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Potential Effect of Mucuna Green Manure Application Rates on the Decomposition and Availability of Nitrogen in Varying Soil Moisture Levels under Greenhouse Conditions

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Abstract

Knowledge on the possible influence of mucuna green manure application rate, and variable soil moisture conditions on decomposition of its biomass and available soil nitrogen levels is vital for efficient resource management. Consequently, potted soil experiment was carried out on these factors for 8 weeks under glasshouse conditions at Field Station-Kabete, University of Nairobi, Kenya in March-April, and repeated in May-June, 2005. The objective was to determine potential effect of mucuna green manure application rate and varying soil moisture level on decomposition pattern and available nitrogen in sandy clay soil collected from an experimental site in southwest Kenya. The treatments studied were: mucuna green manure applied at rates of 0, 60, 120 and 240 kg N ha^{-1} equivalent to 0, 3, 6 and 12 t DM ha^{-1} of the biomass and, soil water potentials at field capacity (-0.01 Mpa), wilt point (-1.5 Mpa), and intermediate (–0.75 Mpa) levels represented by moisture contents of 22, 12 and 18 %, respectively. The two factors were combined factorially in a randomized complete block design with three replications. The treatments were applied and maintained in 10-litre imperforated plastic pots filled with 4 kg soil. Destructive sampling of soil and observation were done at 1, 3, 5 and 8 weeks after treatment. Results obtained showed that mucuna green manure application rate had non-significant effect on decomposition pattern. But, effect of soil moisture level on the pattern was significant. Mucuna green manure showed two phases of decomposition: an initial rapid phase and a slower second one. Half-life of mucuna green manure under field capacity soil moisture condition was one week. But, it took no less than 5 weeks for 50 % of the applied mucuna biomass to disappear if soil water condition was varying from wilting point, intermediate to field capacity as is likely to happen in field environment.

Key words: mucuna rate, soil moisture, decomposition, nitrogen

Introduction

Maize yield in Kenya is constrained by limited application of nitrogen caused by high cost of inorganic fertilizer. Mucuna green manure is one of the possible low-cost organic alternative sources of nitrogen. But, biomass productivity of the legume is low and varies with production circumstances. Also, soil moisture conditions under field environment fluctuate with rainfall, giving erratic crop response to applied mucuna green manure nitrogen possibly because of the role that water plays in mineralization process. Soil microbial activity in decomposing organic residues is controlled by substrate availability, temperature and water among other factors (Schomberg *et al*., 1994). So, understanding the influence of variable soil water conditions on decomposition pattern of different rates of applied mucuna green manure, and soil available nitrogen levels, is critical for efficient resource management.

Determination of available N levels attributed to different application rates of mucuna green manure by direct field sampling of soils from experimental plots planted with maize, has its disadvantages. Maize N uptake may interfere with levels of mineralized N to the extent that treatment differences are distorted. There may be leaching of N, runoff, and the field environment is characterized with changes in weather conditions, particularly rainfall that affects soil moisture levels. To overcome some of the shortfalls, effects of mucuna green manure application rate on, decomposition and soil available N were studied in imperforated plastic pots under glasshouse conditions where soil water content was controlled. This was done to verify the role that soil moisture under rainfed conditions in the field might play in influencing decomposition of applied biomass and its mineralization to release nitrogen. The objective was to determine the potential effect of mucuna green manure application rate and varying soil moisture conditions on decomposition pattern and available soil N in sandy clay soils.

Materials and Methods

Experimental design

The experiment was conducted in greenhouse at the Kabete Field Station, University of Nairobi for two seasons. The first and second seasons covered the period March to April, and May to June 2005, respectively. The experiment consisted of two factors: application rate of mucuna green manure and level of soil moisture. Mucuna was tested at application rates of 0, 60, 120 and 240 kg N ha^{-1} equivalent of the green manure biomass. Soil moisture levels studied were water potentials (Ψ) at field capacity (ψ=-0.01 MPa), wilting point (ψ =-1.5 MPa), and intermediate water condition (ψ =-0.75 MPa). The treatments were combined in factorial and replicated three times in completely randomized design. The amount of soil filled in 10 litre plastic non-perforated pots was 4 kg. The green manure was chopped manually using a machete into small pieces of less than 2 cm and mixed with soil in quantities calculated on dry matter (DM) basis according to the rate of application. At tissue N concentration of 1.6 % for mucuna, application rates of green manure at 0, 60, 120 and 240 kg N ha^{-1} worked out to 0, 7, 14 and 28 g DM/pot. Maize was planted at the rate of one seed/pot. .

Data collection

Soil water retention characteristics

Water retention properties of soil from the field experimental site at Mosocho, Kisii, southwest Kenya, were determined prior to its use in the greenhouse pot experiment. The soil was transported to Kabete Field Station and dried to constant weight in the sun to mimic field condition, and to minimize disruption of soil aggregates. Plant residues and other foreign particles were physically picked out, and large clods broken by hand. There are two soil moisture conditions that are important consideration in connection with plant growth (Al-Khafaf and Hanks, 1974): Field capacity is taken as the maximum amount of water that can be stored in a soil; Wilting point is lower limit of readily available water. These occur at soil water potentials (ψ) of -0.01 MPa and -1.5 MPa, respectively (Salisbury and Ross, 1989). The two water conditions and an intermediate one were determined for the soil. A sub-sample was taken, and using filter paper method (Hamblin, 1981), soil moisture levels at wilting point (-1.5 MPa) and field capacity (-0.01 MPa) were determined. The intermediate moisture level was computed as the median between field capacity and wilt point, and this came to –0.75 MPa.

The three moisture level treatments were maintained by weighing pots on sensitive balance thrice daily and making up loss in weight by addition of water.

Decomposition of mucuna green manure

Decomposition was recorded as percentage of mucuna green manure remaining at 1, 3, 5 and 8 weeks after application (WAA). Anderson and Ingram (1993) state that, direct measure of weight loss is one of the methods that have been used to measure decomposition. Carbon dioxide emission is used as a measure of the process as well.

Soil available nitrogen

The analysis to determine available N level in the soil was done at the Soil Science Laboratory of the University of Nairobi. The procedure used is detailed in the laboratory manual, and is described as titrimetric method. Wet soil samples from the field were sub-sampled into aluminum tins and oven-dried at 105^oC for 72 hours to determine moisture content. At the same time, another sub-sample from the same sample, weighing 2 g was placed into a plastic bottle, and 20 ml of 2 M KCl was added. The bottles were tightly closed and put on shaking machine for 1 hour, after which they were removed and filtered using Whatman No. 42 paper. The filtrate was pipetted into a distillation flask. Magnesium oxide was added into the flask prior to its distillation to release ammonia gas, which was captured in 20 ml of 1 % boric acid, and up to 150 ml of the distillate was collected. This was to be used in determination of NH_4^+ available in the soil. Devarda's alloy was then added to the mixture in same flask, to reduce NO_3^- and NO_2^- to ammonia gas, which was absorbed in 20 ml of 1% boric acid, and up to 150 ml of the distillate was collected. This was used in determination of NO_3^- available in soil.

Mixed indicator was added to the boric acid carrying the absorbed ammonia, and titrated with 0.001 N

H_2SO_4. The indicator turned from green to light pink as end point. The volume of 0.001 N H_2SO_4 involved in the titration was noted and used in computing the milligrams (μg) of N per gram (g) of soil, in both ammonium and nitrate forms. The two were added together to obtain the sum of the mineral N. Sample preparation for analysis was done in triplicate. (1.0 ml of 0.001 N H_2SO_4 = 14 μg).

Data analysis

Data collected from the experiments 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) software was used in performing the analysis. Significant treatment means were subjected to mean separation using the least significant difference (LSD) test.

Results and Discussion

Water release characteristic curve of sandy clay soil

Moisture release characteristic curve developed using the filter paper method and focusing on the three soil water potentials studied is presented in Figure 1. From the curve, soil water contents at wilting point (ψ=-1.5 MPa), intermediate potential (ψ=- 0.75 MPa) and field capacity (ψ=-0.01 MPa) were established as 12, 18 and 22 %, respectively. Regression co-efficient for relationship between soil water potential (Ψ) and its water content (%) was 0.91 that is high and indicates close association between the two parameters for the sandy clay used. This is possibly because water potential of moist soil kept in airtight container with filter paper for 3 days as was done in this case is perhaps the same and close to equilibrium. Hamblin (1981) recommended durations ranging from minutes to days equilibration time for the filter paper method. Al-khafaf and Hanks (1974) recommended 2 days for the same. If kept with moist soil, water or vapour will flow from the soil into the filter paper until equilibrium is achieved (Leong and Rahardjo, 2002). The filter paper like the soil is porous (Al-khafaf and Hanks (1974).

The result shows that the filter paper method and water release curve generated could be used with reliability to predict soil moisture content held at different water potentials of the sandy clay. Certainty in using the filter paper method has been observed by Williams and Sedgley (1965) and, MacQueen and Miller (1968). The curve indicates that available water is between 18 to 20%, with wilting point (ψ=-1.5 MPa) being at 14%, which are narrow ranges perhaps because of the nature of sandy clay soil. The advantages of the method include its simplicity, low cost, and ability to measure a wide range of suctions (Leong and Rahardjo, 2002).

Effect of mucuna green manure application rate on decomposition

The rate of decomposition was evaluated using the percentage of

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

Parameters Measured	Units	Soil depth (cm) 0-15	15-30	30-50	50-100	[2] Critical values and classification.
Particle size						
- Sand	%	46	40	46	40	
- Silt	%	8	10	8	8	Sandy clay soil
- Clay	%	46	50	46	52	
Bulk density	g cm^{-3}	1.0	1.1	1.1	1.1	
pH (ratio 1:2.5) H_2O		5.1	5.9	5.2	5.6	(5.0-5.9)
1 N KCl		4.2	4.6	4.5	4.9	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 (FURP, 1987)
CEC	Cmol kg^{-1}	10.4	11.4	11.8	12.6	(6-12) Low
Overall						Low to medium inherent fertility soil

[1] To convert Cmol kg^{-1} to ppm (mg l^{-1}): Multiply by 1000 x atomic weight (Okalebo *et al*., 2002). To convert % to ppm (mg l^{-1}): divide by 10,000.

[2] Landon, J. R. 1984. Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and sub-tropics. Longman Inc, New York, U.S.A. 450p.

biomass remaining over time. The percentage biomass remaining was significantly higher (65%) in second season (May to June) compared to 50%in the first season (March to April) (Figure 2). The difference in time accounted for 82% to 92% of the variation in proportion of mucuna biomass decomposed in both seasons. The disparity between the percentage remaining biomass at 8 weeks after application (WAA) was probably due to variation in soil microbial population and or composition. This is because soil used in the first season trial was collected from the field during dry spell (February) while that for second season was sampled in wet season (April) and both were air-dried prior to setting up the experiments. Mucuna green manure application rate had non-significant effect on percentage biomass remaining throughout the 8 weeks in the two seasons (Figure 2). Consequently,

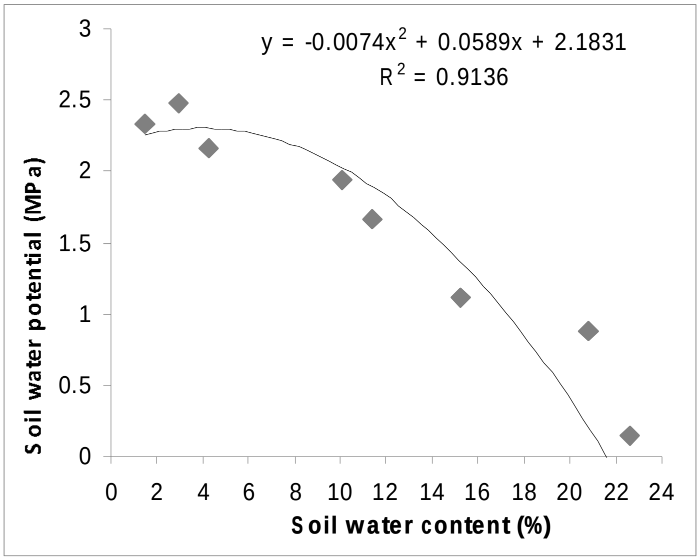

Figure 1. Water release characteristics curve of sandy clay topsoil (0-20 cm) collected from experimental site at Mosocho, Kisii, southwest Kenya

mucuna applied at the rates of 60, 120 and 240 kg N ha^{-1} showed same pattern of disappearance. The result indicated that N release from mucuna biomass might be the same irrespective of quantity used, as it is likely to follow same decomposition pattern (Jama and Nair, 1996). The outcome was attributed to observations by Palm *et al.* (1997), Tian (1992) and Woomer *et al.* (1997) that decomposition is controlled by chemical properties such as C:N ratio, polyphenols and lignin.

Effect of soil moisture level on mucuna green manure decomposition

Decomposition pattern showed two stages: an initial rapid phase, followed by a slower one (Figure 3). The initial rapid phase ended at 5 weeks after biomass application. This was followed by a slower one from 5 to 8 weeks. The exponential decay curve did not show out clearly at wilting point and intermediate soil moisture conditions (Figure 3). Jama and Nair (1996) reported bi-phasic decomposition pattern in fresh plant residue from legume shrubs as observed in this study. Soil moisture level had a significant effect on decomposition of mucuna green manure. There was significantly more loss in green manure biomass at field capacity (Ψ = -0.01 MPa) compared to wilting point (Ψ = -1.5 MPa) and intermediate (Ψ = -0.75 MPa) moisture levels (Figure 3). The exception was at 8 WAA when the % biomass at wilting point moisture

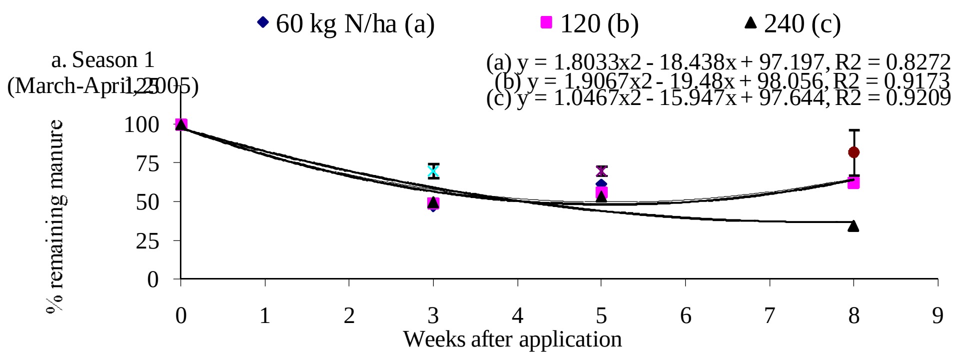

Figure 2. Effect of mucuna green manure application rate on decomposition under greenhouse conditions at Kabete, University of Nairobi in season 1 (March-April) and season 2 (May–June), 2005. Least significant difference bars at $P \leq 0.05$ shown.

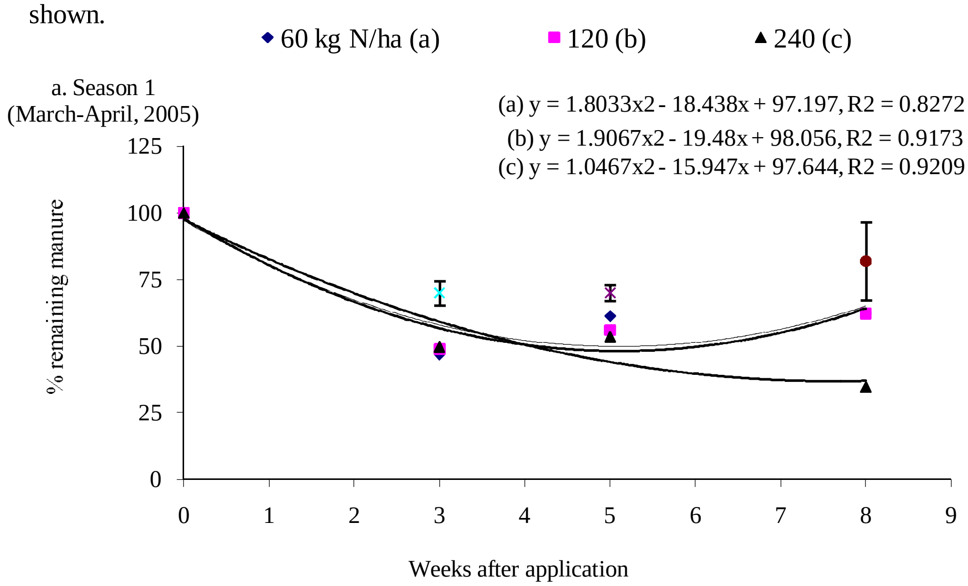

Figure 2. Effect of mucuna green manure application rate on decomposition under greenhouse conditions at Kabete, University of Nairobi in season 1 (March-April) and season 2 (May–June), 2005. Least significant difference bars at $P \leq 0.05$ shown.

content appeared to gain material perhaps due to additions from dead maize leaves. The loss in mucuna green manure mass at wilting point was not significantly different from that in intermediate soil moisture level throughout the 8 weeks.

The low decomposition rates at the low and intermediate water content were perhaps due to sub-optimal decomposer populations and function (Sarrantonio, 1991; Schomberg *et al.*, 1994). The rapid phase in decomposition especially at high soil water content may be attributed to loss of soluble components of the applied biomass followed by a slower phase when lignin and polyphenols decompose (Schomberg *et al.*, 1994; Constantinides and Fownes, 1993). It is possibly the chemical composition of mucuna biomass favoured its rapid decomposition as opined by Fageria and Baligar (2005).

Soil available nitrogen

Soil available N was significantly higher in the second season compared to first one (Figure 4) (Table 2). This was possibly due to the difference in water content of soil used during time of its sampling and collection from the field in the two seasons. Soils used for seasons one and two experiments were collected during a dry (February) and wet spell (April) respectively. This might have influenced the initial mineral N content of the soils in the two different seasons under greenhouse conditions in Kabete (Silgram and Shepherd, 1999). Also, N flush at the on-set of long rains season in April when soil for the second greenhouse trial was collected from the field experimental site in Kisii, might have contributed to the differences in mineral N content. Soil moisture content is considered to affect mineralization process (Cabrera *et al.*, 2005).

Mucuna application rate showed significant ($P \leq 0.05$) effect on soil available N. The available N was comparable at rates of 0 to 120 kg N ha^{-1} equivalent of mucuna green manure but was significantly higher at 240 kg N ha^{-1} (Table 2). Whether applied mucuna leads to N release from the soil compared to the control, would depend on C: N ratio of not only added litter, but also the SOM, and the soil microbial biomass. If the applied N-rich mucuna falls short of meeting soil microbial N requirement to utilize SOM, then the material is unlikely to make positive priming effect (Kuzyakova *et al.*, 2000). This is possibly what may have happened in the use of mucuna green manure applied at rates of 60 and 120 kg N ha^{-1}. The observation corroborates that by Pilbeam and Warren (1995 that the potential of soil to supply N would be up to 69% of the crops' requirements.

Soil moisture had significant ($P \leq 0.05$) effect on available N in the two seasons (Table 2). There was significantly higher available N in the soil at wilt and intermediate water contents compared to field capacity (Table 2). This was perhaps due to reduced maize N uptake at the two lower soil moisture levels compared to shown field capacity condition where N uptake was expected to be higher. There was significant ($P \leq 0.05$) interaction between planting season and mucuna green manure application rate on soil available N (SAN) at 5 WAA (Table 2). The SAN level was specifically higher at wilting point and or intermediate water contents, at mucuna application rates of 120 and 240 kg N ha^{-1}. The results indicate that

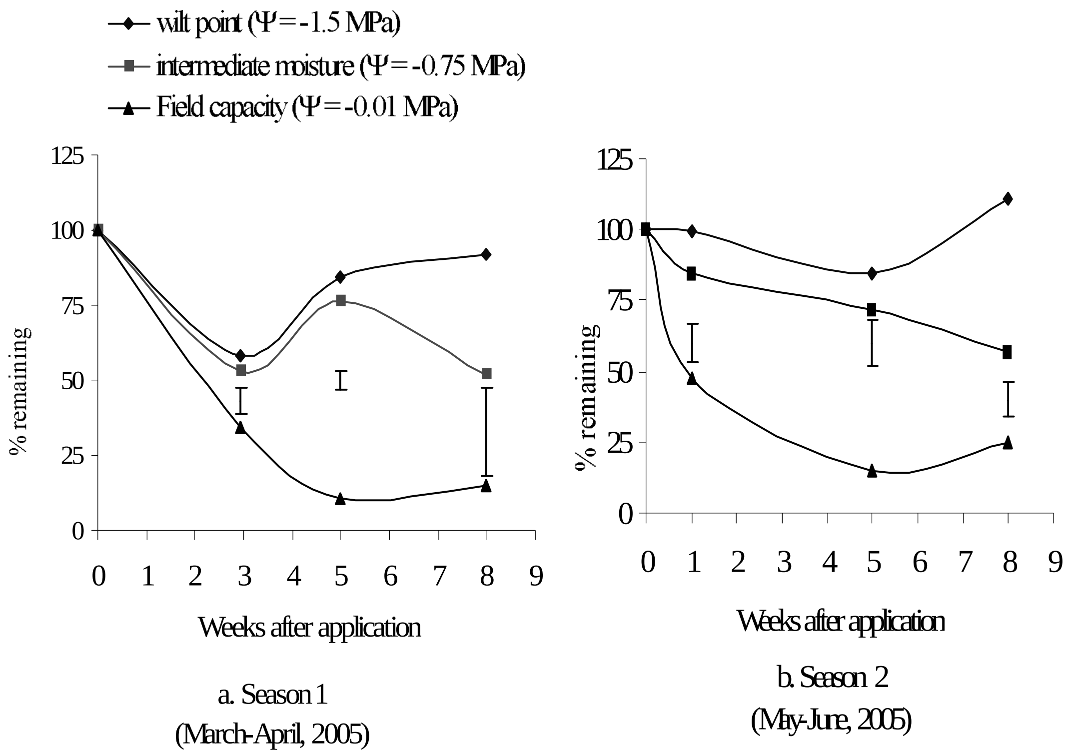

Figure 3. Effect of soil moisture level on mucuna green manure decomposition under greenhouse conditions at Field Station-Kabete, University of Nairobi: (March-June 2005). SED bars at P≤ 0.05

whereas mineralization might have occurred at the two soil moisture levels, N uptake by maize was possibly limited by low water content as a result of which most of the nutrients remained in the potted soil thus raising the SAN level.

On the average, soil mineralized N could supply most of the N for plant growth (Fageria and Baligar, 2005; Pilbeam and Warren, 1995) but lack of crop response is explained by the mismatch between soil mineral N supply and crop demand resulting in N losses. Cropping systems that ensure the presence of a crop in the field early in the season when mineralization is high i.e. permanent crop cover (pasture or tree crops) would optimize use of N mineralized. Additionally mixing crop residues with different decomposition rates to modulate N release rates would improve plant uptake of mineralized N from organic biomass.

Conclusions

Mucuna green manure application rate had non-significant effect on decomposition pattern but soil moisture level showed significant effect on the pattern. The exponential decay curve was more distinct in field capacity compared to; wilt point and intermediate soil moisture levels. Decomposition was more in field capacity than in wilt point and intermediate soil moisture levels.

Mucuna green manure showed two phases of decomposition: an initial rapid phase and a slower second one. Soil moisture had influence on half-life of applied mucuna green manure. In field capacity soil moisture condition, half-life is one week. But it takes at least 5 weeks for 50 % of the applied mucuna to disappear if soil moisture level is varying from wilt point, intermediate to field capacity as is likely to happen under some field situations.

Mucuna application rate of 240 kg N ha^{-1} equivalent to about 12 t DM ha^{-1} of the green manure biomass was necessary in order to noticeably and consistently increase soil available N. Changes in SAN level attributable to lower application rates of the green manure were not detectable.

Acknowledgement

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Table 2. Effect of mucuna green manure application rate on available nitrogen under greenhouse conditions at Field station-Kabete, University of Nairobi (March-June, 2005)♣

Mucuna rate (kg N ha^{-1})	Soil available nitrogen (kg N ha^{-1})															
	Season 1 (March-April)								Season 2 (May-June)							
	3 Weeks after planting				5 Weeks after planting				1 Week after planting				5 Weeks after planting			
	M1	M2	M3	**mean**	M1	M2	M3	**mean**	M1	M2	M3	**mean**	M1	M2	M3	**mean**
	-1.5	-0.75	-0.01		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01		-1.5	-0.75	-0.01	
0	35	36	27	**33**	35	38	25	**33**	69	68	62	**66**	106	135	84	**108**
60	46	46	29	**40**	39	42	41	**41**	63	76	43	**60**	111	108	100	**106**
120	50	37	25	**37**	45	22	40	**36**	69	73	58	**67**	124	164	133	**140**
240	52	91	24	**56**	68	55	33	**52**	110	150	83	**114**	142	200	157	**166**
Mean	**46**	**52**	**26**	**41**	**47**	**39**	**35**	**40**	**78**	**92**	**61**	77	**121**	**152**	**118**	**130**
Seasonal mean								**41**								**104**
LSD seasonal mean																**12**
Nitrogen rate F test				Ns				*				*				*
LSD Nitrogen rate				24				12				26				31
Moisture F test				*				ns				*				*
LSD moisture level				21				10				23				27
N rate x moist. F test				Ns				*				ns				ns
LSD N rate x moisture				42				20				46				55
%C.V Treatment				60				30				35				25

♣F=Fisher test; *=Differences significant, ns=Differences non-significant; LSD=Least significant difference;
N source rates=30, 60,120 kg Nha^{-1}; M1 = Soil moisture at wilt point (-1.5 MPa), M2 = intermediate soil water content –0.75), M3 = Soil moisture at field capacity (-0.01 MPa); A = Nitrogen rate mean; Moist. = soil moisture level.