Decomposition, Mineralization And Nitrogen Loss Following Application Of Different Rates Of Mucuna Green Biomass Under Field Conditions In Kenya

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Abstract

Knowledge on the relationship amongst mucuna green biomass application rate, decomposition pattern, mineralization and its distribution in rooting zone of maize is essential for efficient utilization of the legume as N source for maize production. Consequently, on-farm research was carried out for two seasons on sandy clay soil of southwest Kenya in 2004. The objective was to determine effect of different application rates of mucuna green biomass on its decomposition pattern, available soil N, distribution in rooting zone of maize, and leaching beyond the zone during the season when the biomass is incorporated into the soil. The treatments were mucuna applied at rates of 0, 30, 60, 120, 240 and 480 kg N ha^{-1}; and inorganic fertilizer-urea at 30, 60 and 120 kg N ha^{-1} included for comparison. The approaches employed in evaluating the treatments were: Field incubation using micro-lysimeter technique and, direct field sampling method. Randomized complete block design with three replications was used. Results showed that mucuna decomposition pattern remained same irrespective of application rate. Soil available N (SAN) increased over time after application of either source of N. The SAN level reached a significantly higher peak at 2 weeks after application (WAA). Direct field sampling showed that at 2 WAA most of the N accumulated at 50–100 cm depth, regardless of the N source. Significant differences in SAN level attributed to application of the various rates of mucuna and fertilizer were notable at 2 WAA, but had disappeared by 4 WAA. At the 2 WAA, fertilizer and mucuna applied at 60 and 120 kg N ha^{-1} respectively gave comparable SAN level and had non-significant effect on it at 0-15 and 15–30 cm depths. It required 240 kg N ha^{-1} equivalent of mucuna green biomass, or 120 kg N ha^{-1} of inorganic fertilizer-urea to substantially increase SAN level over the control. The loss of N beyond maize rooting zone was significantly higher from inorganic fertilizer than mucuna and the control, which were the same.

Keywords: Mucuna rate, decomposition, available N, loss beyond rooting zone

Introduction

Maize productivity in Kenya is most often limited by N supply (Hassan *et al*., 1998). *Mucuna pruriens* is considered one of the potentially low-cost alternative sources of N. But, the legume gives variable quantities of green manure biomass, depending on agro-ecological and niche conditions of production. Decomposition is an important process in the conversion of organic N to available N. Decomposition pattern of organic biomass is indicative of N mineralization (Jama and Nair, 1996). Knowledge on the relationship on mucuna green biomass application rate, decomposition pattern, available soil N and its distribution in rooting zone of maize is essential for efficient utilization of the legume as N source for maize production. Organic biomass decomposition is controlled mainly by residue, edaphic and residue management factors (Kumar and Goh, 2000). It is important to manage organic biomass so that most of the N is taken up by crops with little or no loss through leaching beyond the rooting zone of crop to avoid groundwater contamination.

The objective of this study was to determine effect of mucuna green biomass application rate on its decomposition, amount of available soil N in rooting zone of maize, and loss beyond the zone during the season when the legume biomass is incorporated into the soil.

Materials and Methods

Site description

On-farm experiment was carried out at Bokeabu village, Mosocho division, Kisii, southwest Kenya. Rainfall in the area is bi-modally distributed from February to August (long rains) and September to February (short rain season). The long and short rain seasons have rainfall ranging from 800 to 1000 mm, and 450 to 700 mm, respectively. Mean annual temperatures range from 18^{o}C to 21^{o}C and, average minimum from 11^{o} to 14^{o}C with a mean maximum of 25 ^{o}C. The experimental area lies in lower midlands zone one to two (LM_1-$_2$). Rainfall recorded at the site is presented in Figure 1.

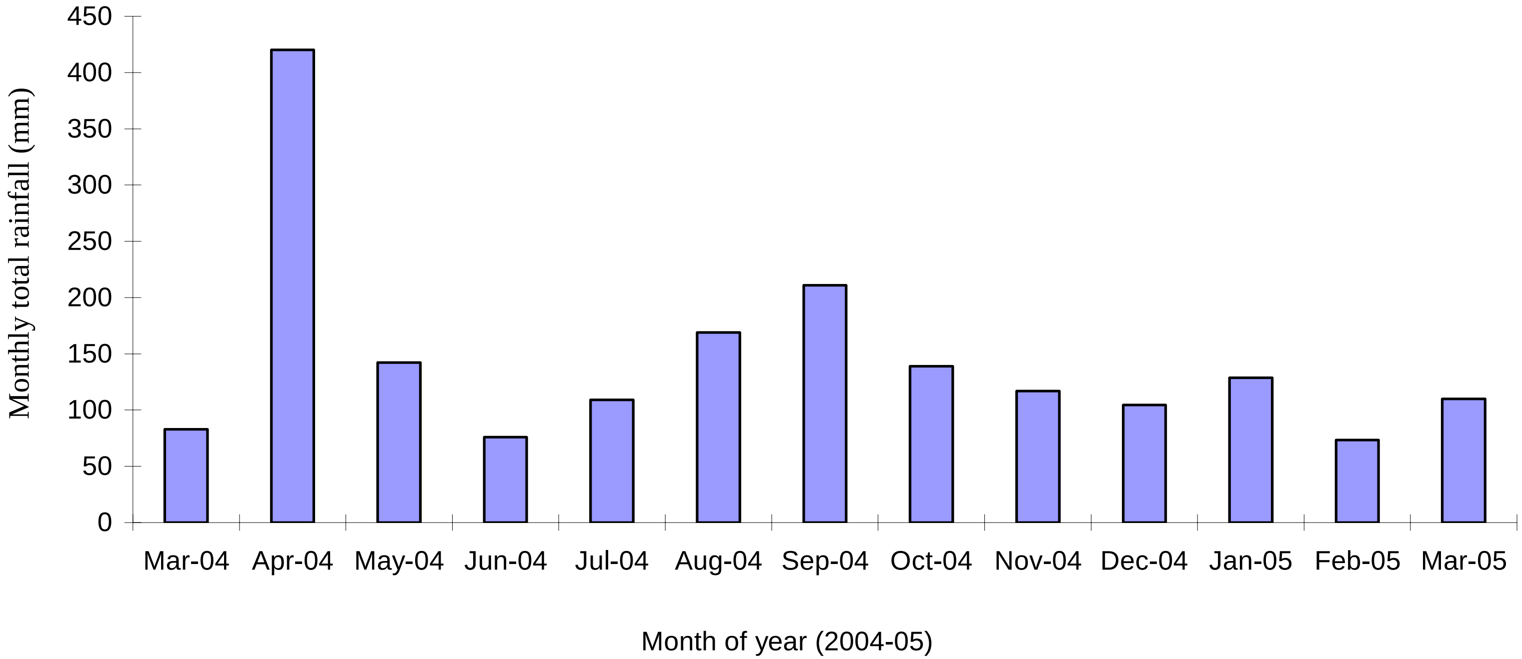


Figure 1. Monthly total rainfall during the experimental period (March 2004–March 2005) in the field trial site at Bokeabu village, Mosocho division, Kisii district, southwest Kenya. The arrow shows planting date and start of season. Amount of rainfall received is shown in brackets.

Site characterization

Table 1. Physical and chemical properties of soil in field experimental site at Bokeabu village, Mosocho division, Kisii district, southwest Kenya[1]

Parameter Measured	Units	Soil depth (cm)				[2] Critical values and classification.
		0-15	**15-30**	**30-50**	**50-100**	
Particle size						
- Sand	%	46	40	46	40	
- Silt	%	8	10	8	8	Sandy clay soil
- Clay	%	46	50	46	52	
pH (ratio 1:2.5) H_2O		5.1	5.9	5.2	5.6	(5.0-5.9) Strongly acid
Organic matter (O.M)	%	3.8	2.8	2.3	1.7	(2.1-4.2) Medium
Organic carbon (O.C)	%	2.2	1.6	1.3	1.0	(1.6-2.0) Medium
Total nitrogen (N)	%	0.18	0.14	0.07	0.05	(< 0.2) Low
C: N ratio		12	12	19	19	(< 20) Low
Avail. Phosphorus (Mehlich method)	ppm	8.5	1.5	0.25	0.22	(<20) Low
Avail. Potassium (K)	Cmol kg^{-1}	1.00	0.95	0.20	0.15	(0.2-1.5) Adequate
Calcium (Ca)	Cmol kg^{-1}	0.55	0.45	0.23	0.30	(< 2.0) Low
Magnesium (Mg)	Cmol kg^{-1}	4.7	5.15	5.15	3.35	(>3.0) Excessive
Sodium	Cmol kg^{-1}	0.01	0.01	0.01	0.01	(< 2.0) Adequate
Base saturation (Ca^{2+}, Mg^{2+}, K^+ and Na)	%	60	58	47	30	(40-85) Medium
CEC	Cmol kg^{-1}	10.4	11.4	11.8	12.6	(6-12) Low
Overall						Low to medium inherent fertility soil

Experimental design

There were two approaches used in evaluating soil available N levels from the treatments: (1). Field incubation using micro-lysimeter technique and, (2). Direct field sampling. The first approach provided for simultaneous observation on decomposition and available N levels, while the second one was suitable only for monitoring soil available N (SAN) level.

1. Field incubation using micro-lysimeter method

The treatments included mucuna green manure applied at rates of 0, 30, 60, 120, 240 and 480 kg N ha^{-1}. Randomized complete block design with three replications was employed. Treated soil and the control were incubated in micro-lysimeters made of plastic tubes, and vertically stood in holes 30 cm deep into soil in corresponding treatment plots. This was done same day after incorporation of mucuna directly into field plots at start of season (Figure 1). The experiment was carried out during long and short rain 2004.

2. Direct field sampling

<u>During application season</u>

Treatments were mucuna green manure rates of 0, 30, 60, 120, 240 and 480 kg N ha^{-1} directly incorporated into field plots at start of season (Figure 1), and inorganic fertilizer-urea applied at 30, 60 and 120 kg N ha^{-1}. Randomised complete block design with four replications was used. The experiment was carried out on-farm during long rain 2004.

Data collection

1. ***Field incubation using micro-lysimeter method***

i. *Decomposition*

To extract mucuna green manure left over at specified time, the micro-lysimeters were sampled into icebox and taken to laboratory. The incubated soil in the micro-lysimeter was soaked under running water tap into a bucket, and gently stirred to float remaining mucuna green manure. The un-decomposed manure was removed using 2 mm sieve and oven-dried at 105 ^{0}C for 72 hours, prior to dry weight determination. The sampling was done at 1, 2, 4 and 8 weeks after application during both long and short rain 2004.

ii. *Soil available N level*

In every time that destructive sampling of the micro-lysimeters was done for observation on left over mucuna green manure, soil sub-samples were collected into nylon bag and icebox, for laboratory analysis of soil available N. The sampling was done at 1, 2, 4 and 8 weeks after application of mucuna during short rain 2004.

2***. Direct field sampling method***

Soil auger was used to collect soil samples from treated plots at profile depths of 0-15, 15-30, 30-50 and 50-100 cm in 1, 2 and 4 weeks during application. Two soil sub-samples of the soil weighing 100g were taken. One of the samples was oven dried at 105 ^{0}C in 72 hours, and re-weighed to determine field soil moisture. The other to be used in determination of $NH4^{+}$ and NO_3^{-} was refrigerated at 4 ^{0} C until analysis time, when laboratory soil moisture was again measured. Soil analysis for available N was done by colorimetric method, using spectrophotometer at KEFRI/ICRAF/KARI Maseno Laboratory in Kisumu, west Kenya. Soil available N levels in experimental plots were determined during application season in long rains 2004.

Data analysis

Data collected was examined using the analysis of variance (ANOVA) procedures to determine the statistically significant result at probability level of 0.05. Genstat Discovery edition 2 (2007) was used in performing the analysis. The treatments found to be significant were subjected to mean separation using twice the standard error of difference (SED) to obtain the least significant difference (LSD). In presentation of result, LSD bars in figures are shown only where treatment mean differences are significant.

Results and Discussion

Mucuna green manure decomposition in micro-lysimeters

Decomposition pattern of mucuna green manure was bi-phasic with an initial rapid phase, followed by a long but slow second one (Figure 2). By the end of first week, 30 to 90 % of the biomass had decomposed. The remaining green manure decomposed at a slower rate and by the 8 and 16 weeks in the second phase approximately 5 to 30 % of the initial biomass remained (Figure 2). The initial phase of decomposition may be attributed to breakdown of water-soluble organic matter such as sugars and starch, cellulose, hemicellulose and amino acids mainly in the leaves and the second slower phase possibly due to decomposition of lignin and other resistant material in the stems (Wong and Nortcliff, 1995). Leaves and stems of cover crop species have different decomposition and mineralization kinetics due to differences in lignin and C:N ratios (Cabrera *et al*., 2005). In the mucuna green manure applied, C:N ratio of stem was 51:1 which was higher compared to 22:1 and 30:1 for leaves and pods, respectively. This may have contributed to the observed decomposition kinetics.

The percentage of remaining mucuna biomass was less in short than in long rain season suggesting faster decomposition in the former season (Figure 2). This was probably due to differences in rainfall amounts and distribution in the two seasons (Figure 1). The amount of rainfall in the months of March and September when green manure biomass was applied in long and short rains, respectively perhaps caused the observed differences. Although the total rainfall in long rain season 2004 was higher than in short rain season 2004, the amount of rainfall received in the first two weeks in the latter was higher than in the former and this might have accounted for variation in initial decomposition rates. Also, soil temperature differences amongst the seasons might have played role as well by influencing soil biomass activity. But, probably as observed by Cavelier *et al*. (2000) though microbial activity in decomposing residues is controlled by substrate availability, temperature and water, the latter factor was the main one. Bacteria and protozoa are sensitive to low matric potential since they can only move in water filled pores while, fungi and actinomycetes are less sensitive since they are able to take up nutrients at water potentials as low as -10 MPa (Wong and Nortcliff, 1995). So, it is probable that soil microbial biomass composition and populations might have varied between the two seasons with changes in soil moisture, giving rise to the seasonal trend observed.

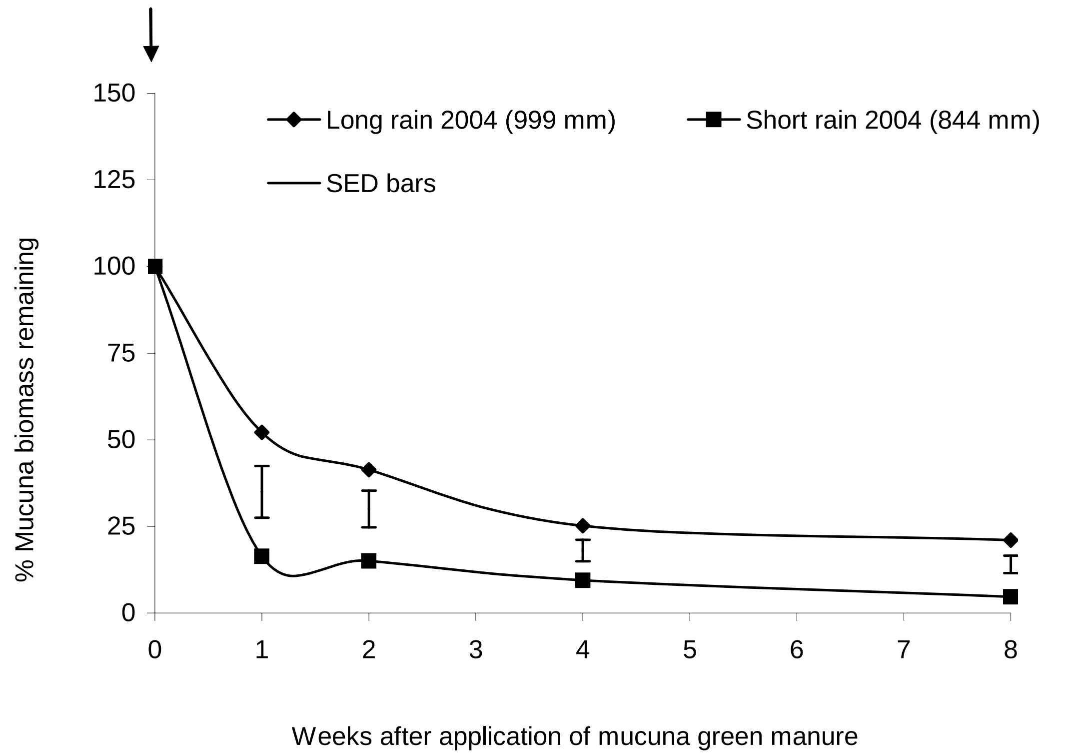
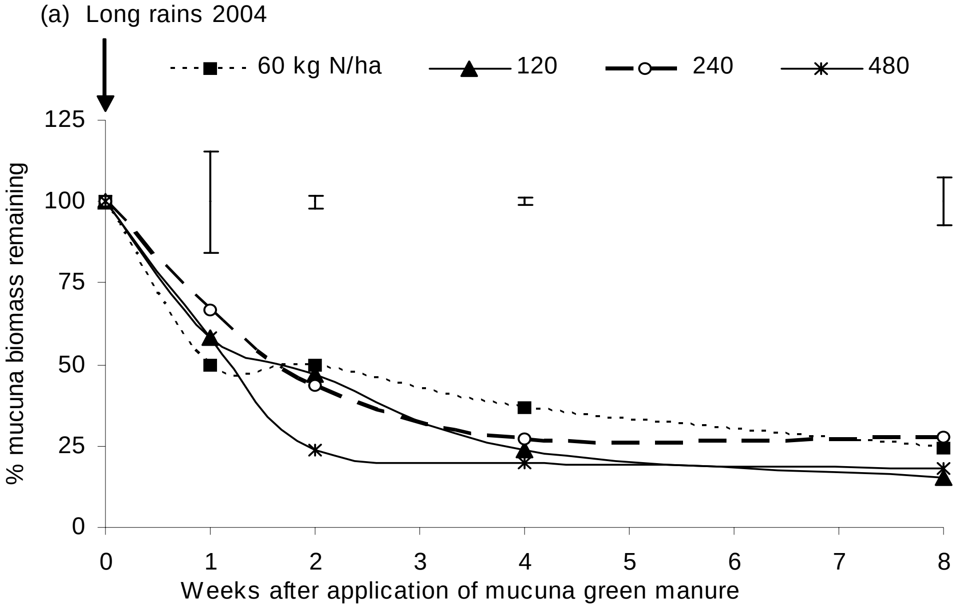


Figure 2. Mucuna green manure decomposition rate in field incubated micro-lysimeters at Mosocho, Kisii, southwest Kenya: Arrow shows planting date.

Mucuna green manure application rate had non-significant effect on decomposition of the biomass in long and short rain seasons; with the exception at 2 and 4 weeks after planting in long rains 2004 but the trend was inconsistent (Figure 3). According to Constantinides and Fownes (1993) nitrogen release pattern is influenced by chemical characteristics of the substrate for instance tissue N concentration, C: N ratio, lignin and polyphenols. In this study, the tissue N, lignin and polyphenol concentration of mucuna green manure applied was 1.6%, 7 % and 3%, respectively. The observed N concentration is within threshold for transition from net immobilization to net mineralization (Wong and Nortcliff, 1995). But the lignin and polyphenol contents are below the thresholds of 15 % and 4% considered to slow N release and result in net immobilization of N (Palm, 2001). Thus, the tissue N concentration of the substrate may have been major determinant of N release process in this case.



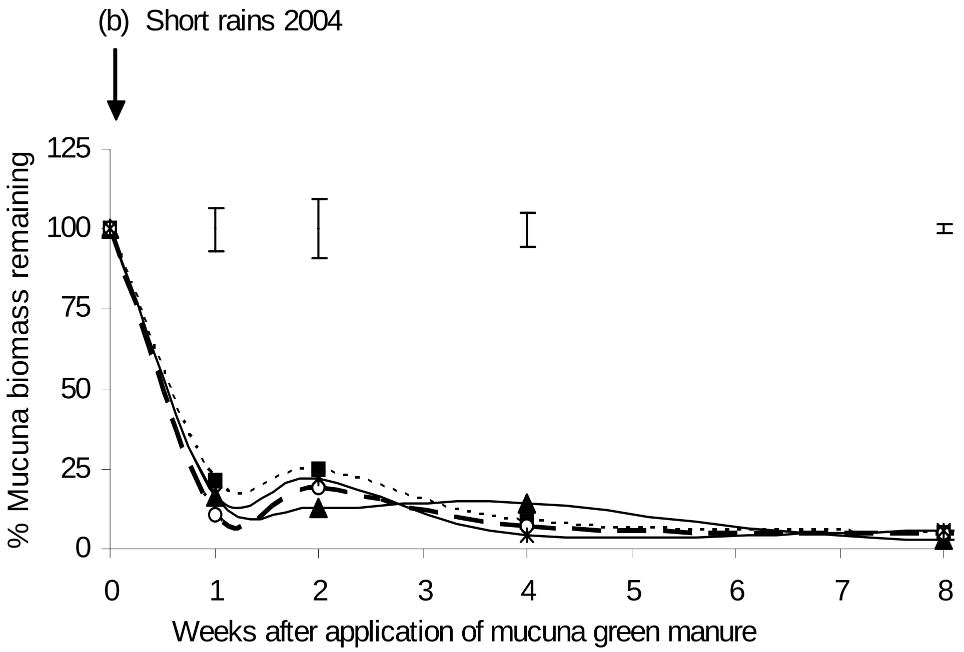


Figure 3. Effect of application rate on decomposition of mucuna green manure in field incubated micro-lysimeters at Mosocho, Kisii, southwest Kenya in the long and short rain 2004 seasons. SED bars indicated and arrows show planting dates.

Soil available N from field incubated mucuna biomass in micro-lysimeters

Nitrogen release pattern was similar irrespective of mucuna green manure application rate (Figure 4). Soil available nitrogen (SAN) was initially low at one week after application (WAA) but increased rapidly at two WAA and decreased rapidly by the fourth week, then changed thereafter. The similarity in the SAN at different times irrespective of mucuna green manure rates was possibly because of similarity in the chemical properties of the applied biomass and the environmental factors controlling N mineralization process, like soil temperature and moisture (Cabrera *et al*., 2005). The variation in the amount of SAN amongst treatments occurred only at 2 WAA but was primarily influenced by amount of biomass applied. Soil available N was comparable at 0 to 120 kg N mucuna ha^{-1} application rate but higher and comparable at 240 and 480 kg N mucuna ha^{-1}.

The N release trend observed was comparable to the decomposition trends (Figures 2, 3 and 4). This is not surprising because biomass decomposition and N mineralization occur simultaneously (Anderson and Ingram, 1993). The available soil N patterns are comparable to those reported by Jama and Nair (1996). Ambrosano *et al*. (2003) noted that mineralization of organic N in plant material added to the soil is initially fast, because of the breakdown of the more easily decomposable components, but it slows down subsequently until stabilization of the organic residue. In this study, N mineralization pattern in different rates of applied mucuna green manure was similar to the control. This was perhaps because cultivation of the field prior to planting may have disrupted soil aggregates thereby increasing availability of carbon substrates for microbial activity, leading to a mineralization flush soon after, possibly giving rise to the observed N peak at two weeks, irrespective of treatment (Jarvis *et al*., 1996). Protected soil organic matter has low C:N ratio than the rest and is ready to mineralize upon disruption of soil aggregates because of increased substrate supply and modified soil environment conditions (aeration, water content, temperature), which enhance microbial activity (Silgram and Shepherd, 1999).

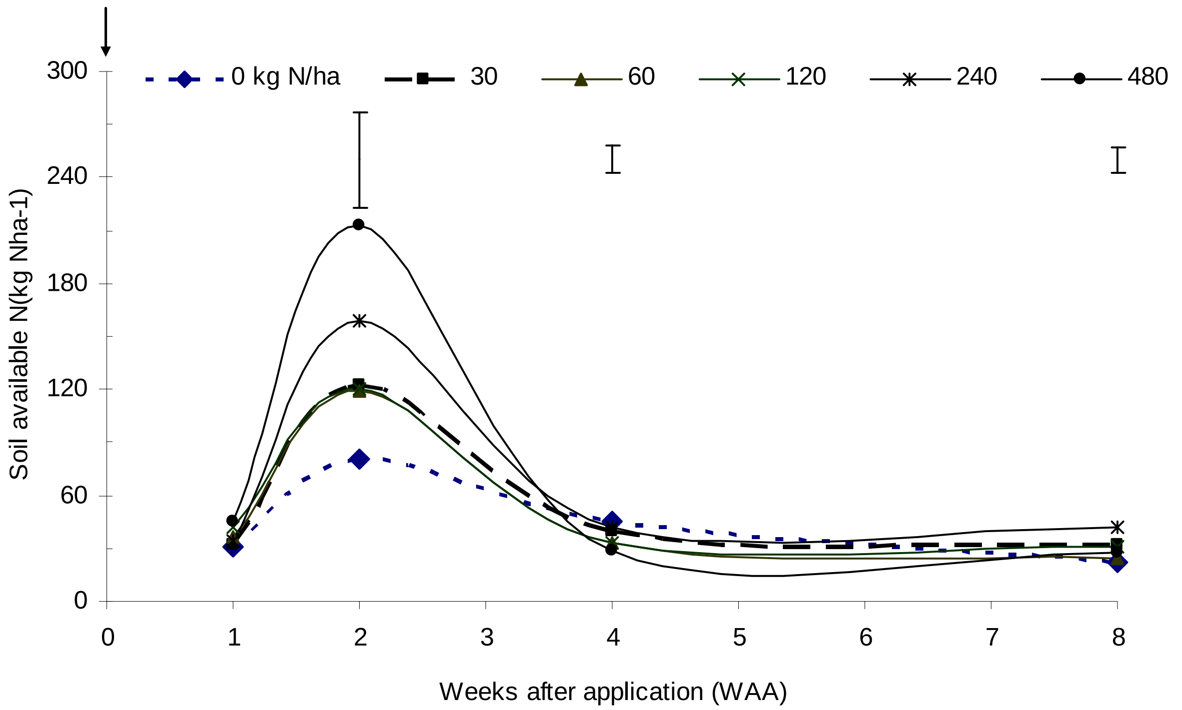


Figure 4. Soil available N levels from different application rates of mucuna green manure in micro-lysimeters at Mosocho, Kisii, southwest Kenya (Short rain 2004). Arrow shows planting date.

At week 4 after mucuna application and maize planting, the soil available N stabilized at 25 to 50 kg N ha^{-1}, with or without addition of green manure (Figure 4). This is probably because some N is tied up in the recalcitrant material left over perhaps from stem tissues which are high in lignin and polyphenols contents and are considered to regulate the slow and second decomposition phase (Jama and Nair, 1996). Twigs and leaves from agroforestry species, namely, *Leucaena leucocephala* and *Cassia siamea* were found to get to steady level of decay at 6 to 10 weeks (Jama and Nair, 1996). From the SAN results, it is clear that whatever crop response to applied green manure obtained was dependent on amounts of N released at about 2 week. Also, the response could have been dependent on N amounts released thereafter (Figure 4).

Soil available N in cropped field area during season in which mucuna or inorganic fertilizer was applied.

The total soil available nitrogen (SAN) in the cropped area in the top 100 cm varied significantly in response to applied N irrespective of source and was highest two weeks after application then decreased (Figure 5). The SAN was comparable at 60 and 120 kg at all times irrespective of N source but were significantly lower compared to where mucuna N was applied at 240 and 480 kg N ha^{-1} (Figure 5, Table 2).

The SAN was highest in all soil layers at 2 WAP and then declined at 4 WAP (Figure 5) and there was no significant interaction effect between application rate and depth (Table 2). The results suggest that the quantity of SAN was primarily influenced by soil organic matter mineralization process and not the treatments. Mtambanengwe and Mapfumo (2006) observed that the quantity of legume residue applied did not significantly interact with either resource quality or sampling depth, suggesting that N-mineralization patterns of the different organic resources were generally the same irrespective of application rate.

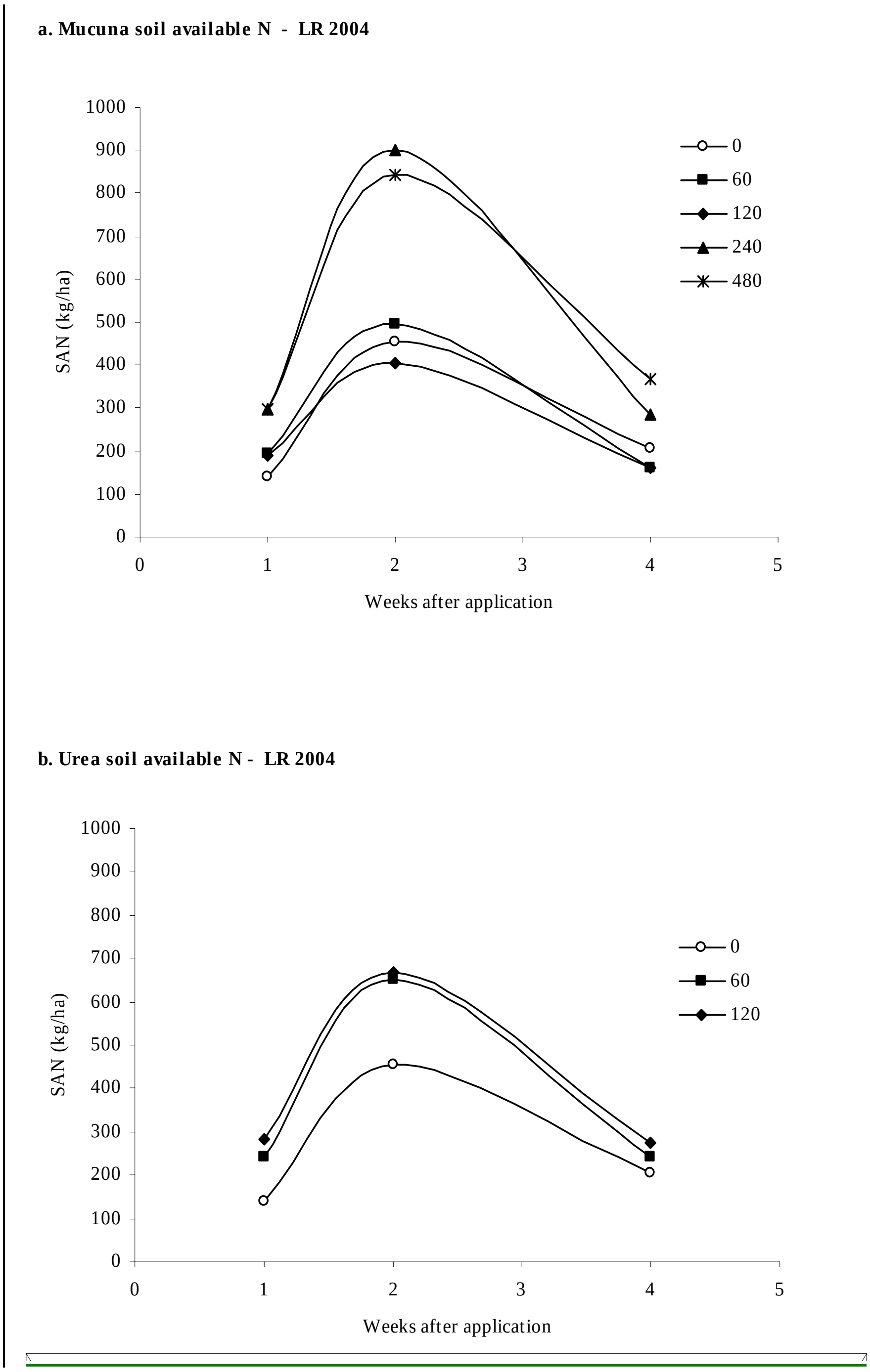


Figure 5. Effect of mucuna and inorganic fertilizer-urea application rate on available soil N in the top 100 cm in the season of application at Mosocho, Kisii, southwest Kenya (Long rains 2004) (Rainfall=999 mm).

The available N levels in soil varied significantly in the profile depth sampled (Table 2, Figure 6). The levels increased with depth and were highest at 50–100 cm in 4 weeks after application possibly due to leaching of N in soil water over time (Brady, 1994). Bowen *et al* (1988) observed that upon incorporation of legume green manure, inorganic N accumulated in the top 60 cm but by 12 weeks, most of it had leached due to heavy rainfall and was located between 60 cm and 120 cm. There was decrease of SAN level in the 50-100 cm soil layer at 4 WAA (Figure 6, Table 2). This may have been primarily due to leaching into higher depths of the soil profile as observed by Bowen *et al* (1988), and to a lesser extent due to uptake by plants.

The SAN was highest in all soil layers at 2 WAP and then declined at 4 WAP and there was no significant interaction effect between application rate and depth (Table 2) (Figure 7). The results suggest that the quantity of SAN might have been influenced primarily by soil organic matter mineralization process and not the treatments. Mtambanengwe and Mapfumo (2006) observed that the quantity of legume residue applied did not significantly interact with either resource quality or sampling depth, suggesting that N-mineralization patterns of the different organic resources were generally the same irrespective of application rate. The idea is supported by observation that soil mineralization pattern was same irrespective of whether the source of N applied was mucuna green biomass or inorganic fertilizer-urea (Figure 7).

Table 2. Effect of mucuna green manure and inorganic fertilizer-urea application rate on soil available nitrogen in 1, 2 and 4 weeks after application (WAA), during application season, at Mosocho, Kisii, southwest Kenya (Long rain 2004) (Rainfall = 999 mm).

Applied fertilizer N source and rate (kg N ha^{-1})		**Soil available nitrogen (kg N ha^{-1}) at 1, 2 and 4 weeks after application (WAA)**															
		1 WAA				**2 WAA**				**4 WAA**				**Sampling time and interactions**			
		0-15	15-30	30-50	50-100	0-15	15-30	30-50	50-100	0-15	15-30	30-50	50-100	0-15	15-30	30-50	50-100
Source	N kg/ha																
Mucuna	0	24	25	24	66	35	72	107	242	34	23	38	110				
	60	41	26	24	104	46	82	87	281	42	15	22	81				
	120	34	30	36	91	43	80	78	203	39	17	34	73				
	240	23	26	53	195	90	91	236	485	50	28	54	154				
	480	46	42	43	167	116	121	153	455	73	51	71	172				
Urea	60	24	19	78	121	45	80	102	425	41	21	34	147				
fertilizer	120	33	37	122	91	36	61	120	449	76	20	39	138				
Mean		**32**	**29**	**54**	**119**	**59**	**84**	**126**	**363**	**51**	**25**	**42**	**125**				
Time F test														*	*	*	*
LSD time (T)														16	13	27	102
N Source (NS) F		ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns	*				
LSD N Source		16	32	55	70	16	28	34	132	31	14	13	43				
LSD N Source rates				85	69								74				
N Source x time F														ns	ns	*	ns
LSD NS x time														11	22	32	77
Nitrogen rate F test		ns	ns	*	*	*	*	*	*	ns	*	*	*				
LSDN rate (NR)		22	32	57	49	36	33	69	170	34	12	14	60				
Nitrogen rate x time														*	*	*	*
LSD NR x time														31	25	23	102
%C.V Treatment		39	48	59	18	35	22	31	26	38	28	19	27				

F=Fisher test; * =Differences significant, ns=Differences non-significant; LSD=Least significant difference; N source rates=60 and 120 kg N ha^{-1}

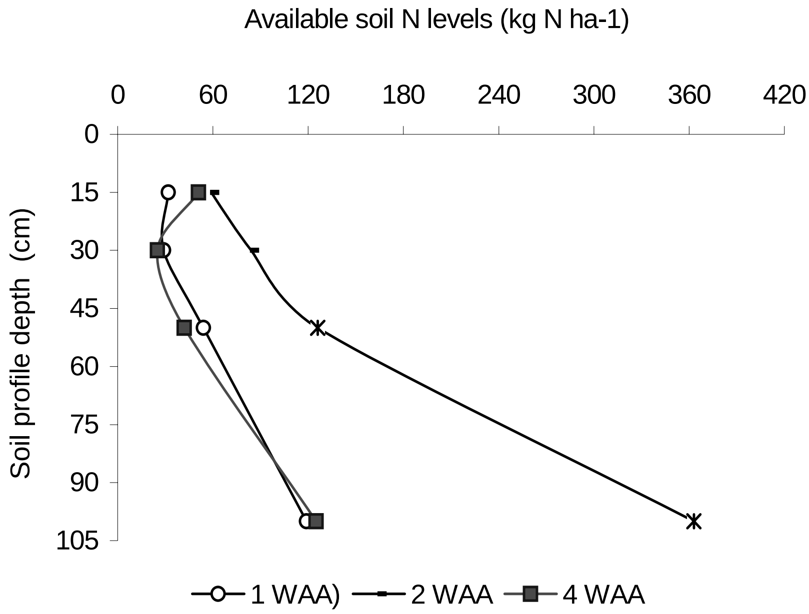
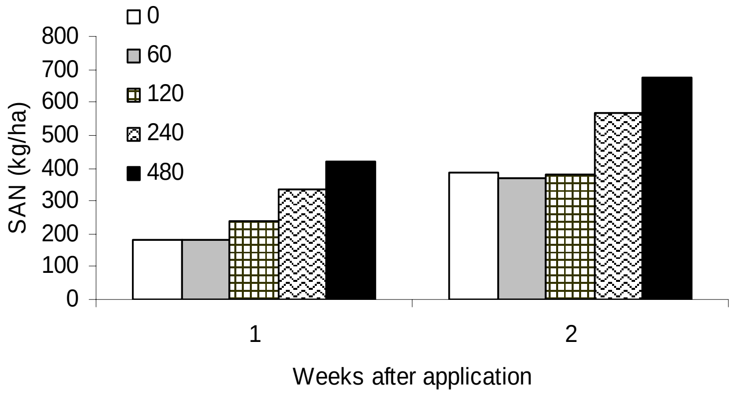


Figure 6. Available soil N levels at different soil depths at 1, 2 and 4 weeks after application of nitrogen and planting of maize at Mosocho, Kisii, southwest Kenya

a. Mucuna green biomass soil available N - SR 2004



b. Urea fertilizer soil available N - SR 2004

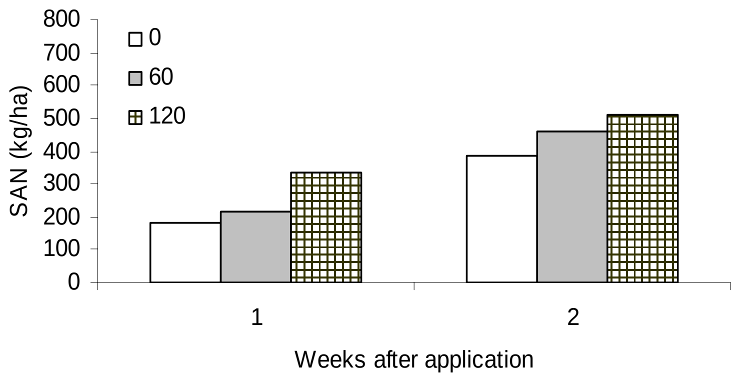


Figure 7. Effect of mucuna and urea fertilizer application rate on available Soil N in the top 100 cm in one season after N application.

Conclusions

Mucuna green manure has two phases of decomposition: an initial rapid phase and a slower second one. Half-life of incorporated mucuna green manure under field conditions was one week. Decomposition pattern remained the same irrespective of mucuna green manure application rate. Nitrogen release peaked at two weeks after application.

At application rates of 60 and 120 kg N ha^{-1}, available soil N levels attributed to mucuna green manure and inorganic fertilizer were the same.

During the application season, mucuna green manure and inorganic fertilizer rates of 60 and 120 kg N ha^{-1} had non-significant effect on soil available N whether under field planted with maize or in soil protected from maize N uptake inside micro-lysimeters.

It required mucuna green manure applied at 240 kg N ha^{-1} or inorganic fertilizer at 120 kg N ha^{-1} to significantly raise available N levels over the control.

The loss of N beyond maize rooting zone was significantly higher from inorganic fertilizer than mucuna and the control, which were the same.

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