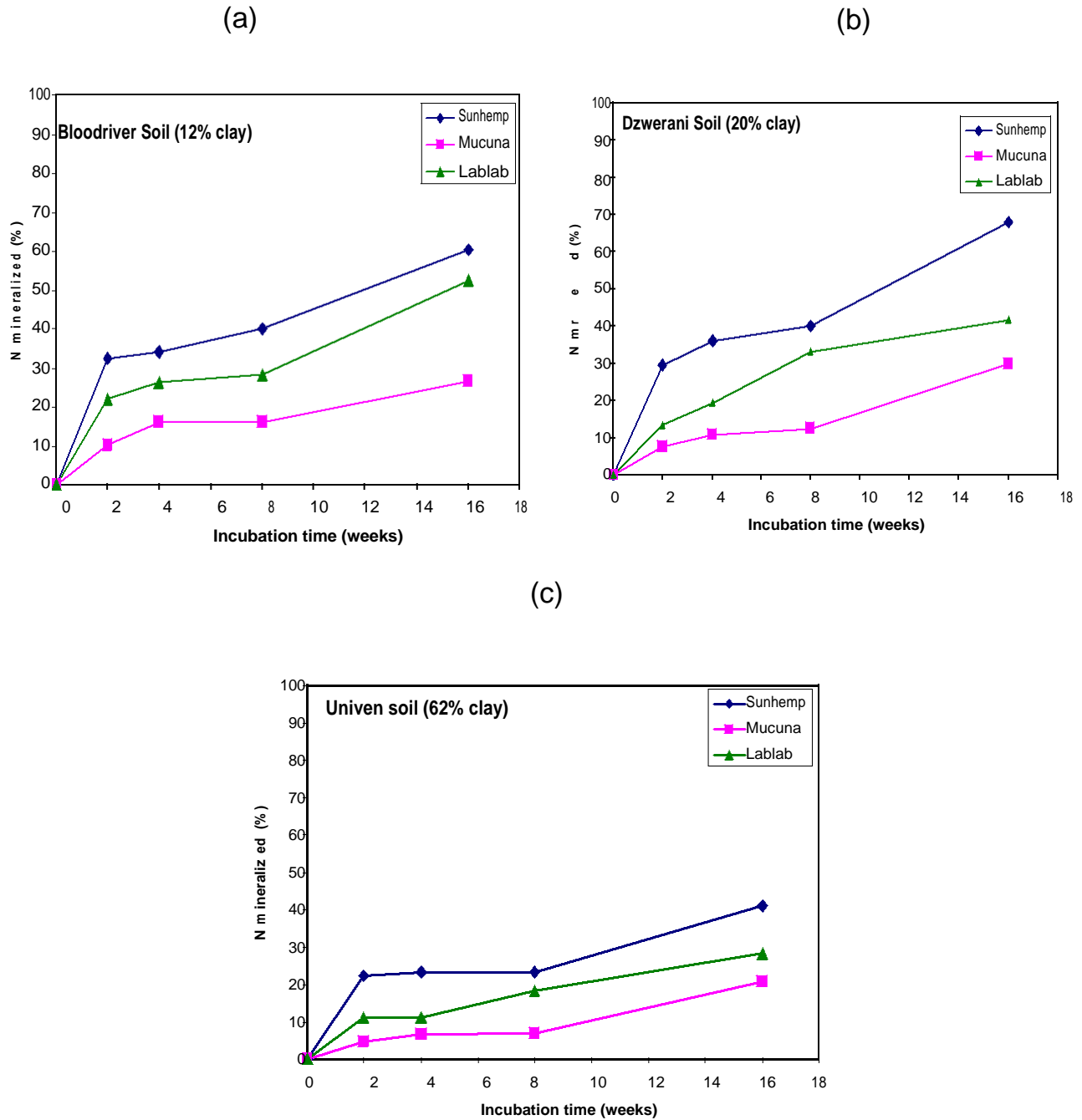
Figure 2. N mineralized from legume residues recovered as mineral N in (a) 12% clay soil (b) 20% clay soil and (c) 62% clay soil.

mg kg^{-1}) and 42% (94 mg kg^{-1}) of the initial added N contained in the sunhemp, mucuna and lablab residues, respectively. In UNIVEN soil, the amount of N recovered as mineral N was 41% (89 mg kg^{-1}), 21% (60 mg kg^{-1}) and 28% (64 mg kg^{-1}) of the initial added N contained in the sunhemp, mucuna and lablab residues, respectively. For each soil type, the average cumulative N recovered as mineral N after 16 weeks of incubation across all residue treatments was significantly different from N reco-

vered as mineral N after 2, 4 and 8 weeks of incubation (Table 3).

Relationship between residue quality and N mineralization

Table 4 shows the relationship between substrate quality variables of legume residues and N mineralization rate

Table 2. Some chemical properties of residues used in the incubation study.

Sample	N	C/N	Hemicellulose (%)	Cellulose (%)	Lignin (%)
Mucuna	2.9	16	13.8	22.9	8.6
Lablab	2.3	19	11.3	25.7	5.8
Sunhemp	2.2	21	6.59	40.6	7.7

Table 3. Average cumulative N recovered as mineral N after 16 weeks of incubation across all residue treatments in three soil types.

Incubation period (weeks)	Mineral N (mg kg^{-1})		
	Bloodriver	Dzwerani	UNIVEN
2	46.75 b	37.7 b	42.8 b
4	55.83 b	50.7 b	45.4 b
8	68.04 b	64.7 b	55.1 b
16	97.39 a	103.9 a	85.2 a
CV (%)	21.3	27.1	18.3

Within Columns, means followed by the same letter are not significantly different at p = 0.05.

Table 4. Coefficients of determination (R^2) for linear regressions between substrate quality variables of legume residues and N mineralization rate constants (k) of the residues incubated for 16 weeks.

Substrate quality variable	Coefficient of determination (R^2)
N (%)	0.70*
Net N mineralized	0.49*
C/N	0.86**
Lignin/N ratio	0.51*

*Significant at 5%; **Significant at 0.1%.

constant (k) of the residues incubated for 16 weeks. Mineralization rate constant, k, was significantly linearly related to the residue N content (R^2 = 0.70, p = 0.05), net N mineralized (R^2 = 0.49, p = 0.05), Lignin/N ratio (R^2 = 0.51, p = 0.05), and C/N (R^2 = 0.86, p = 0.001). For sunhemp treated soils, the mineralization rate constant varied from 0.005 to 0.012 week^{-1}. In Mucuna treated soil, the mineralization rate constant varied from 0.003 to 0.004 week^{-1}, while in lablab treated soils, the mineralization rate constant varied from 0.004 to 0.008 week^{-1}.

DISCUSSION

Sunhemp treated soil consistently had the highest amount of mineral N release, followed by lablab and then mucuna, treated soils, respectively, thus indicating that it was easily mineralized as compared to lablab and mucuna. Mucuna, despite having the highest N content of the three legumes, consistently released less mineral N. This may be attributed to the slightly higher lignin content (8.6%) as compared to lablab (5.8%) and sunhemp (7.7%). Sakala et al. (2000) made a similar observation with N release from pigeon pea residues, which despite having a high N content (1.86 - 3.18%) released less N than expected due to the substantial amounts of lignin (13 - 16%).

However, all the legumes produced significant amounts of mineral N by the end of the 16 week incubation period which potentially can contribute significantly to the N requirement of a subsequent crop, which in this case is most likely to be a maize crop (dominantly grown by farmers in this area). The tasseling period of maize in this region is approximately 10 - 12 weeks after planting. This period coincides with the maximum demand for N by the maize crop and the amount of N released by the decomposing legume residues can greatly benefit a subsequent maize crop.

In terms of the effects of soil type on N release, N release rate increased with incubation time in all the soils, although at a slower rate in the UNIVEN soil which had the highest clay content. UNIVEN soil, which had the highest clay content, had the least amount of mineral N content for all the residue treatments at the end of the

incubation period, with less than 50% of the initial added N being mineralized by the end of the incubation period. This could be attributed to the stabilizing effect of the clay on microorganisms and microbial metabolites which leads to slower decomposition and N turnover (van Veen et al., 1985). Many investigators have observed that organic residues decompose more slowly in soils with higher clay contents, especially clays having higher ex-change capacities (Lynch and Cotnoir, 1956; Sorensen, 1975). Microbial activity is controlled by soil physical conditions such as compaction, temperature and oxygen; by chemical conditions such as substrate availability and by biological conditions such as predatory or antagonistic organisms (Grant et al., 1993).

Reduced soil aeration in the UNIVEN clayey soil compared with the Dzwerani sandy loam to sandy clay loam and Bloodriver sandy soil may have further contributed to slower residue decomposition rate in the UNIVEN soil. Mineralization rate constant, k, was significantly linearly related to the residue N content, net mineralized N, C/N ratio and Lignin/N ratio (Table 4). In summary, results obtained in this study confirms findings by Neely et al. (1991) and Hunt (1977) which indicates the importance of the interactions between residue quality and microclimate influence in determining processes of decomposition and nutrient release.

Conclusion

The results from this study indicate that all the three legumes can contribute significant amounts of N for uptake by plants, with sunhemp tending to release N at a faster rate, followed by lablab and then mucuna. This may be of significant benefit to smallholder farmers in this region with limited resources to purchase sufficient N fertilizers, although field trials are necessary to validate the results in terms of the synchrony between N release by the legume residues and uptake by the crop. The rate of N release and the cumulative mineral N amount at the end of the 16 week incubation period in the high clay content (62%) UNIVEN soil was however lower than in Dzwerani and Bloodriver soils which had clay contents of 20 and 12%, respectively. Given that by the end of the 16 week incubation period, N release by the decomposing legume residues was still on an increasing trend, a study with a more prolonged incubation period to cover complete duration of maize crop growth to harvest maturity would provide some useful insights on the long-term dynamics of N mineralization/release in soil amended with these residues.

ACKNOWLEDGEMENT

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