Tropical and Subtropical Agroecosystems

COMPOSTING CATTLE MANURE FROM ZERO GRAZING SYSTEM WITH AGRO-ORGANIC WASTES TO MINIMISE NITROGEN LOSSES IN SMALLHOLDER FARMS IN KENYA.

[ELABORACIÓN DE COMPOSTA DE EXCRETAS BOVINAS PROVENIENTE DE SISTEMAS SIN PASTOREO CON RESIDUOS AGRO ORGÁNICOS PARA MINIMIZAR LAS PÉRDIDAS DE NITROGENO EN GRANJAS DE PEQUEÑOS PRODUCTORES DE KENYA]

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SUMMARY

Livestock manure is a valuable source of plant nutrients for crop production in the Central Kenyan highlands but its quality in terms of available nitrogen (N) is low due to considerable N losses through ammonia volatilization. This study aimed at assessing the potential of agro-organic wastes to reduce N losses from manure heaps during the storage period. Three organic amendments selected from a laboratory simulation experiment were evaluated under farmers' conditions in Karura, Kiambu District for their ability to reduce N losses from cattle manure heaps. The effect of a polyethylene sheet covering of manure heaps on N retention was also determined. There were eight treatments that comprised three agro-organic amendments (maize stover, coffee pulp and sawdust) and the control, with or without a polyethylene cover. Agronomic effectiveness of the "treated" manure samples and N uptake by maize seedlings was evaluated in a glasshouse experiment. Total N content of manure amended with organic materials ranged from 1.26 to 1.85%. The N in manures with organic amendments at the start and at the end of storage was significantly different ($p \leq 0.05$). Cumulative N loss ranged from 1.60 to 6.80 g kg^{-1} depending on the type of amendment. Nitrogen lost from non-amended manure was 2.74 g kg^{-1} with polyethylene cover and 6.80 g kg^{-1} without the polyethylene cover, which represented 19 and 46% of the initial N respectively. Maize growth improved significantly ($p \leq 0.05$) with increasing rates of manure irrespective of the organic treatments except for manure amended with sawdust. Treatments that received the recommended rate of N at 100 kg N ha^{-1} had significantly higher ($p \leq 0.05$) biomass (21.55 g $plant^{-1}$) than the control which produced only 2.78 g/plant. Nitrogen uptake increased with increasing rates of manure and was higher ($p \leq 0.05$) with manure amended with coffee pulp. Covering manure heaps to reduce moisture loss was also beneficial in reducing N losses.

Key words: Agro-organic materials, manure, nitrogen, volatilisation

RESUMEN

Las excretas animals son una fuente valiosa de nutrimentos para para la producción de cultivos en el Kenya pero su calidad en términos de N disponible es baja debido a las pérdidas debidas a la volatilización de amonio. Este trabajo tuvo como objetivo evaluar el potencial de residuos agro-orgánicos para reducir las pérdidas de N durante el almacenamiento. Tres enmiendas orgánicas seleccionadas a partir de experimentos de laboratorio se evaluaron en condiciones de campo en Karura, en cuanto a su habilidad para reducir la pérdida de N de excretas bovinas. Se evaluó también el efecto de emplear cubiertas de polietileno. En total se evaluaron ocho tratamientos compuestos por las tres enmiendas orgánicas (rastrojo de maíz, pulpa de café y aserrín) y el control, con y sin cubierta de polietileno. El valor agronómico de la excreta "tratada" y la captura de N por plántulas de maíz fueron evaluados en un experimento de invernadero. El contenido total de N de las excretas con enmiendas orgánicas fue de 1.26 a 1.85%. El contenido de N al inicio y al final del período de almacenamiento fue diferente ($P<0.05$). La pérdida acumulada de N fue de 1.6 a 6.8 g Kg^{-1} dependiendo del tipo de enmienda. La pérdida de N de las excretas sin enmienda fue de 2.74 g Kg^{-1} con cubierta de polietileno y 6.80 g Kg^{-1} sin cubierta, el cual representó el 19 y 46% del contenido inicial de N. El crecimiento de maíz mejoro ($P<0.05$) con la cantidad de excreta independientemente de su tratamiento con excepción del tratamiento con aserrín. Los tratamiento que recibieron las dosis recomendadas de N de 100 Kg N ha^{-1} tuvieron mayor producción de biomasa (21.55 g $plant^{-1}$) que el tratamiento control

(2.78 g plant^{-1}). La captura de N incremento conforme se incremento la cantidad de excreta y fue mayor ($p<0.05$) con la enmienda de pulpa de café. Emplear la cubierta plástica para reducir la pérdida de humedad fue también benéfico para reducir la pérdida de N.

Palabras clave: materiales agro-orgánicos, excretas, nitrogen, volatilización.

INTRODUCTION

Smallholder farmers in the Central Kenyan highlands are faced with declining crop yields resulting from low soil fertility caused by nutrient depletion through continuous harvest and insufficient return of nutrients through fertilizer or organic resources. Attempts to improve the productivity of traditional farming systems through the introduction of inorganic fertilizers have not been widely adopted in the Central Kenyan highlands (Karanja *et al.,* 1997). This is because of the high cost of the inorganic fertilizers, poor infrastructure and insufficient knowledge on its use. Utilization of animal manures assumes great importance in this region as a way of returning some of the nutrients removed from soil back to the croplands. This is partly because of easy accessibility of the manures in these mixed farms (Karanja *et al.,* 1997; Woomer *et al*., 1998). Livestock manure is a valuable source of N for crop production and as a soil conditioner, but its quality in terms of available N is low (Murwira *et al.,* 1993; Woomer et al., 1998; Karanja *et al.,* 1997). This has been attributed to considerable N losses through ammonia (NH_3) volatilization (Al-Kanani *et al.,* 1992). Ammonia losses can be reduced through use of organic materials that impart a number of changes on the environment such as direct adsorption of NH_4^+ and promotion of production of organic acids by the micro-organisms that lower manure pH while others might enhance microbial N immobilisation (Subair *et al.,* 1999). This study was conducted in selected small-scale farms in the Central Kenyan highlands to evaluate the effectiveness of selected organic amendments commonly found in these farms in reducing N losses from cattle manure heaps during storage under field conditions.

MATERIALS AND METHODS

Description of the study area.

The study was conducted on farmers' fields in Karura, Kiambu District. The area is characterised by reliable, bimodal rainfall and the soils are rich, red clays, classified as Humic Nitisols (Woomer *et al.,* 1998). The natural vegetation is afromontane forest and evergreen bushland (Murage *et al.,* 2000) that has mostly been cleared for cultivation. Farmers cultivate coffee and tea, which is marketed through co-operative societies, as well as vegetables, bananas, maize and beans for household consumption and sale through local networks. Crop residues are regarded as harvest products and are fed to livestock, which are often too few in number to accommodate the demand for manure as additions to soil (Woomer *et al.,* 1998). Farmers maintain fewer and high quality livestock in confinement allowing maximum collection of manures that are usually stored in heaps and exposed to the loss mechanisms such as ammonia volatilization, denitrification, leaching and runoff. Farmers supplement the nutrient requirements of higher value crops with inorganic fertilizers to compensate the small quantities and low quality of the manures available in the area (Woomer *et al.,* 1998).

Characterisation of agro-organic wastes and manure mixtures.

Cattle manure was collected from zero grazing units in farmers' fields in Karura, Kiambu district. The organic amendments included: filter mud (FM) from Muhoroni Sugar Company, sawdust (SD) by-product of timber mills, and maize stover (MS) ,which is the most common crop residue on farms. Other materials were wood ash (WA) which is easily obtained from traditional cooking "jikos", Ondiri peat (OP) which is a partially decomposed peat from the Kikuyu Ondiri swamps in Kiambu District, and coffee pulp (CP), a waste product from coffee factories. Samples were air-dried, homogenised and ground to pass through a 2-mm sieve and analysed. The samples were analysed for total macro-elements, (N, P, K, and Ca), organic carbon, NH_4^+ and NO_3^-, pH, CEC and moisture content. Moisture content was determined by drying the sub-samples at 65 ^oC for 72 hours. Manure pH was determined in 1:5 manure: water mixture using a pH meter. Exchangeable NH_4^+ and NO_3^- were determined using the method described by Okalebo *et al.,* (2000) and Anderson and Ingram (1993). Total N was determined by steam distillation after Kjeldal digestion (Bremner and Mulvaney ,1982) using moist samples to avoid N losses during drying and values corrected for water content. Organic C was determined by Kurmies procedure (Walinga *et al.,* 1992). Other macro-elements (P, K, Ca and Mg) were determined following the wet ashing technique (Okalebo *et al.,* 2000) and the neutral 1M NH_4OAc saturation procedure was used to determine the CEC.

Experimental design and layout.

Three organic amendments (selected from a simulated screening experiment under laboratory conditions), based on their ability to reduce ammonia volatilisation from cattle manure were evaluated under farmers' conditions. The effect of a polyethylene cover on N retention during manure storage was also determined. There were in total eight treatments that comprised of three organic amendments (maize stover, coffee pulp and sawdust) and non-amended (control). The treatments were evaluated either with or without a polyethylene cover. The organic materials and fresh cattle manure were mixed thoroughly at a ratio of 1:5 (amendment: cattle manure) and were then stored in heaps placed on polyethylene sheet (gauge 1000) lining at the bottom and top for covered treatments. The lining prevented nutrient leaching, runoff losses and minimized contamination of manure with the soil.

The treated manure heaps were incubated for a period of 12 weeks during which samples were taken at two weeks intervals for pH and total N determination. After the storage period, 2 kg samples were taken from each heap for use in an agronomic effectiveness assessment in the glasshouse at Kabete Field Station, University of Nairobi. Surface layer soil (0-30 cm) was collected from infertile soil patches found in some of the farms in Karura, Kiambu District as described by Murage *et al.,* (1999). The soils were air-dried and 4 kg composite samples placed in clean plastic pots of 20 cm in diameter and 20 cm in height. Manure and soil sub-samples were taken, dried, ground and used for nutrient determination using methods described by Anderson and Ingram (1993) and Okalebo *et al.,* (2000). Manure was added at rates equivalent to 5, 7 and 10 t ha^{-1} and thoroughly mixed with the soil. Three checks (controls) were included in the experiment and comprised of recommended rate of N (100 kg N ha^{-1} as calcium ammonium nitrate), farmers' practice (manure 7 t ha^{-1} + 18 kg N ha^{-1} as diammonium phosphate) and non-amended treatment. Phosphorus and potassium were applied as triple super phosphate (46% P_2O_5) and KCl (60-62% K_2O), respectively to all experimental pots at a rate equivalent to 100 kg P ha^{-1} and 100 kg K ha^{-1}. Micronutrients (Mn, Zn, Cu, Mo, Co, Fe and B) were also applied to all pots as foliar spray after the plants had established. The treatments were laid out in a completely randomised design and replicated three times.

Maize was sown at four seeds per pot at a depth of 1.5 cm and covered with a layer of soil. The plants were thinned after establishment to two plants per pot. Tap water was added twice a week to maintain adequate soil moisture for the growing plants. Soil samples were taken at 4 weeks after planting from each pot using a cork borer for NH_4^+-N and NO^-_3-N determination using micro- Kjeldal distillation method (Bremner and Mulvaney, 1982) after extraction with 2M KCl. The available manure N was calculated using the equation suggested by Goran (2000):

$$AmN = \frac{\underline{(Nm - Nsc)}}{(Nm\ A)} \times 100\ \%$$

Where : Am N is the available manure N, Nm and Nsc are, respectively mineral N values for a soil manure mixture and, the corresponding soil control while NmA is the amount of N applied. This method assumed that mineralization of soil organic matter is equal in all plots.

The shoots were harvested 8 weeks after planting by cutting the seedlings at first node level. They were oven dried at 65°C for 72 hours, weighed, and ground to pass through a 0.5 mm sieve and analysed for total N using the micro-Kjeldal method (Bremner and Mulvaney, 1982). The plant N derived from the manure was calculated using the following equation (Kihanda and Wood, 1996).

$$NpM = NpSM - NpS$$

Where: NpM is plant N derived from the manure, NpSM and NpS are plant N for the soil and manure and plant N in soil alone respectively.

The data obtained was subjected to analysis of variance (ANOVA) using Genstat 5 Release 3.2 (1995). Treatment means were compared using the least significant difference (LSD) (Gomez and Gomez, 1984).

RESULTS

Chemical characteristics of manure and organic amendments.

The results of the chemical characteristics of fresh manure and organic amendments that were used are presented in tables 1 and 2. The pH values from the manure extracts were slightly alkaline while those of organic amendments were slightly acidic to neutral. Sawdust and coffee pulp were slightly acidic (5.2 and 5.6) while maize stover was neutral. Total percent N in the organic amendments ranged from 0.1 to 2.0%. Sawdust had the highest organic carbon (51.2%), C: N ratio and lignin: N ratio.

Table 1. Chemical characteristics of the agro-organic wastes and cattle manure.

Organic material	pH 1:5	Na	K	Ca (g kg^{-1})	Mg	P	N %	C %	C/N ratio	Lignin/N ratio
Filter mud	7.2	1.3	20.7	43.5	33.3	8.4	1.2	19.3	17	7
Saw dust	5.2	1.7	2.1	6.5	Trace	2.2	0.1	51.3	366	231
Maize stover	7.0	2.6	69.1	8.5	16.7	8.4	0.9	41.4	49	8
Wood ash	13.6	55.7	228.9	67.5	18.3	76.3	0.1	3.7	37	23
Ondiri peat	5.1	8.7	3.8	4.0	4.2	12.4	1.4	23.5	17	21
Coffee pulp	5.6	7.4	118.5	28.5	16.7	16.4	2.0	40.1	20	7
Cattle manure	8.2	-	8.7	10.4	-	6.4	1.7	26.5	15.5	8

Table 2. Chemical characteristics of the soil used in the pot experiment.

Characteristics	Content
Moisture content (%)	14.3
$pH_{(water)}$ (1:2.5)	5.3
EC (dSm^{-1}) (1:5) (25^0C)	2.2
N (%)	0.17
Extractable P (Olsen) ($mgkg^{-1}$)	16.83
Exchangeable K ($cmolkg^{-1}$)	3.14
Exchangeable Ca ($cmolkg^{-1}$)	8.37
Exchangeable Mg ($cmolkg^{-1}$)	2.44
NO_3-N (mg kg^{-1})	16.26
Organic C (%)	1.23

Chemical characteristics of the soil used in the agronomic effectiveness experiment.

The soil used in this experiment was collected from infertile patches found in most of the farms in the study site. The chemical characteristics of these soils are presented in table 2. The soils contained relatively low levels of organic carbon, total N, available phosphorus and potassium. The chemical characteristics of the manure x organic amendment, which were evaluated for their agronomic effectiveness, are presented in table 3. The C: N ratio of the mixtures ranged from 16 to 35. Manure amended with sawdust had the highest amount of organic carbon and higher C: N ratio compared to other amendments (Table 3). Treatments that were amended with coffee pulp had the lowest C: N ratio.

Effect of different agro-organic amendments on nitrogen loss from manure during storage.

Nitrogen content in manures amended with different agro-organic materials ranged from 1.26% to 1.85% while that of non-amended manure was 1.42% (Table 4). Manure amended with coffee pulp had the highest N content while that amended with sawdust had the lowest N level. Cumulative N lost ranged from 1.60 to 6.80 g kg^{-1} depending on the type of amendment. Nitrogen lost from non-amended manure was the highest among the treatments and was 2.74 g kg^{-1} with polyethylene cover and 6.80 g kg^{-1} without polyethylene cover. The N loss was equivalent to 19.23% with cover and 46.13% without cover, respectively. Covered manures maintained high moisture content of about 68% (data not presented) throughout the storage period thus making the conditions anaerobic. N losses under these conditions were minimal exception of non-amended cattle manure which had lost 19.23% of the initial N content.

Table 3. Chemical characteristics of amendments x manure mixtures

Amended manure type	Nutrient Total N	Organic C	C:N
	(gkg^{-1})		Ratio
CP + C	16.88	309.13	18
CP – C	14.72	228.31	16
MA + C	11.50	239.26	21
MA – C	7.31	128.33	18
MS + C	12.10	284.14	24
MS – C	9.94	178.2	18
SD + C	11.17	372.70	33
SD – C	9.05	318.51	35

CP = Coffee pulp + manure,
MA =Non-amended manure,
MS = Maize stover + manure,
SD = Sawdust + manure,
+C = with polyethylene cover and
–C = without polyethylene cover

Effect of manure quality and rate of application on biomass production of maize seedlings.

The growth of maize seedlings significantly ($P \leq 0.05$) improved as the rates of manure increased with manure amended with coffee pulp and maize stover showing the best performance (Table 5). Addition of the recommended rate of N of 100 kg N ha^{-1} (FURP, 1994) alone gave the highest biomass of 21.6 g/plant while the control produced small plants that weighed only 2.8 g/plant. Nitrogen uptake by maize seedlings increased with increasing rates for all manure types (Table 6). Plant tissue N ranged from 1.14 to 2.03 g

kg^{-1} in non-amended manure treatment while in the control it was 1.28 g kg^{-1}. Manure treatments that were amended with coffee pulp and uncovered had significantly higher tissue N ($p \leq 0.05$) than other types of manures and the control (Table 6). The lowest plant tissue N was observed at day 56 in treatments that were amended with sawdust.

Table 4: Effect of organic amendment and polyethylene cover on the amount of nitrogen lost from the cattle manure heaps

Treatment	Cover	Total N-loss (g kg^{-1})	Percent N-loss
Manure/ coffee pulp	+	1.60	8.68
Manure/ coffee pulp	-	3.47	19.09
Non-amended manure	+	2.74	19.23
Non-amended manure	-	6.80	46.13
Manure/ maize stover	+	1.23	9.22
Manure/ maize stover	-	3.48	25.98
Manure/ sawdust	+	1.48	11.72
Manure/ sawdust	-	3.61	28.49
$LSD_{0.05}$		0.59	4.48
CV		11.20	12.1
S.E		0.34	2.59

Table 5: Effect of manure type x rate of application on biomass (g/plant) of maize seedlings at 56 days after planting.

Manure	Rate of application		
Type	5 tha^{-1}	7 tha^{-1}	10 tha^{-1}
CP + C	4.25	6.16	9.63
CP – C	5.27	7.76	13.70
MA + C	3.01	3.33	3.70
MA – C	3.17	3.44	3.99
MS + C	3.58	3.87	5.30
MS – C	3.79	4.13	6.53
SD + C	2.01	2.18	2.66
SD – C	2.29	2.35	2.81
N-REC	21.55		
	$Lsd_{0.05,\ 48df)}$ = 0.66		
FP	13.03	S.E = 0.404	
Control	2.78		

CP = Coffee pulp + manure,
MA = Non-amended manure,
MS = Maize stover + manure
SD = Sawdust + manure,
N-REC = FURP (1994) recommendation (100 kg N ha^{-1}),
FP = Farmers practice (7 t ha^{-1} manure + 18 kg N ha^{-1})
Control = No soil amendment added.
+C= with a polyethylene cover
–C= without a polyethylene cover.

Table 6. The effect of manure type and rate of application on plant tissue N (g/kg) at 56 days after planting.

Manure	Rate of application		
Type	5 tha^{-1}	7 tha^{-1}	10 tha^{-1}
CP + C	2.34	3.82	6.74
CP – C	3.11	5.43	10.82
MA + C	1.14	1.47	1.81
MA - C	1.30	1.62	2.03
MS + C	1.90	2.13	3.29
MS – C	2.20	2.44	4.18
SD + C	0.56	0.72	1.09
SD – C	0.73	0.87	1.24
N-REC	24.57		
	$LSD_{(0.05,\ 48df)}$(interaction)= 0.35		
FP	9.77		S.E = 0.29
Control	1.28		

CP = Coffee pulp + manure,
MA = Non-amended manure,
MS = Maize stover + manure
SD = Sawdust + manure,
N-REC = FURP (1994) recommendation (100 kg N ha^{-1}),
FP = Farmers practice (7 t ha^{-1} manure + 18 kg N ha^{-1})
Control = No soil amendment added.
+C= with a polyethylene cover
–C= without a polyethylene cover.

DISCUSSION

Effect of organic amendments and inclusion of polyethylene cover on nitrogen losses from stored manure heaps.

The amount of N lost from manures that were covered was lower than that of uncovered manures. The covered manures also had higher moisture content during storage than the uncovered one and this may have accounted for the low N losses. Kirchmann and Lundvall (1998) in their study reported low N losses under anaerobic conditions. The energy and nutrient balance of organic materials is usually inferred from the C: N ratio and the ideal C: N ratios between 15 and 25:1. Al-Kanani *et al.,* (1992) reported the presence of insufficient organic carbon for the micro-organisms to make use of all the N when the C: N ratio were lower than 15:1 Conversely, when the C: N ratios are greater than 25:1, a deficiency of N is likely to occur, thereby restricting population growth of the micro-organisms responsible for decomposition of the manure. Though materials with high organic carbon and low N would be expected to cause net N immobilization when mixed with animal manures (Subair *et al.,* 1999), manure amended with sawdust with a C: N ratio of 34 lost more N than manure amended with coffee pulp and maize stover that had relatively lower C: N ratios of 16 and 19 respectively. Sawdust also had very high lignin: N ratio of 231 compared to the other agro-organic materials. Subair *et al.,* (1999), found that slow decomposing materials that were high in lignin exhibited a lower rate of N immobilization, with immobilized N remaining in organic form for a long time. In contrast, low lignin materials exhibit high rates of decomposition, causing rapid N immobilization and subsequent re-mineralization without producing a pool of stable organic N (Subair *et. al.,* 1999). Thus, Subair *et al.,* (1999) concluded that materials with moderate lignin contents were more effective in reducing volatile N loss from amended manure. In this study, coffee pulp and maize stover with lower lignin: N ratios were more effective in reducing N losses through ammonia volatilization. Maize stover constitutes the main fodder for stall-fed cattle in the study area and the leftovers are usually incorporated into the manure heaps. Dry stover is placed in the cowsheds as bedding material, which ends up in the manure heaps. In the coffee growing zones, coffee pulps are common pollutants around the factories and are usually available for free and as such the promising results show that there is a need to encourage farmers to incorporate these relatively cheap agro-organic wastes into manures to improve their quality.

Response of maize to the organic amended manures.

The beneficial effects of manure in maintaining soil fertility and in particular its role as a source of plant nutrients, are dependent on the efficiency of the biodegradation process (Kihanda, 1996), which in turn determines the rate of release of nutrients and the equilibrium between retention and loss from the soil (Palm and Sanchez, 1991). The N from manure may be retained in the soil organic forms or released in inorganic form to the soil solution where it either accumulates, hence taken up by plants or lost through leaching or gaseous emissions (Murwira *et al.,* 1993). The rate of N mineralization from manure and indeed organic residues is regulated by temperature, moisture, soil type, soil pH and the quality of the organic material that is being decomposed.

Materials with a high C: N ratio and high lignin: N ratio and which immobilizes N such as sawdust are considered to be of low quality. Quality in this context referring to intrinsic factors that affect the rate of decomposition of the organic material such as C: N ratio, lignin content, nutrient content and particle size (Palm and Sanchez, 1991). High quality materials such as coffee pulp with lower C: N ratio and lower lignin: N ratio decompose rapidly and mineralize N easily upon incorporation into the soil, hence their N release can be synchronized with crop demand (Myers *et al.,* 1994). However, the low quality organic materials would require more time to decompose (Amolo and Karanja, 1995). In this study, treatments where manure amended with sawdust added the net N immobilization occurred at all rates of manure application while with the unamended manure N immobilization occurred only at the highest rate of 10 t ha^{-1}. Kirchmann and Lundvall (1998) and, Lekasi *et al.,* (2000) observed net N mineralization in aerobically produced manure when the C: N ratio was less than 15, while a net immobilisation occurred when the C: N ratio was greater than 25 and biomass yield and N-uptake were directly related to the N contribution. Since in this experiment traces of ammonium were measured in all different manure types, ammonium may have been reduced followed by denitrification. Ammonia volatilization from the soil surface was unlikely because of moderately acidic soil conditions (pH 5.2).

The higher biomass and plant tissue N obtained from N-REC, FP, CP+C and CP-C treatments may have been due to the higher N supply from the organic resources. Lower plant tissue N in the other treatments where sawdust was added was due to the net immobilization of N as observed at day 56. The results of this study are in agreement with studies reported by other investigators (Herbert *et al.,* 1991; Nyamangara *et al*., 1999; Wheatley *et al.,* 1991; Ndayegamiye and Cote, 1989) who observed depressed rates of N mineralisation in soils receiving heavy application of wheat straw and sewage sludge.

CONCLUSION

The results of this study clearly demonstrate that efficient cycling of nutrients within the low external input farming systems used by smallholder farmers in the highlands of Central Kenya can be improved by minimising nutrient losses from the systems for long-term sustainability. The current practices are inefficient due to considerable nutrient losses during manure storage. As much as 40% of total N is lost under the current practice where manure is heaped outside the kraals and exposed to heat and rain. As the farms intensify and become smaller through subdivision, the need to enhance nutrient turnover becomes more important. The current systems can be improved by reducing nutrient losses from animal manures during storage and during field application. This can be achieved by improving the recovery of urinary N by using bedding materials such as sawdust, maize stover and other organic materials with high C: N ratio that would absorb urine and temporally immobilise N. The common practice in the agricultural areas is to burn these wastes (e.g. maize stover and sawdust) while coffee pulp is usually left to rot on factory grounds while small amounts are used as coffee mulch. Mixing these organic agro-wastes with stored manure is an economical and environmentally acceptable strategy of managing plant nutrients. Another strategy is to improve the handling and storage of manure through composting to stabilise N in organic forms that are less susceptible to losses. Covering manure heaps during storage should also be promoted as substantial reduction in N losses is achieved when heaps are covered and sheltered from rain and heat.

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