Wageningen UR Livestock Research

Partner in livestock innovations

Report 258

Cattle manure management in East Africa: Review of manure quality and nutrient losses and scenarios for cattle and manure management.

September 2009

LIVESTOCK RESEARCH
WAGENINGEN UR

Colophon

Publisher
Wageningen UR Livestock Research
P.O. Box 65, 8200 AB Lelystad
Telephone +31 320 - 238238
Fax +31 320 - 238050
E-mail info.livestockresearch@wur.nl
Internet http://www.livestockresearch.wur.nl

Editing
Communication Services

Wageningen UR Livestock Research, 'ASG Veehouderij' in full, Central Veterinary Institute and the Department of Animal Sciences of Wageningen University comprises the Animal Sciences Group of Wageningen UR.

Single numbers can be obtained from the website.

Abstract
Nutrient excretion of cattle, manure quality and nutrient losses during manure collection and storage strongly vary under conditions of smallholders in East Africa. On the basis of a literature review, a summary table is constructed, giving indicative nutrient losses for six different systems of collection and storage of cattle manure.
Results of a scenario approach indicate that with intensification and import of external nutrients, nutrient and manure availability increase. Risks for nutrient losses also increase substantially, unless manure collection and storage are improved at the same time

Keywords
smallholders, East Africa, Kenya, manure, collection, nutrients, nitrogen, storage, losses, urine

Reference
ISSN 1570 - 8616

Author(s)
Snijders Paul, Davies Onduru, Bram Wouters, Louis Gachimbi, Joshua Zake, Peter Ebanyat, Kebebe Ergano, Muktar Abduke and Herman van Keulen.

Title
Cattle manure management in East Africa: Review of manure quality and nutrient losses and scenarios for cattle and manure management.

Report 258

Cattle manure management in East Africa: Review of manure quality and nutrient losses and scenarios for cattle and manure management.

Snijders Paul, Davies Onduru, Bram Wouters, Louis Gachimbi, Joshua Zake, Peter Ebanyat, Kebebe Ergano, Muktar Abduke and Herman van Keulen.

September 2009

Report 258

Integrated Nutrient Management to Attain Sustainable Soil Productivity increases in East African farming systems (INMASP)

Cattle manure management in East Africa: Review of manure quality and nutrient losses and scenarios for cattle and manure management

Snijders Paul[1], Davies Onduru[2], Bram Wouters[1], Louis Gachimbi[3], Joshua Zake[4], Peter Ebanyat[5], Kebebe Ergano[6], Muktar Abduke[7] and Herman van Keulen[8]

1) Animal Sciences Group, Wageningen University and Research centre, P.O. Box 65, 8200 AB Lelystad, the Netherlands (corresponding author); 2) ETC-East Africa, P.O. Box 76378, Nairobi, Kenya; 3) Kenya Agricultural Research Institute, P.O. Box 14733, Nairobi, Kenya; 4) Environmental Alert, P.O. Box 1259, Kampala, Uganda; 5) Makerere University, P.O. Box 7062, Kampala, Uganda; 6) Debub University, P.O. Box 5, Awassa, Ethiopia; 7) SOS Sahel, P.O. Box 3262, Addis Ababa, Ethiopia; 8) Plant Research International, Wageningen University and Research centre, P.O. Box 16, 6700 AA Wageningen, the Netherlands.

Lelystad, 2009

Abbreviations and definitions

C Carbon
CP Nutrients (NPK) ingested by **C**attle divided by nutrients in animal **P**roducts
DM **D**ry **M**atter
FC **F**orage **C**onsumed (ingested)
FR **F**orage **R**efused
FYM Farm Yard Manure
INMASP “Integrated Nutrient Management to Attain Sustainable Productivity increases in East African farming systems”
LW Live Weight of cattle in kg
MS Nutrients applied to **S**oil divided by nutrients (including FR) going to **M**anure
N Nitrogen
K Potassium
P Phosphorus
SF Nutrients in harvested **F**orage divided by nutrients applied to **S**oil
TLU Tropical Livestock Unit (1 TLU is equivalent to a LW of 250 kg)

Cattle Unit one mature cow with young stock (followers)
External nutrient balance for cattle External NPK inputs minus external NPK outputs for cattle at farm level (farm balance for the cattle component of the farm only) In case of grazing outside the farm border, only ingested nutrients are imported, nutrients in grazing residues not!
Net nutrient balance External nutrient (NPK) balance minus the nutrient losses during manure collection and storage (including nutrients not collected due to grazing)
Soil deficit Difference between nutrients in harvested forage and soil applied nutrients

Acknowledgements
The authors are indebted to Dr Rene Schils and Michel Smits from Wageningen University and Research Centre (Wageningen UR) and Sije Schukking and Dr Gerrit Zemmelink (formerly Wageningen UR) for their comments and suggestions. We also thank Dr Andre de Jager, Ronald Zom, Hendrik Jan van Dooren, Jantine van Middelkoop, Gidi Smolders, Dr Andre Bannink, Dr Simon Oosting and Dr Henk Udo (all Wageningen UR), Dr Danny Romney (International Livestock Research Institute, ILRI) and Dr John Kariuki and Dr John Muia (Kenya Agricultural Research Institute, KARI) who all contributed at one stage or another to the development of the spreadsheet with calculation rules used to prepare the scenarios in this report. However, the authors remain responsible for the content!

Summary

Manure is an important source of nutrients for many smallholder farmers in East Africa, with cattle manure being the dominant type. Information on nutrient losses between excretion and application of manure is still limited under smallholder conditions in the tropics, due to the wide variation in farming conditions and variation in livestock and manure management. In the first part of this report, quality of mainly cattle manure, and nutrient losses during manure collection and storage are reviewed. The second part explores and discusses effects of eight cattle and manure management scenarios on nutrient and manure availability.

Nutrient excretion and manure quality strongly vary, due to variation in feed quality and intake, addition of organic material, nutrient losses and contamination with soil. Total nitrogen content of manure on a dry matter basis ranges from below 0.5 to over 4%. Contents of soluble nitrogen (ammonia N) also strongly vary. Nutrient and carbon losses during manure collection and storage vary substantially, depending on cattle and manure management. Nitrogen losses for example may vary from less than 10% to about 90%. Nitrogen losses tend to be lower for more compact and anaerobic manure storage systems and for manures with higher carbon to nitrogen ratios.

On the basis of the review, a summary table is constructed, giving indicative nutrient losses for six different systems of collection and storage of cattle manure. Losses are indicated separately for dung and urine, because of the high risk for losses of soluble nutrients from urine. High, moderate and low loss levels are indicated to account for the large variation in collection and storage conditions. Differences in relative losses among manure storage systems are larger for urine and smaller under favorable storage conditions. Nitrogen losses indicated in Table 6 vary from 20-100% for urine and from 5-50% for faeces. Losses of phosphorus from faeces vary from 3-30% and potassium losses from urine from 5-80%. The proposed losses are used for a subsequent scenario study.

First some example scenarios are discussed, followed by a description of characteristics of farms participating in a project on Integrated Nutrient Management and Soil Productivity (INMASP) in Eastern Africa. Subsequently the starting points for the eight scenarios studied are indicated, scenarios ranging from rather extensive grazing to intensive zero-grazing, and being (partly) derived from the characteristics of farms participating in INMASP. Comparable to INMASP farms, no fertilizer N was used on forage crops.

The results indicate that with intensification and import of external nutrients, nutrient and manure availability increase. But the risks for nutrient losses from manure on farms also increase substantially, unless manure collection and storage are improved at the same time.

In most scenarios cattle positively contribute to the external (farm) nutrient balance and crop nutrient availability because of import of external inputs through either grazing outside the farm or purchased feeds and/or nitrogen fixation from legumes. No fertilizer N was used on forage crops. But the estimated “net” contribution of cattle to the N balance however, after taking into account losses during manure collection and storage (excluding manure application!), is much less favorable. The contribution of cattle to the external nitrogen (N) balance varies from 0 to 56 kg N per Cattle Unit, while the contribution to the “net” nitrogen balance varies from –39 kg N to + 29 kg N per Cattle Unit. Annual nitrogen and manure availability for land application vary much, ranging respectively from 5 to 77 kg N and 0.4 to 1.8 ton manure dry matter (DM) per cow respectively. Differences become smaller if expressed per tropical livestock unit (TLU), but larger if converted to stocking rates found on participating farms in Mbeere and Kibichoi in Kenya (respectively 0.9 and 5.0 TLU per ha).

Aerobic and often cheaper systems of manure storage are probably more feasible in extensive situations with relatively lower N excretion in urine, more so if the cropping system does not facilitate use of liquid manures without appropriate storage. Deep litter systems with more or less frequent removal of deep litter become more applicable if supply of organic material (such as from feed refusals) and labor are sufficient. But with higher N excretion in urine, higher amounts of suitable (dry) bedding material are required to limit nitrogen losses. With intensification due to higher stocking rates and rations with higher protein contents, more anaerobic systems of manure storage become more feasible, including separate storage of solid manure in compact and covered heaps/pits and urine in a closed pit. On more specialised dairy farms storage as slurry (mixture of dung and urine) may become an option as well. Improved systems usually require more labour and/or higher investment in storage facilities for slurry systems in particular if regular and proper use of (urine) liquids is not feasible.

More quantitative information is required on innovative farmers to asses manure availability and quality and the potential to reduce nutrient losses in relation to variation in livestock management and manure handling systems, including variation among seasons, housing systems and socio-economic conditions. Linking visual and sensible ("feel") characteristics of soils, feeds and manures to more scientific indicators may help to better assess manure quality and risks for nutrient losses and to improve manure handling and soil and animal productivity.

Keywords: smallholders, East Africa, Kenya, manure, collection methods, nutrients, nitrogen, storage, losses, urine

Samenvatting

Mest is een belangrijke bron van nutriënten voor veel kleine boeren in Oost Afrika, waarbij mest van rundvee het belangrijkst is. De kennis over de verliezen van nutriënten, vanaf excretie tot aanwending van mest, is nog onvoldoende bekend onder de omstandigheden van kleine boeren in de tropen, ook door de grote variatie in omstandigheden in vee- en mestmanagement. In het eerste deel van dit rapport behandelen we de mestkwaliteit, vooral van runderen, en de nutriëntenverliezen bij het verzamelen en bewaren van mest, vooral op basis van literatuuronderzoek. In het tweede deel worden de resultaten van acht scenario's met verschillen in rundvee- en mestmanagement behandeld.

Mestkwaliteit en verlies van nutriënten
De excretie van nutriënten in mest en de mestkwaliteit variëren sterk door variatie in voerkwaliteit en voeropname, de toevoeging van organisch materiaal, nutriëntenverliezen en verontreiniging met grond. Het totale gehalte aan stikstof in mest op droge stof basis varieert van minder dan 0,5% tot meer dan 4%. Het gehalte aan oplosbare stikstof (N) varieert ook sterk. De verliezen aan stikstof en koolstof tijdens het verzamelen en bewaren variëren ook aanzienlijk, afhankelijk van vee- en mestmanagement. Stikstofverliezen bijvoorbeeld kunnen variëren van minder dan 10 tot ongeveer 90%. Er is bij de N verliezen een dalende trend bij meer compacte en anaerobe bewaarsystemen en bij een mestkwaliteit met een hogere koolstof/stikstofverhouding.
Op basis van het literatuuronderzoek is een overzichtstabel geconstrueerd met indicatieve nutriënten verliezen voor zes verschillende systemen van verzamelen en opslag van rundveemest. De verliezen zijn apart vermeld voor de faeces en urine door het grote risico voor verliezen van oplosbare nutriënten in urine. Om rekening te houden met de grote variatie in verzamel- en bewaaromstandigheden zijn hoge, matige en lage verliesniveaus aangegeven. Verschillen in relatieve verliezen tussen de systemen zijn hoger voor urine en lager onder gunstige bewaaromstandigheden. De voorgestelde verliezen zijn gebruikt in een daarop volgende scenario studie.

Benadering door middel van scenario's
Eerst behandelen we enkele voorbeeldscenario's, gevolgd door een beschrijving van de belangrijkste kenmerken van deelnemende bedrijven aan het project " Integrated Nutrient Management and Soil Productivity" (INMASP) in Oost Afrika. Daarna worden de uitgangspunten voor acht te behandelen scenario's aangegeven, variërend van extensief beweiden tot intensief stalvoeren. De uitgangspunten zijn (deels) afkomstig van de kenmerken van de aan INMASP deelnemende bedrijven. Vergelijkbaar met deze bedrijven wordt er geen kunstmest gegeven op voedergewassen.
De resultaten geven aan dat met intensivering en import van nutriënten, de beschikbaarheid van nutriënten en mest op bedrijfsniveau toenemen. Maar de risico's voor verlies van nutriënten van de vee- en mestcomponent van het bedrijfssysteem nemen ook aanzienlijk toe, tenzij het verzamelen en bewaren van mest tegelijkertijd worden verbeterd.
In de meeste scenario's is een positieve bijdrage van rundvee aan de externe nutriëntenbalans en de beschikbaarheid van nutriënten voor gewassen, door de import van nutriënten via beweiding buiten het bedrijf, de aankoop van voeders en/of biologische stikstofbinding door vlinderbloemigen. De geschatte "netto" bijdrage van vee aan de N balans, rekening houdend met verliezen bij verzamelen en bewaren (maar nog zonder de stikstofverliezen bij aanwenden!), is echter veel minder gunstig. De bijdrage aan de externe stikstofbalans varieert van 0 tot 56 kg N per koe met bijbehorend jongvee, maar de bijdrage aan de "netto" stikstofbalans varieert van -39 tot +29 kg N per koe met jongvee. De per jaar beschikbare hoeveelheid stikstof (N) en mest voor aanwending op gewassen variëren sterk, respectievelijk van 5 tot 77 kg N en van 0,4 tot 1,8 ton drogestof uit mest per koe. De verschillen worden kleiner bij weergave per Tropical Livestock Unit (1 TLU komt overeen met een levend gewicht van 250 kg), maar groter bij omrekening naar de veebezettingen gemeten op de deelnemende bedrijven in de districten Mbeere en Kibichoi in Kenia (resp. 0,9 en 5 TLU ha^{-1}).

Meer aerobe en vaak goedkopere systemen van mestopslag zijn waarschijnlijk meer geschikt in extensieve situaties met een relatief geringere stikstofexcretie via urine, vooral als de gewascombinatie geen (regelmatig) gebruik van urine of dunne mest toelaten zonder langdurige opslag. Mestopslag in een potstal, met meer of minder regelmatig verwijderen van mest, is beter toepasbaar als de beschikbaarheid van organisch materiaal en arbeid voldoende zijn. Bij een toenemende stikstofexcretie via urine zijn echter grotere hoeveelheden geschikt (droog) strooisel nodig om de stikstofverliezen te beperken. Met intensivering en hogere veebezettingen en rantsoenen met hogere eiwitgehalten worden meer anaerobe systemen van mestopslag waarschijnlijk aantrekkelijker, inclusief gescheiden opslag van vaste mest in compacte en afgedekte hopen/kuilen en

van urine in afgesloten silo's/kelders. Op meer gespecialiseerde melkveebedrijven kan opslag als dunne mest (faeces en urine) ook een optie zijn. Verbeterde systemen vragen gewoonlijk meer arbeid en/of een hogere investering in opslagfaciliteiten, in het bijzonder bij langdurige opslag van dunne mest (of urine) als regelmatige en goede aanwending moeilijk is.
Er is meer kwantitatieve informatie van innovatieve bedrijven nodig voor het beter beoordelen van de beschikbaarheid en kwaliteit van mest en de mogelijkheden om de nutriëntenverliezen te beperken bij verschillende vormen van vee- en mestmanagement. Daarbij zijn ook verschillen tussen seizoenen, huisvesting en sociaaleconomische omstandigheden van belang. Het in verband brengen van visuele en voelbare karakteristieken van grond, voer en mest met meer wetenschappelijke kenmerken kan helpen om de mestkwaliteit en het risico voor verlies van nutriënten beter te beoordelen en om het bewaren en aanwenden van mest en de productie van bodem en vee te verhogen.

Zoekwoorden: kleine boeren, Oost Afrika, Kenia, mest, verzamelen, opslag, nutriënten, stikstof, verliezen, urine

Table of contents

1 Introduction

Manure is an important source of nutrients for many smallholder farmers in East Africa who can not afford or those only using limited amounts of chemical fertilizer, including farmers who participated in INMASP, a project on “Integrated Nutrient Management to Attain Sustainable Productivity increases in East African farming systems” (Elias, 1998; Elias et al., 2002; Walaga et al., 2003; De Jager et al., 2007; Onduru et al., 2008; www.inmasp.nl; carried out during 2002-2005 in Kenya, Uganda and Ethiopia). Smallholder farmers in Central Kenya, for example, highly value dairy cows for the production of manure, in addition to their production of milk (Lekasi et al., 2001a; 2003; Kimani and Lekasi, 2004). INMASP farmers identified insufficient manure, labor and/or knowledge as important constraints to using manure. In mixed farming systems, manure and nutrient availability vary temporally and spatially, due to variations in crop/livestock ratio and livestock and manure management. Powell and Williams (1995) indicate the risk of increasing nutrient losses, if the transition from open grazing to stall feeding is not accompanied by adoption of improved manure handling techniques. Nutrient losses during collection and storage of manure on smallholder farms have been studied less frequently than utilization of nutrients from applied manure (Powell and Williams 1995; Powell, 2004; Rufino et al., 2006). However, it is difficult to assess the combined effects of all factors, among others because of lack of information on nutrient losses during manure handling.
The objective of this report is to explore and discuss effects of variation in livestock management and manure handling techniques on manure quality and manure and nutrient availability. The second chapter reviews results derived from literature on manure quality and nutrient losses during manure collection and storage and suggests indicative losses for different manure handling systems. The third chapter explores effects of variation in cattle and manure management on manure and nutrient availability, using a scenario approach. The scenario approach is outlined in Section 3.1. The scenarios discussed in Section 3.3 have been (partly) derived from the variation in farm systems of INMASP project participants and farmer’s suggestions and/or innovations. The characteristics of these farm systems are described in 3.2. Scenarios concentrate on cattle because of their dominant role in nutrient cycling on smallholder farms in East Africa (Lekasi et al., 2001a; b; 2003; De Jager et al., 2007).

2 Manure quality and nutrient losses

2.1 Nutrient contents and reasons for variation

Nutriënt contents

The variation in nitrogen (N), phosphorus (P), potassium (K) and carbon (C) contents of farm yard (cattle) manures (FYM) from Africa, including some (liquid) cattle slurries (mixtures of dung and urine) is large (Table 1). In two surveys in Central Kenya (Lekasi et al., 2001a; 2003), total N contents (in dry matter, DM) varied from 0.3-2%, with averages of about 1.4 and 1.12% N, similar to the ranges reported by other sources in Table 1. Average N content of 25 cattle slurries from Central Kenya, stored in a covered lined pit for less than a week, was about 50% higher than in the FYM's from Table 1 (Snijders et al., 1992). C/N ratio of FYM from the surveys in Central Kenya are also highly variable. Only about 5% of total N in FYM was ammonia N (data not given) compared to about 25% for slurries from Kenya. N contents in slurries and FYM from temperate countries are often higher, probably due to higher protein contents in feed rations and more favorable collection and storage conditions, including lower temperatures. In the Netherlands, for example, average N contents in cattle slurry and FYM of about 4-5% and 2.5%, respectively have been reported, with about 50 and 25% respectively of total N in the form of ammonium N (Anonymous, 1997). The variation in N content in urine is even larger than in FYM. It may vary from well below 5 to more than 10 g N per l (mainly mineral N), depending on ration composition, dilution with water, and storage and weather conditions (Bannink et al., 1999; Kűlling et al., 2001; 2003; Rufino et al., 2006).

Table 1 Reported average nitrogen (N), phosphorus (P), potassium (K) and carbon (C) contents (in dry matter) (and their ranges) of (cattle) manures from Africa. Where necessary, C has been derived from organic matter content, assuming 55% C in organic matter. For comparison the composition of cattle slurry and Farm Yard Manure from The Netherlands is given (see text for explanation)

Manure type	% N (range)	% P (range)	% K (range)	% C	C/N	Reference
Cattle manure	1.4 (0.5-2)	0.6 (0.2-1.6)	1.3 (0.5-2.7)	35	25	Lekasi et al., 2001a, Kenya
Manure/compost	1.12 (0.3-1.9)	0.3 (0.1-0.8)	2.4 (0.4-7)	24	23	Lekasi et al., 2003, Kenya
Farm yard manure	1.62	0.5	1.43			Kimani and Lekasi, 2004, Kenya
Cattle manure	1.41 (1.1-1.9)	0.53 (0.4-1)	1.54 (0.9-2.1)			Onduru et al., 2008, Kenya
Cattle manure	1.22 (0.6-1.8)	0.29	2.14			Onduru et al., 2008, Kenya
Cattle slurry	2.1 (1.9-2.2)	0.53 (0.4-0.7)	3.9 (2.7-4.3)	33	16	Snijders et al., 1992, Kenya
Manure solid	0.89 (0.1-2.8)			13	14	Nhamo, 2004, Zimbabwe
Indoor manure	1.96	0.36	1.75		10	Jackson and Mtengeti, 2005, Tanzania
Kraal manure	1.13	0.19	1.16		19	
Earthen pit	1.58	0.27	0.94		11	
FYM	0.3-2.2	0.04-0.92	0.4-1.2			Harris, 2002, W. Africa
Cattle manure fresh	1.4-2.8	0.5-1.01	0.5-0.6			FAO, 2001
Cattle kraal + litter	0.5-2.3	0.22-0.81	0.77-5.44			
Cattle kraal – litter	1.5-2.5	0.2-0.6	1.5-2.0			
Cattle slurry	4.9	0.84	5.6	32.7	7	Anon., 1997, the Netherlands
FYM average	2.94	0.72	2.61	35.8	12	

Non-chemical manure characteristics may be useful for farmers if laboratory analysis is not feasible (Lekasi et al. 2001b; 2003, Thorne and Tanner, 2002). In an assessment tool for manure quality, Lekasi et al. (2003) indicated that manures with finer texture and older manures were characterized by lower C/N ratios and higher contents of mineral N. Use of bedding material widened the C/N ratio, while turning of manure increased mineral N content. Farmers may consider a grayish black color, fine texture, longer composting time, decomposed manure and/or a fungal smell as indicators of better manure quality (Kimani and Lekasi, 2004). Farmers participating in INMASP in the southern highlands of Ethiopia distinguished between dry and wet season manure, wet season manure being darker and wetter and used near the homestead, while dry season manure was generally used further from the homestead. Zaaijer and Noordhuizen (2002) discuss the relation between manure characteristics and feed quality, including fecal consistency and fiber content of freshly excreted faeces. Fibrous, higher dung heaps immediately after excretion may indicate lower feed digestibility. A darker color of dung (or slurry) directly after excretion may indicate higher nitrogen contents in some situations, although further investigations are necessary to confirm this.

Reasons for variation in nutrient content of manures
Variations in nutrient content of manures are associated with:

- Variation in ration composition and utilization by animals
- Collection, storage and processing of excreta, including contamination with soil
- Addition of organic materials, in particular feed refusals

Rations Variation in ration digestibility and protein content can result in large variations in nitrogen excretion in urine (from below 10% to over 70% of total excreta N) and N contents of dung and urine (Delve et al., 2001; Lekasi et al., 2001a; b; Kűlling et al., 2001; Broderick et al., 2003; Snijders and Wouters, 2003). N content of faeces was 0.9-1.7% and the C/N ratio 27 and 22 for animals fed with a basal ration of barley straw only and barley straw supplemented with 30% Calliandra leaves, respectively (Delve et al., 2001). N contents of 1.53% and 2.98% were measured in slurries produced on rations with 9.4 and 14.7% crude protein, respectively (Table 3; Hiddink, 1987). Manure quantity and composition can vary substantially between seasons due to differences in feed availability and quality, i.e. manure quantity and quality in West Africa are generally (much) lower in the dry season than in the rainy season (Powell, 2004), except in situations where cropping strongly limits feed availability during the rainy season (Powell and Williams, 1995).

Collection Manure collection methods, both of dung and urine, vary widely due to for instance variation in labor availability and housing and storage facilities (Section 2.3). During collection and processing, manure can be contaminated with soil, while soil may be added on purpose, for instance during composting.

Additives In Maragua district in Central Kenya, almost 70% of the farmers added some form of bedding material to manure, often fodder refusals (Lekasi et al., 2003). Most farmers (67%) stored manure in a heap or pit while 33% used deep litter storage. A majority (90 %) did not cover manure. Age of manure heaps varied from 1-8 months. Most farmers added at least some urine to the manure heap, but without clear effect on N concentration in (composted) manure, although mineral N content was slightly higher.

Ash (and carbon) contents of manures can vary strongly, due to variation in organic matter content, feed digestibility, and contamination of feeds and excreta with soil, thereby also changing N content. Adopting for example a carbon content of 35% C in the second survey of Lekasi et al (2003 in Table1) instead of 24% C, similar to the average 35% C from the first survey (Lekasi et al, 2001), and using a carbon content of 55% in manure organic matter (Reijs et al., 2007), average N content would become 1.6% instead of 1.12%, being higher in the second survey after correction for differences in C (and ash) content. Nhamo et al. (2004) measured low nitrogen and high ash contents in manures from Zimbabwe, but manures had a rather low C/N ratio of 14 (Table 1). Rufino et al. (2006) also refer to low N contents and very high ash contents for manures in semi-arid eastern Kenya.

2.2 Nutrient, carbon and dry matter losses during manure collection and storage

Nutrient losses
Variation in nutrient loss during manure collection, storage/processing and application is high (Bussink and Oenema, 1998; Kűlling et al., 2001; 2003; Kimani and Lekasi, 2004; Rotz, 2004; Rufino et al., 2006). The most important processes are:

- Leaching of soluble nutrients, from urine in particular (nitrogen, potassium, sulfur)
- Gaseous losses during collection, storage and application (in particular ammonia)

In experiments of Lekasi et al (2001; Table 2), addition of urine (containing on average 39% of excreted N) and feed refusals from maize stover to faeces, increased total N losses from about 35-40% to about 60%. For manures with urine addition, N loss was much higher than for manures without addition of urine, and most N was already lost during the first collection and heaping phase (about 40%, representing the excreted urine N). Nitrogen loss was much higher than for the treatments without urine addition. However, in another experiment, where only about 20-30% of N was excreted in urine and finer chopped wheat straw was added instead of (relatively) coarse maize stover (Lekasi et al., 2001b; results not shown in Table 2), average N losses were lower, and addition of urine tended to reduce N losses. It should also be noted that N-losses from storage of urine for treatments without urine are not included (not measured). The absorption capacity of different bedding materials (including feed refusals) for liquids varies, among others due to differences in moisture content and texture, affecting absorption and distribution (Misselbrook and Powell, 2005).

Table 2 Nitrogen losses (%) from different systems for collection of cattle manure during 144 days of collection and composting (derived from Lekasi et al., 2001b).

System manure collection and storage	N loss
Faeces + urine + feed refusals: animal mix	63
Faeces + urine + feed refusals	61
Faeces + feed refusals	34
Faeces + urine	46
Faeces	41

Table 3 Dry matter (DM) and nutrient contents (% in DM) before and losses during 3 weeks of storage of manure as slurry in a soil heap or pit for manure produced from 2 rations with different crude protein (CP) contents (adapted from Hiddink, 1987)

Manure quality	% DM	N	P	K	C/N ratio
Ration 1: 9.4% CP	16.5	1.53	0.48	3.78	18
Ration 2: 14.7% CP	10.7	2.98	0.86	4.4	10
Dry matter and nutrient losses in % (% DM and % N in manure after storage in brackets)					
	DM	N	P	K	
Heap ration 1	10 (25.8)	33 (1.14)	1	27	
Pit ration 1	6 (17.4)	17 (1.35)	3	16	
Heap ration 2	17 (63.5)	57 (1.56)	11	39	
Pit ration 2	2 (13.4)	19 (2.44)	-2	6	
Average heaps	14	45	6	33	
Average pits	4	18	1	12	

On commercial farms in Kenya, storage of dung with more or less urine and feed refusals in a shallow heap is quite common. Hiddink (1987) compared in two experiments: storage of faeces and urine from dairy cattle as slurry in either heaps or pits without cover, the surface exposed being much smaller for pit storage (Table 3). Slurry was produced by dairy cows housed in an open, partly roofed, zero-grazing unit with cubicles and a sloping concrete floor. Manure was shoveled manually twice daily into a covered slurry pit. Average ration crude protein content fed in experiment 2 was higher and slurry contained more N. Losses of potassium, dry matter and nitrogen in particular, were much higher for heap storage, with large differences for the manure from the ration with higher protein content. Estimates based on the nitrogen balance and expected N excretion of cows, suggest that in both experiments about 20-25% of the excreted nitrogen was lost between excretion and removal from the slurry pit (3 times per week), probably mainly due to ammonia volatilization before collection in the pit in the warm, sunny climate.

Kwakye, cited by Harris (2002), found N losses of up to 59% during three months storage of manure in Ghana. In Zimbabwe, losses of ammonia N were lower for manure composted an-aerobically in a pit than composted aerobically in an open-air heap on the ground as deduced from better manure quality and higher maize yields. Losses of ammonia N from kraals were 80% lower when crop residues were added (Nzuma and Murwira, 2000; Murwira, 2004). Undisturbed natural crusts and layers of straw on top of a manure tank/pit may substantially reduce ammonia losses (Rotz, 2004). In uncovered earthen pits or heaps losses due to leaching may be important as found in Tanzania by Jackson and Mtengeti (2005). Drainage of seepage (or leached liquids) into a covered pit/channel can help to reduce losses. Chadwick (2005) found lower losses if heaps of farm yard manure were compacted and covered.

In experiments under Swiss conditions (Kűlling et al., 2001; 2003), including rations with variable protein content and three manure storage systems: slurry, deep litter (with 11.8 kg straw per cow per day added) and the combination of farm yard manure (with 1.75 kg straw per cow per day added) with separate urine liquids, N losses during storage tended to increase sharply for excreta from rations with higher protein content, in particular for excreta with C/N ratios below 15 (Table 4). The C/N ratio decreased with higher protein content in the ration. Losses were highest for urine liquids, with a C/N ratio of 8 or lower, and lowest for deep litter with a C/N ratio of about 25. Although conditions are different from East Africa, similar principles probably apply.

Table 4 Nitrogen losses (%) during storage of cattle excreta from rations with variable crude protein (CP) content stored as deep litter, slurry, or separate farm yard manure and urine liquids (storage period 7 weeks). The carbon to nitrogen (C/N) ratio before storage is included (derived from Kűlling et al., 2001)

Storage system	% CP	C/N ratio	% N loss
Slurry	17.5	10	24
Slurry	15	13	18
Slurry	12.5	14	11
Urine liquids	17.5	4	49
Urine liquids	15	7	37
Urine liquids	12.5	8	24
Farm yard manure	17.5	17	11
Farm yard manure	15	16	18
Farm yard manure	12.5	18	9
Deep litter	17.5	25	11
Deep litter	15	26	0
Deep litter	12.5	25	16

Table 5 Indicative losses (%, average and range) of dry matter and nitrogen for different housing and manure storage systems in the USA (derived from Rotz, 2004)

Housing system	DM	N
Cattle tie stall		8 (2-35)
Cattle free stall		16 (10-20)
Cattle bedded pack		35 (25-40)
Cattle feedlot		50 (40-90)
Manure storage system		
Solid heap cattle	20	20 (10-40)
Solid compost	40	40 (20-50)
Slurry tank filled from top	10	30 (20-35)
Slurry tank filled from bottom, enclosed	10	6 (2-10)

In the USA, variation in losses is large, with high values for long-term storage in open feedlots and open lagoons (Table 5). In Western Europe, N losses from slurry systems with water-tight storage are estimated at about 10% during collection and storage (Ketelaars and Van der Meer, 2000). Kolenbrander and De La Lande Creemer (1987) indicated that N losses from urine stored in “semi-closed” pits/cellars in the Netherlands sharply increase with increasing N concentration (from about 1 to 5% per month for urine containing 1 and 5 g N per litre, respectively). N losses from open pits during winter were estimated to be double, reaching values of 10% per month in summer, even at low N concentrations.

Nitrogen losses during anaerobic storage are lower than during aerobic storage (Kirchmann and Lundvall, 1998; Thompson, 2000; Rufino et al., 2006), but losses can be substantial during long storage periods, even under anaerobic conditions (Dewes et al., 1990). N losses during (aerobic) composting can vary from about 20 to 80% (Martins and Dewes, 1992; Barrington et al., 2002; Tiquia et al., 2002). Aeration through turning intensifies the composting process, increasing temperatures, and (rates of) N loss (Tiquia et al., 2002; Parkinson et al., 2004), although higher temperatures can help to control weeds and pests.

Based on a review of losses during composting, Shepard et al. (2000) derived the following:

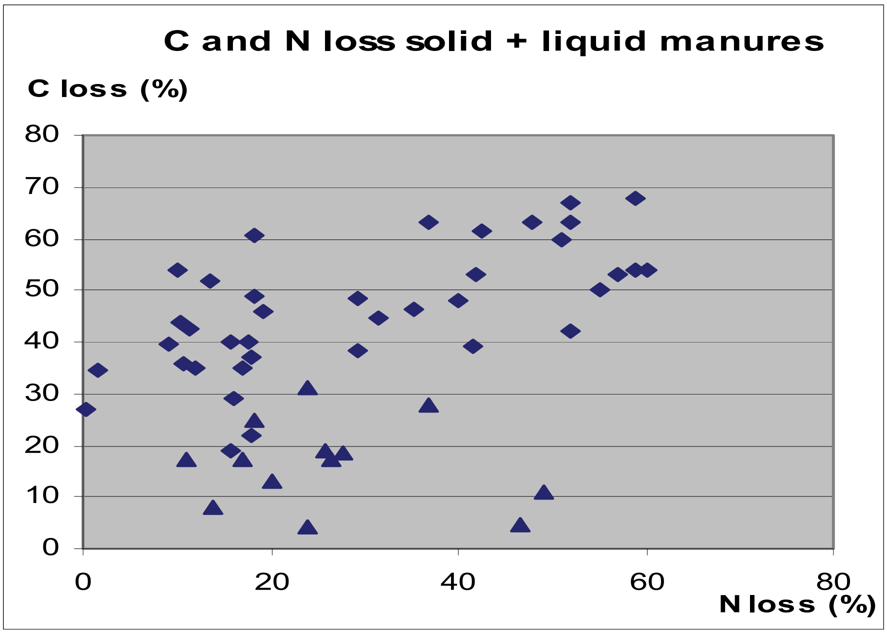
- C/N ratio below 20: N loss = 115-5*C/N ratio
- C/N ratio of 20 and above: N loss is 10%

However, differences also exist among sources of carbon (and N), faster decomposing carbon sources (composition and particle size) being more effective in reducing ammonia loss (Liang et al., 2006).

Carbon and dry matter losses

The variation in carbon and dry matter losses during storage and composting of manure is large. Figure 1 shows the variation in carbon loss for solid and liquid manures in relation to N loss. C-losses tend to be higher for solid than for liquid manures (slurry or urine). For liquid manures, slurry (urine and faeces) tend to have higher C losses and lower N losses than urine liquids (urine not shown separately). For solid manures in Figure 1 the relation between C- and N-losses (C-loss = 33.5+0.43*N-loss; r^2=0.65) is statistically significant, but not for liquid manures.

Figure 1 Relation between carbon loss and nitrogen loss of solid and liquid manures during storage/composting. Sources: Barrington et al., 2002; Chadwick, 2005; Eghball et al., 1997; Hao et al., 2004; Kűlling et al., 2001; 2003; Sommer, 2001; Tiquia, 2002. Data are treatment averages. Liquid manures (derived from Kűlling et al., 2001 and 2003) are positioned as triangles in the lower part. See text for further explanation.



The sources underlying Figure 1 indicate that C-loss is influenced by variation in storage conditions (more or less aerobic due to for instance type of storage, compaction and turning) and manure characteristics such as C/N ratio and “degradability” of organic matter (similar to feed degradability). Type of storage (liquid or solid, compacting, covering), extent of composting, N leaching and possibly soil content may affect storage conditions and manure characteristics. C-loss of compacted (Chadwick, 2005), unturned (Tiquia et al., 2002) or covered (Hansen et al., 2006) solid manure tends to be substantially lower. This type of manure storage method can possibly be considered intermediate between more aerobic solid composting and more anaerobic liquid manure storage. Covering reduces losses of carbon, ammonia N and production of greenhouse gases (Hansen et al., 2006). Carbon losses are relatively lower from less degradable carbon sources. Barrington et al. (2005) found a negative correlation between C and N losses for substrates with strongly varying C-degradability. The highest C losses in Figure 1 (upper right hand corner) were recorded in turned pig manure in a heap with corn stalks (Tiquia et al., 2002), both probably rather degradable. Without these pig manures, average carbon losses for solid manures are about 40%, while the correlation with N loss is weaker. However, the variation is still large (storage conditions and manure characteristics). Longer storage periods of (slurry) manure and higher temperatures can increase C (and N) losses, depending on storage conditions (Steinfeld et al., 2007). Under anaerobic conditions this may result in biogas production.

There is a relatively good correlation between N loss and C/N ratio for both, solid and liquid manures in Figure 1 (C/N ratio not shown; see also Section 2.2.1). For solid manures, N loss = 68-2.1 * C/N ratio (r^2=0.79), and for liquid manures, N-loss = 55-2.9 * C/N ratio (r^2=0.92).

Reported dry matter losses (for instance by Tiquia et al., 2002) tended to be lower than carbon losses (about 80-90% of C-loss), but they are probably related to storage conditions, including the risk for leaching. Dry matter losses during storage of slurry for three weeks in a heap and pit were respectively 14% and 4% (Table 3), and 10-40% for manure storage systems in the USA (Table %).

2.3 Housing and manure collection and storage

Housing of cattle constitutes an important aspect of manure management. For confined animals (simultaneous) optimization of both housing and manure management is important to facilitate feeding, hygiene and animal health/welfare, manure collection and nutrient conservation and to save labor. On smallholder farms in East Africa cattle are often confined in an open or roofed kraal/boma and sometimes indoors. On more intensive farms, in for example Kenya, improved zero-grazing units have been established, with cubicles, a roof and a concrete floor. In Central Kenya a large variation in housing and manure management systems was observed (Lekasi et al., 2001a; 2003, Onduru et al., 2008; Section 3.2). Manure was often heaped outside the cattle boma, but also (deep) litter systems were quite common. Many farmers added (some) urine to manure heaps. Some farmers collected urine separately in a pit outside or inside the boma or drained urine via channels to perennial crops such as Napier and banana. More frequent collection/cleaning can contribute to reducing N losses.

In practice, management and dimensions of manure heaps vary, and heaps may be partly aerobic and/or partly anaerobic. In compacted and covered heaps/pits, with a water-tight floor (or collection of leached liquids), N losses are lower. A larger surface area for the (collection) and storage facility of manure increases the risks for ammonia volatilization (Smits et al., 1995; Chadwick, 2005) and leaching. Compact heaps are easier to cover. In India, a system for storage of solid manure is used, consisting of two small and long pits that are filled and covered stepwise and emptied alternately (Gupta, 2000).

A well-managed zero-grazing unit, with cubicles, a concrete floor and a slurry pit, allows rather efficient collection of excreta as slurry. Liquid manures however, are difficult to store and to handle and to use on annual crops, and are therefore best used soon after excretion to limit N losses. Alternatively, dung and urine can be collected separately, with frequent dung removal and instantaneous drainage of urine into a closed and water-tight pit, where it may be diluted with water (practiced by for example an INMASP participant in Wakiso, Uganda). N-losses in such systems are probably relatively low. Also in a tie stall, still used by many smaller farmers in Europe, urine and dung can be collected and stored separately, with relatively low N losses, provided that urine is properly stored (Hutchings et al., 2001; Kulling et al., 2001). The mixture of dung and bedding material is transferred twice daily to a (covered) compact storage facility for farm yard manure, from where leached liquids can be drained into the urine pit.

Kűlling et al. (2001; 2003) show that in a covered deep litter stall (boma) nutrients are conserved rather well, if sufficient good quality bedding material is used appropriately. If the quantity and/or quality (or distribution) of added bedding material is insufficient, as on many smallholder farms, nutrient losses can be high (Lekasi et al., 2001b).

Chicken and goats can be kept on a raised wired or slatted floor, allowing easy collection of excreta below the floor (for example in a pit). (Fast) drying of poultry manure (to about 50% dry matter or more) substantially reduces the risk for N loss (Kirchmann and Lundvall, 1998), in particular beyond about 80% dry matter. On Java, Indonesia, cattle excreta are also collected below cattle barns, with ample feed refusals being added daily to increase compost production (Zemmelink et al., 1992).

2.4 Indicative nutrient losses during manure collection and storage

Based on the literature review, indicative values (averages and ranges) have been constructed for N, P and K losses for six manure collection and storage systems used on smallholder farms, including losses between excretion and collection (Table 6). The variation is large and more insight is needed in losses under practical conditions (Lekasi et al., 2003; Rufino et al., 2006). Losses are presented separately for urine and faeces, because of the variation in proportional nutrient excretion in urine and faeces and the higher risk for losses of soluble nutrients from urine. Although in practice urine and faeces are often stored jointly, N losses in particular originate to a large extent from urine. For reasons of simplicity it is assumed that P is excreted in faeces only and K only in urine, although approximately 10% of K can be excreted in faeces (Bannink et al., 1999).

The sequence of the systems in Table 6, from kraal to liquid manure, represents increasing intensification of livestock systems, characterized by increasing investments in manure handling (capital and/or labor). This is reflected in the use of increasingly compact and air- and water-tight systems of manure storage, separate storage of urine and dung and/or improved composting due to the addition of more organic material to reduce N losses for heaps and deep litter systems. In a kraal (no roof) and for deep litter systems, manure is stored in the same area where cattle are confined. Within a given storage system, modifications in manure management and composition result in changes in the magnitude of losses.

Table 6 Indicative nutrient losses (% N, P and K) from 6 systems of manure collection and storage under various management conditions. Per system intermediate (average), and low and high loss levels are shown separately for urine and faeces.(table constructed based on review!)

Manure system	Urine N	Faeces N	Faeces P	Urine K
Open kraal/boma	70 (30-100)	30 (10-50)	15 (10-30)	45 (10-80)
Manure/compost heap	60 (20-100)	20 (10-30)	10 (5-25)	40 (10-70)
Manure/compost pit	50 (20-80)	15 (5-25)	10 (5-20)	20 (10-30)
Deep litter/compost	55 (20-90)	15 (5-25)	10 (5-25)	25 (10-40)
Compact pit/heap + urine pit	40 (20-60)	10 (5-15)	5 (3-10)	10 (5-15)
Slurry pit (water tight, covered)	30 (20-40)	7 (5-10)	5 (3-10)	10 (5-15)

Average carbon losses for solid cattle manure are estimated at about 40%, but the value may vary as a result of variation in storage conditions (aeration, storage period, temperature), and manure characteristics (degradability, moisture content), that strongly affect (rate of) organic matter degradation and C loss.

Some additional remarks on Table 6 and its use are given below.

- The indicated difference in nutrient losses among manure handling systems is much larger for urine than for faeces and smaller for average and low loss levels in comparison to high loss levels. The lowest losses are associated with excellent collection and storage conditions and low N losses before collection. Relatively high losses for faeces reflect mainly poor collection methods. Losses are by far the highest for nitrogen, followed by potassium and phosphorus.
- The risk for N-losses reduces going from more aerobic storage systems (as in compost heaps above ground) to more compact and covered anaerobic storage systems in manure or slurry pits and/or (separate) collection of (urine) liquids or manure with a higher C/N ratio. Combinations or intermediate situations are also possible, such as separate, more aerobic storage of solid manure in heaps and separate more “anaerobic” urine storage in pits, or partly aerobic/anaerobic heaps (or pits). Under “completely” anaerobic conditions such as in “closed” slurry pits, biogas fermentation is possible with minimal N losses.
- Aeration (associated with turning of manure/compost or a higher wind speed), higher temperatures, and higher N concentration increase the risk for N loss before collection and during storage. These conditions lead to higher rates of manure decomposition. Turning has a similar stimulating effect on decomposition as tillage on soil organic matter decomposition.
- Frequent excreta collection, smaller exposed collection and storage surfaces, including covering manure, and short storage periods all lead to reduced N volatilisation. A roof and/or other cover and/or a water-tight floor for animal houses and manure storage facilities prevent or reduce leaching, with stronger effects in areas with higher precipitation. Collection of leached liquids will reduce N and K losses. Manure may be more liquid and relatively richer during the rainy season. If kraals are rotated, urine in particular may be better utilised (Powell et al., 1998).
- Rations with higher digestibility and crude protein contents lead to higher N contents in faeces and N excretion in urine, with higher risks for N losses, in particular from rations with crude protein contents exceeding 11-12% (Snijders and Wouters, 2003). Consumption (browsing) of forages containing tannins may limit N excretion and losses from urine (Delve et al., 2003). If N excretion in urine increases, use of (partly) liquid systems becomes probably more feasible.

Linking farmers' indicators such as color and texture for soils, forages and manures to (more) scientific indicators may help to identify opportunities for improved nutrient use. Palm et al. (2001) developed a system based on leaf color (green to yellow), fiber content and taste. Kimani and Lekasi (2004) suggest that the relatively better utilization of Masai (cattle) manure in their experiment, despite lower N content, may be due to its fine texture.

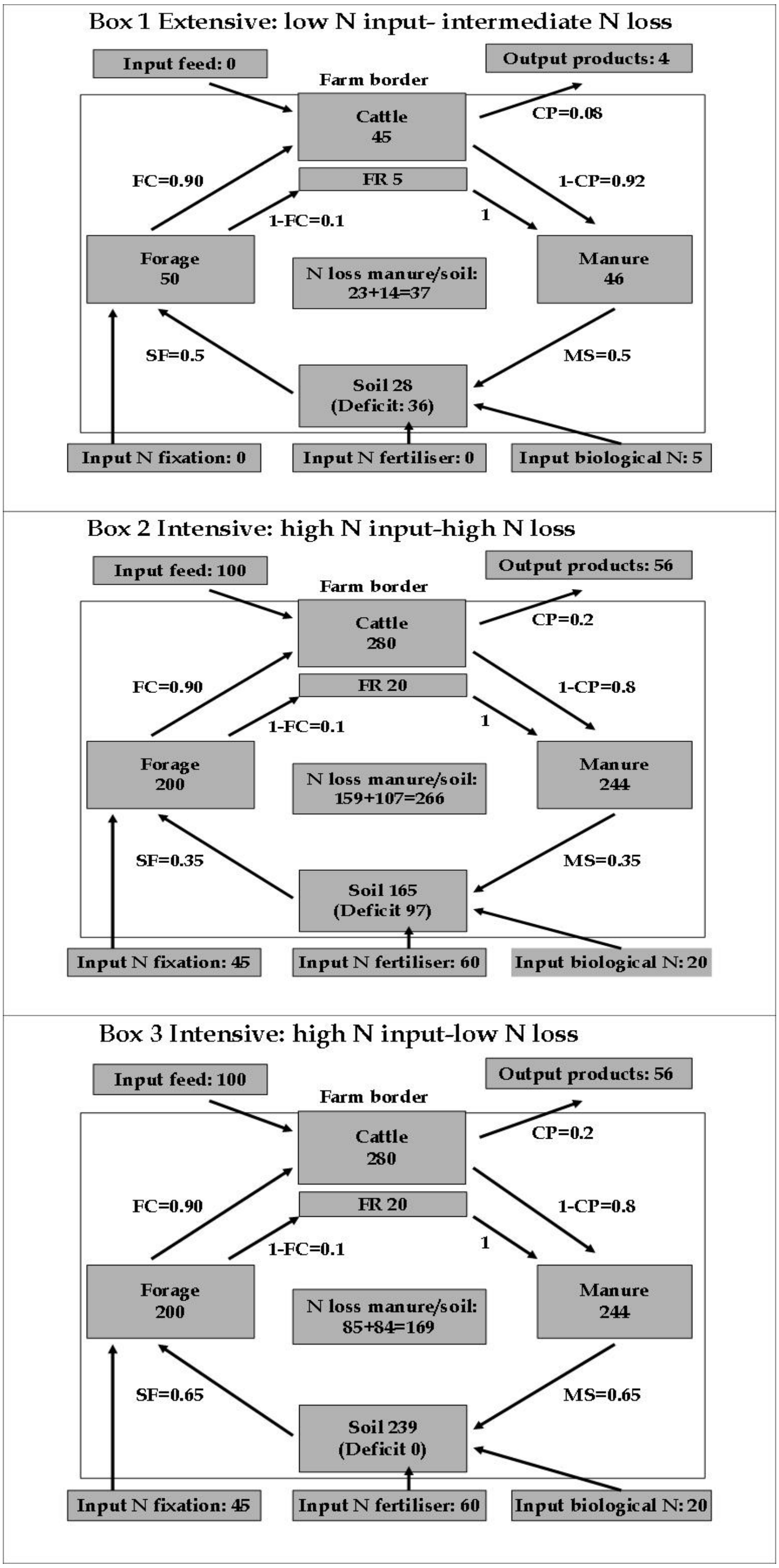
Losses during manure application are excluded, but N conserved during collection and storage may still be lost, in particular after surface application (Kirchmann and Lundvall, 1998; Amon et al., 2001; Rufino et al., 2006). For compost, nitrogen losses during composting tend to be higher, while losses during application are relatively small.

3 Scenario approach

3.1 Scenario approach: explanation and examples

On a mixed crop-livestock farm, nutrients such as nitrogen (N), phosphorus (P) and potassium (K) cycle from soils to crops to animals to manure, and back to soil. During cycling through these “compartments” nutrients are converted (utilised) by crops and animals, while “losses” occur. Nutrients enter (inputs) and leave (outputs) the farm system via the farm gate, for example in feeds, fertilisers and milk. A scenario approach can support exploration of the sensitivity of nutrient cycling to changes in system characteristics such as forage production, external nutrient inputs and outputs, animal nutrition, and nutrient losses from manure and soil. To explain the scenario approach, Boxes 1-3 show three example scenarios for N, emphasising the forage and cattle components of the farm system (adapted from Schröder et al., 2003). Quantities of N cycling through the compartments forages, cattle, manure and soil are situated inside the farm boundary, while N inputs and outputs are outside.
Box 1 shows a scenario representing an extensive farming system without external N inputs, except for 5 kg N from precipitation. N losses from manure and soil are assumed to be intermediate. Harvested forage, i.e. grass and crop residues (as maize stover; grain, not being fed, is excluded!) contains 50 kg N. Of the N in home grown forage, 90 % is ingested by cattle (FC=0.9), the remaining 10%, representing feed refusals (FR=1-FC), flows via cattle to manure. The efficiency of conversion of ingested N to cattle produce is set to 0.08 (CP=0.08), which is assumed (for reasons of simplicity) to leave the system through the farm gate (equivalent to an annual milk production of about 750 kg). The conversion efficiencies from manure to soil (MS) and from soil-applied manure to forage (SF) are both set to 0.5, indicating N “losses” of 50% during manure collection and storage and 50% from applied manure (for the dynamics of SF under long-term application see further discussion). These assumptions result in annual N losses of 23 and 14 kg from manure and soil respectively (total 37 kg). The total of 28 kg soil applied N (including 5 kg N from precipitation) results in a soil deficit of 36 kg N. This indicates that an additional 72 kg N is required to sustain a forage yield of 50 kg N (if SF remains 0.5) without depleting soil N.
Boxes 2 and 3 show intensive scenarios. Harvested forage contains 200 kg N and external N inputs are supplied in imported feeds such as dairy meal and/or forage, chemical fertilizer (60 kg N) and symbiotic nitrogen fixation (60 kg N, of which 45 kg is harvested in forage and 15 kg is added to the soil in stubble and roots). Forage N is converted more efficiently into cattle produce (CP=0.2). Conversion efficiencies MS and SF are both set to 0.35 in Box 2 (rather low), and 0.65 in Box 3 (rather high). These assumptions result in N losses of 159 kg and 85 kg from manure, total losses of 266 and 169 kg, and soil-N deficits of 97 and 0 kg, respectively. These examples illustrate the potential importance of the (cattle) manure component in N cycling.

Box 1-3 Extensive (Box 1) and intensive (Box 2-3) example scenarios for N cycling (kg N year^{-1})

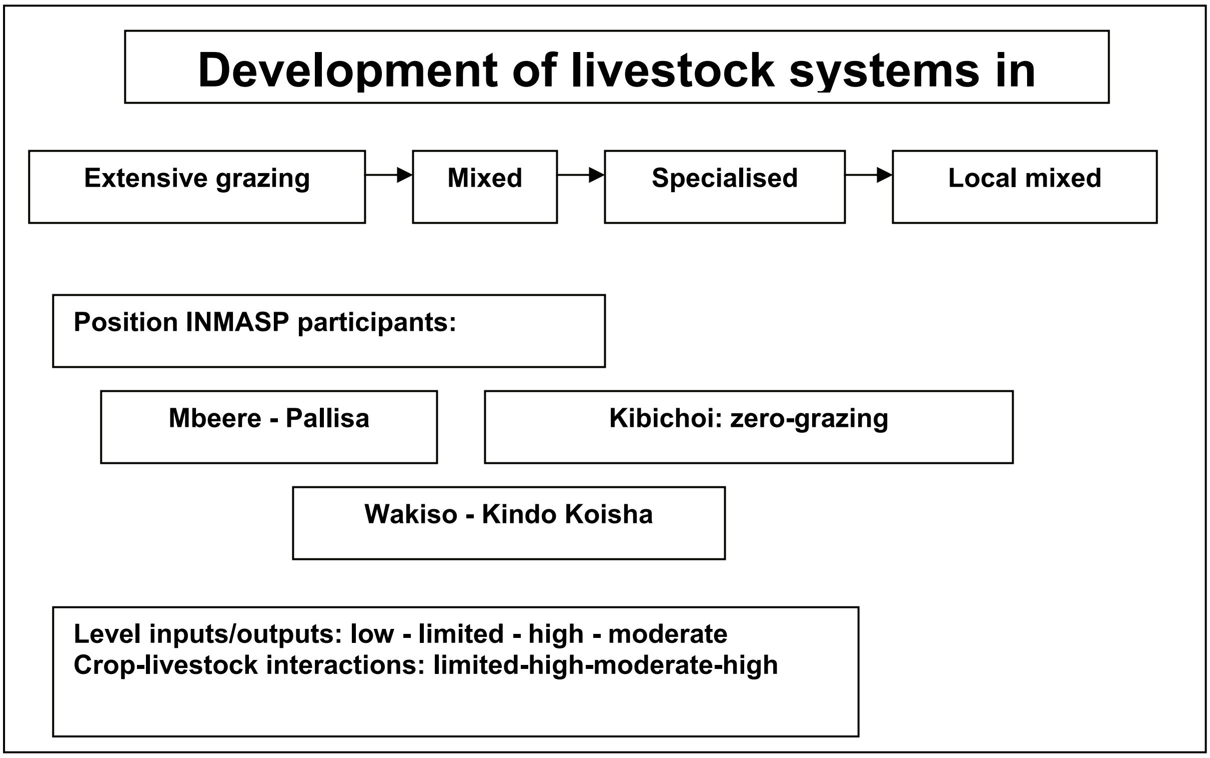


3.2 Characteristics of farms participating in INMASP

Box 4 shows some important characteristics of the temporal dynamics of crop-livestock systems (adapted from Steinfield et al., 1996; Schiere et al., 2002). The scheme shows the following trend:

Extensive grazing => mixed farming => specialised livestock farms => integrated mixed farming at local/regional level.

Box 4 Schematic representation of the temporal characteristics of livestock systems, and the position of INMASP participants (see further text)



Extensive grazing may include the use of communal land. More or less integrated and specialised "partner" enterprises may exchange or trade in for example forage (Staal et al., 1998) and/or manure to optimize local resource use and/or land productivity. Possible changes in level of inputs and outputs and the extent of interaction (integration) between crops and livestock are also indicated.
The majority of INMASP farms can be categorized in one of these groups. Many are smallholder mixed farms, but some are rather extensive, with emphasis on communal grazing, while more specialized farms keep cattle under total confinement (zero-grazing) and may trade or exchange forages. INMASP farms have been divided in 3 groups, based on regional differences and agro-ecology, farming intensity, market distance, and region/country. However, the groups partly overlap, because of large variation in farms within and among regions. Farm characteristics are extensively discussed in Elias (2002), Onduru et al. (2002), Ebanyat et al. (2003), Walaga et al. (2003), Gachimbi et al. (2004), De Jager et al. (2007) and Onduru et al. (2008).

Group 1 Extensive grazing systems

In Mbeere, in Eastern Kenya (semi arid) and in Pallisa in Eastern Uganda (wetter) the prevailing livestock system is extensive (communal) grazing of mainly local cattle breeds. In Mbeere farmers on average cultivate about 1.5 ha, depending on the study site, with a density of 0.9 Tropical Livestock Units per ha (one TLU being equivalent to an animal live weight of 250 kg), mainly as cattle (and goats). In Pallisa, farm size is similar. Important reasons to keep livestock in both Mbeere and Pallisa are the provision of draft power and of manure. Manure management is relatively poor. In Mbeere most farmers own goats, but only about half of them keep cows.
Crops and animal nutrition In Mbeere about 90 % of grass ingested during the rainy season is reported to originate from outside the farm, with hardly any use of external inputs. In Pallisa, some farmers have started zero-grazing systems, with small plots of legumes for forage or green manure.

Important crops in Mbeere are cereals such as maize and sorghum, and cowpea, and in Pallisa sorghum, finger millet, cotton, groundnuts and rice. The ration, in addition to grazing, comprises some elephant grass (*Pennisetum purpureum*), crop residues (from cereals and banana) and weeds. Limited or no concentrate supplementation was recorded.
Housing and manure In both, Mbeere and Pallisa, cattle are mainly kept in an open boma/kraal, about 25% being fitted with a roof in Mbeere and none in Pallisa. No concrete floors, bedding material or separate drains for urine collection are used. Manure often remains in the boma until transport to the field, or is heaped, generally without cover. Not all manure is used, due to lack of transport/labour. In Pallisa, overgrazing and lack of manure were mentioned as reasons for poor soil fertility. To improve the situation, farmers suggested use of manure and legumes, controlled grazing and pasture establishment.

Group 2 Semi-intensive systems

In Wakiso (Central Uganda) and in Kindo Koisha (here-after called Kindo, in the southern Highlands of Ethiopia) farming is more intensive. Average farm size is about 0.8 ha in Wakiso and 0.5 ha in Kindo. Average annual precipitation is 1320 mm in Wakiso and 1270 mm in Kindo, but droughts are not uncommon. Livestock is kept for manure, cash, home consumption and, especially in Kindo, for draft power. About 75% of the farmers keep cattle. Some farmers in Wakiso keep improved dairy cattle, those in Kindo mainly local breeds but they have started to adopt Jersey crossbreeds. Use of external inputs is low, especially in Kindo. Low soil fertility and inadequate manure, forage (especially Kindo) and labour availability are important constraints.
Crops and animal nutrition Banana is the most important crop in Wakiso, enset or false banana (*Ensete ventricosum*) in Kindo. Other crops are cereals such as maize (important) and sorghum, root crops such as sweet potato, beans and coffee, some (fodder) tree legumes, and, in Wakiso, vegetables and sugar cane, and, in Kindo, small tree plots (woodlot) at the lower farm end. Cattle are sometimes grazed or tethered during daytime, but are increasingly confined. Natural pastures are important, although their role is decreasing (occupying about 15 % of the farm land in Kindo). Other feed resources include elephant grass (in Wakiso), Panicum (in Kindo, on anti-erosion bunds), crop residues (from maize, small grains, banana, enset and sweet potato) and some weeds. The most important supplement in Wakiso is maize bran, with dairy meal, oil seed cake (cotton and sunflower) and fish meal being less important. In Kindo use of supplements is rare.
Housing and manure Housing of cattle varies. In Wakiso, local cattle are kept in (open) bomas, but improved dairy cattle on more intensive farms are housed in (improved) zero-grazing units. In Kindo, local cattle are often kept in a section of the farm house. Various manure handling methods are practiced. Composting is quite common in Wakiso but not in Kindo. In Wakiso, covered, un-covered and shaded manure heaps are found. However, some manure is transported directly to the field. About 20% of the farmers collect urine separately and about 15% use “manure tea” (manure diluted with water). Many farmers mix manure with bedding material. Following application, manure is normally covered with soil. In Kindo, most farmers use bedding material in the livestock pen. Manure is either heaped temporarily outside the house or directly in the field without special attention to minimising nutrient losses. Manure application is concentrated on plots near the homestead. Dry season manure is sometimes applied in limited amounts to plots further from the homestead.

Group 3 Intensive zero-grazing systems

In densely populated Kiambu (Kibichoi study site) in Central Kenya, average farm size is 0.8 ha, with a total of 5.0 TLU per ha, of which 90% are cattle. Farms are rather commercially-oriented, with easily accessible markets such as Nairobi. Average annual precipitation is about 1200 mm at the INMASP study site. Dairy production is rather intensive. Important reasons to keep livestock are manure and cash. Crossbred and purebred dairy cattle are kept under zero-grazing.
Crops and animal nutrition Feed supply for lactating cows, recorded during the rainy season, consisted of about 60 % forage, on dry matter (DM) basis, and supplemented with different types of supplements. Crops include maize, coffee, (intercropped) beans, fruits (banana), sweet potato and vegetables. Feed resources include elephant grass (60% of the forage during the rainy season), local grasses, crop residues (maize stover, limited amounts of banana stems and leaves and sweet potato vines) and limited quantities of forage and tree legumes (Lucerne, *Desmodium* and *Leucaena*). During the rainy season on average about 25% of elephant grass, most of the local grass, and about 40% of the banana residues were purchased, a few large farms with 4-8 dairy cows purchasing up to 70% of the forage. Important supplements were dairy meal and by-products from milling such as wheat bran and pollard. In addition, cottonseed cake, brewers waste (on a few farms), rice bran and molasses were used.

Housing and manure Cattle houses are roofed on about 80% of the farms, about half have a concrete floor and about 40% have a separate slurry drain. About 40% of the farmers mix manure with bedding material. In zero-grazing units without a floor, crop residues and feed refusals are added to the manure and mixed by animal action. On more than 80% of the farms manure is heaped, about 40 % of heaps being covered or shaded, while about 30% of the farms practice composting. Most manure is applied to food crops such as maize and banana, but also to elephant grass. Constraints include insufficient manure and labour shortage.

3.3 Scenarios to assess effects of cattle and manure management on nutrient and manure availability

Based on the farming situations described above, eight scenarios' were developed: rather extensive (Mbeere; scenario 1 and 2), semi-intensive (Wakiso; scenario 3 and 4) and rather intensive (Kibichoi; scenario 5 and 6), each with a baseline and an "improved", more intensive scenario. For Kibichoi, two additional improved scenarios were developed to asses the effects of poor manure handling under intensive nutrient cycling (scenario 7) and further intensification through purchase of forage (scenario 8). In the improved scenarios, cattle nutrition is improved through both better quality forage (younger grass and more legumes) and higher supplementation, allowing higher milk production, while nutrient losses during manure collection and storage are lower in most of the improved scenarios. A direct comparison with farmers' situations is not possible, because of the large variation among farms and insufficient information.
In all scenarios' only cattle are included, because of the dominant contribution to manure production. The basis is one cattle unit (CU), consisting of 1 mature cow and 0.8 head of young stock (calves and heifers). Live weight per cow (LW, representing breed) can vary between scenarios (see Table 7). The effect of stocking rate, also accounting for variable LW, is shortly discussed under results. Scenarios describe the animal component of the system, excluding nutrient flows from crop components not used as forage, but including grazed grass and crop residues fed. Scenarios cover a full year, i.e. rainy and dry seasons combined.

Calculation rules
The scenarios consist of relatively simple calculation rules, programmed in Microsoft Excel (Snijders et al, 2008). Forage type, supply and intake and breed vary per scenario. The basis for forage supply is potential forage intake, derived from feed quality (organic matter digestibility and crude protein content) and LW (Zemmelink et al., 2003). But actual forage supplied can be lower, depending on the scenario, because forage intake can be constrained by availability (especially during the dry season in Mbeere) and concentrate supplementation (substitution beyond a certain level). Forage supply is set to 1.1 times intake, to account for feed refusals. Energy, crude protein and phosphorus requirements for maintenance, (potential) milk production and/or LW gain are based on NRC (1989). For lactating cows, potential milk (4% fat and 3.33% protein) production is derived from feed supply minus requirements for maintenance and LW gain. Requirements for LW gain of young stock are derived from an increase in LW from 7.5% of mature LW for a calf at birth, to 90% for a heifer at first calving. Average age at first calving is set to 3 years in the baseline scenarios and 2.5 years in the improved scenarios. Dry cows and young stock are fed according to requirements.
N in excreta is partitioned over urine and faeces based on apparent feed digestibility and productivity. For reasons of simplicity it is assumed that all P is excreted in faeces and all K in urine. Feed refusals are added to (solid) excreta. The system of manure collection and storage and related nutrient and carbon (C) losses are scenario-specific (see below). K losses from solid manure (only from added feed refusals) are set to 20% of N losses and dry matter losses during manure storage to 80% of carbon losses.

Nutrient balances
External NPK-balances for cattle are calculated as: external NPK-inputs – external NPK-outputs of the cattle component. In case of external grazing, grazing residues are not imported (only ingested forage), but in case of zero-grazing (cut and carry) feed residues from imported forage are included in imports! "Net" NPK balances are defined as: external NPK balances minus nutrient losses during manure collection and storage (including nutrients not collected due to grazing). N fixation from legumes is included as an external N input, assuming 75% of harvested legume N to be derived from fixation. N in non-forage crop parts, from precipitation and non-symbiotic N fixation is not included. Annual home consumption of milk (humans and calves) is assumed to be 300 kg per cow in all scenarios, the remaining milk being sold. Sales of animals are not considered. In the improved scenarios mineral mixtures are purchased to cover ration P shortages. No fertilizer is used on forage.

In calculating the soil N balance for forage, a recovery of 50% for applied manure N is assumed in all scenarios (SF=0.5; assuming that residual effects from repeated manure application over years are accounted for) However, in reality, SF may vary among scenarios, depending on manure and soil characteristics (such as C/N ratio, amount of urine N; Rufino et al., 2006; Reijs et al., 2007) and weather conditions.

Starting points
Table 7 shows the most important starting points per scenario for the regions, including some information on feed supply and resulting milk production.

Table 7 Starting points per scenario per Cattle Unit (B=baseline scenario, I=improved scenario; Manure storage: K=kraal, H=heap, CH=compact heap, UP=urine pit; nutrient losses: h=high, i=intermediate, l=low). *The LW of a CU (cow + young stock) is 45% higher than for mature cattle only. See text for further explanation.

Region	Mbeere (=M)		Wakiso (=W)		Kibichoi (=K)			
Scenario acronym	1 MB	2 MI	3 WB	4 WI	5 KB	6 KI	7 KI	8 KI
Manure storage system	Kh	Hi	Hi	CH+UPi	Hi	CH+UPi	Hh	CH+UPi
LW mature cattle (kg)*	250	250	350	350	450	450	450	450
% forage in ration (DM)	100	98	97	88	90	77	77	77
% external forage (DM)	71	60	0	0	0	0	0	27
External feed N (kg)	24	33	2	10	12	33	33	60
External legume N (kg)	0	5	1	16	1	20	20	20
CP content ration (%)	8.2	11.2	8.6	12.7	10.1	14.1	14.1	14.1
DM intake cows (kg/day)	4.6	6.2	7.3	9.2	10.1	13.0	13.0	13.0
Milk (kg/cow/year)	335	1227	1002	2734	2035	4701	4701	4701
N/P loss solid manure (%)	50/30	20/10	20/10	10/5	20/10	10/5	30/25	10/5
N/K loss urine (%)	100/80	60/40	60/40	40/10	60/40	40/10	100/70	40/10
Carbon loss (%)	50	30	30	20	30	20	40	20

In the Mbeere scenario, local cattle are assumed to mainly graze external communal land, spending 10 hours per day outside the boma/kraal. At night, very little forage and no supplements are fed. Due to limited forage supply, forage intake is on average only about 85% and 95% of potential intake in the baseline and improved scenarios respectively. In the semi-intensive and intensive scenarios for Wakiso and Kibichoi, cattle are kept under zero-grazing, and LW of cattle is higher than in Mbeere. Forage supply is higher, and cows are able to realise potential forage intake. The daily milk production per cow in Mbeere would be slightly lower if extra requirements for maintenance because of grazing had been included! In the improved scenarios, feed supply and ration quality are higher because of younger grass (see below) , (limited) use of forage and tree legumes in addition to legume haulms, and (higher) use of supplements (ranging from 0 kg concentrates per lactation day in Mbeere to 5 kg for improved scenarios in Kibichoi). This results in rations with lower forage contents, and higher crude protein contents, dry matter intake and potential milk production per cow. In scenario 8 for Kibichoi, 40% of grass supplied is purchased.
The calving interval between 2 lactations is 450 days with a dry period of 150 and 125 days in the baseline scenarios for Mbeere and for Wakiso and Kibichoi respectively, and 125 and 100 days in the improved scenarios.
Forage quality. In the baseline scenarios, important forages during the rainy season are medium young and medium old grass, while during the dry season relatively more crop residues (mainly maize stover) complement medium old and old (mature) grass. In the improved scenarios, young and medium young grass is supplied during the rainy season and medium young and medium old grass during the dry season. In Wakiso and Kibichoi, grass is assumed to be a mixture of planted more coarse elephant grass and finer local grasses such as Kikuyu grass. The composition of forages and supplements is shown in Table 8.

Table 8 Composition of feeds used (in % of dry matter=DM; OM=organic matter; OMD=organic matter digestibility; CP=crude protein; TDN=Total Digestible Nutrients; P=phosphorus; K=potassium)

Forages	DM	OM	OMD	CP	TDN	P	K
Old grass	21	87	58	6	51.7	0.11	2.25
Medium old grass	19	85	65	8	56.5	0.18	2.50
Medium young grass	16	83	72	12	61	0.24	2.75
Young grass	15	81	76	15	62.8	0.30	2.95
Maize stover	33	90	55	5	50.8	0.10	1.25
Banana stems	16	90	61	10	56.2	0.17	3.00
Legume stover	20	90	55	10	50.8	0.10	1.50
Legumes fresh	20	92	62	17	58.3	0.16	1.50
Fodder tree leaves	25	88	75	22	67.3	0.30	2.50
Concentrates/supplements							
Dairy meal	90	93	88	16	80	0.60	0.60
Maize bran	87	88	80	10	85	0.32	0.37
Cotton seed cake	93	90	80	38	78	1.25	1.35

Manure storage In the baseline scenarios manure is stored in a kraal with high losses (Mbeere), or in heaps with intermediate losses (Wakiso and Kibichoi). In most improved scenarios, improved manure handling methods are applied. In case of Wakiso and Kibichoi, faeces and feed refusals are stored in compact and covered heaps, while urine is stored separately in closed pits with intermediate losses. Only in scenario 7 (for Kibichoi), all excreta are stored in a poor quality heap with high nutrient losses. Feed refusals are added to (solid) manure.

Results
Total N input per Cattle Unit (including FR) varies from 35 kg in the baseline scenario 1 for Mbeere to 130 kg for improved scenario for Kibichoi (Figure 2). The quantity of N converted into animal products (milk and LW gain; =N-animal) increases with increasing N input, but with insufficient attention for manure storage, N losses are also highest.
The N input per CU from home grown forage varies from 10 to 98 kg (Table 9). External N balances are positive, because of N inputs from external grazing (Mbeere), or purchased feeds except for the baseline scenario for Wakiso (low N input from supplements and relatively high milk sales). However, the “net” N balance is only positive in the improved Mbeere and Kibichoi scenarios, where good-quality manure storage practices are assumed. N losses are highest in scenario 7, resulting in a very negative contribution of cattle to the “net” N balance. Differences are smaller for the “net” P balance (surplus of 7 kg P for scenario 8), but higher for K, (mainly) due higher losses (high solubility of K) and differences between P and K contents of rations.

Figure 2 N input per Cattle Unit (cow + young stock) into the cattle "compartment" (totals per column) for scenarios' 1-8 (scenario 8=6), and distribution of N output over: animal produce (=N animal), N loss from manure and N remaining available for land application after storage. See further text and abbreviations in Table 7.

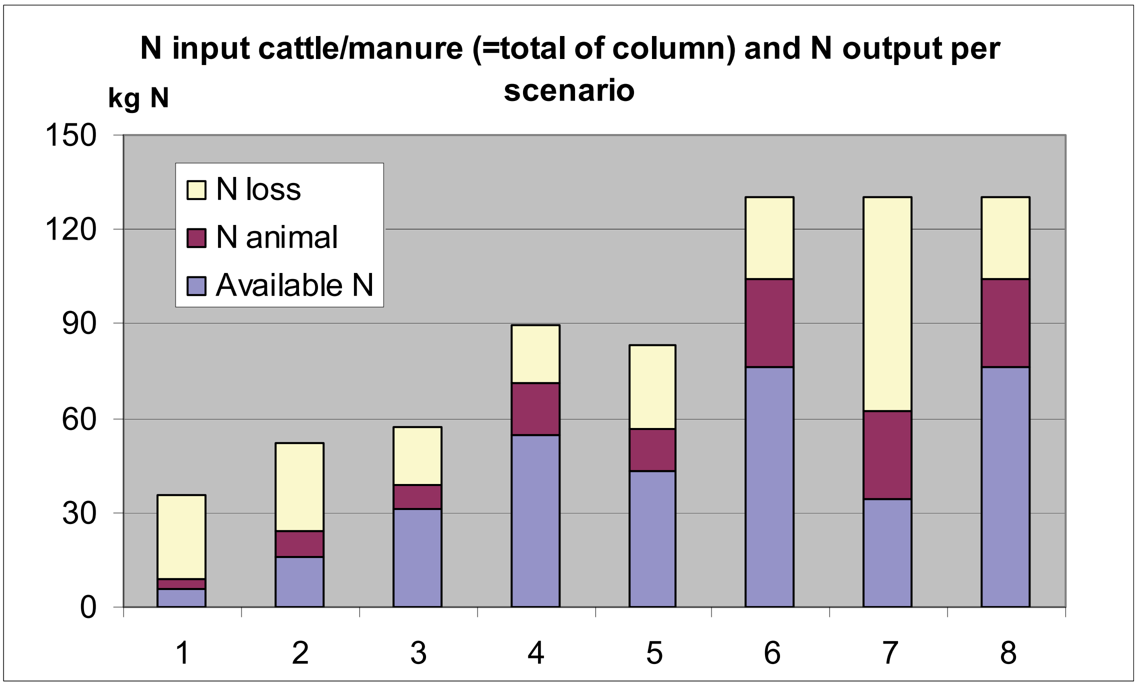


Table 9 Results per scenario per Cattle Unit (see further Table 7 and text; between brackets the C/N ratio of manure including urine N). *N loss for Mbeere includes N excreted during grazing (see discussion)

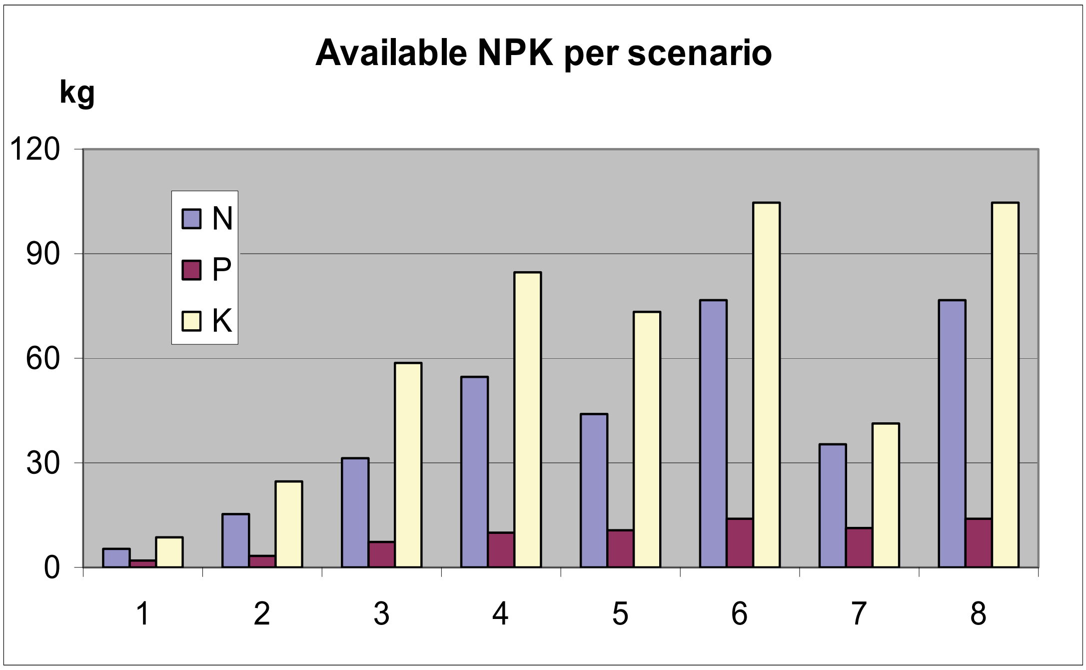
Region	Mbeere		Wakiso		Kibichoi			
Scenario acronym	1 MB	2 MI	3 WB	4 WI	5 KB	6 KI	7 KI	8 KI
Manure storage system	Kh	Hi	Hi	CH+UPi	Hi	CH+UPi	Hh	CH+UPi
Forage N farm land (kg)	10	19	55	79	71	98	98	71
External N balance cattle (kg)	24	32	0	13	4	29	29	56
N loss manure (kg)*	26	28	18	18	27	26	68	26
N loss per 100 kg milk*	7.8	2.3	1.8	0.7	1.3	0.6	1.45	0.6
Net N balance (kg)	-2	4	-19	-5	-22	3	-39	29
Net P balance (kg)	2	2	1	1	1	3	0	7
Net K balance (kg)	-9	2	-35	-10	-42	-10	-73	27
Available N (kg)	5	16	31	54	44	77	35	77
Available manure (t DM)	0.4	0.5	1.3	1.5	1.6	1.8	1.5	1.8
N solid manure (% of DM)	1.4	3	2.4	2.2	2.7	2.4	2.4	2.4
Soil deficit forage N (kg)	-5	-4	-35	-34	-46	-38	-58	-11
C/N ratio solid manure	25	12	15	16 (10)	13	14 (8)	14	14 (8)

Nutrient (Figure 3) and manure availability are higher in the more intensive scenarios with zero-grazing and improved manure storage practices. Nitrogen available for land application varies from 5 to 77 kg, with 22 and 32 kg being available as urine N in scenarios 4 and 6/8 (results not shown). Solid manure available for land application after storage varies from 0.4 to 1.8 Mg DM per cow. N content in solid manure only (without soil contamination!), varies from 1.4 to 3%, and its C/N ratio from 12 to 25 (lower for separate storage if urine N is included!).

If calculated for average stocking rates recorded in the surveys in Mbeere and Kibichoi (0.9 and 5.0 TLU/ha), respectively 0.2 and 3.8 Mg manure DM and 3 and 160 kg N would be available per ha of land in scenarios 2 and 6 (assuming that cattle are the only livestock; in reality there are also some other livestock; see Section 3.2).

Soil N deficit for SF=0.5, varies from -4 to -58 kg (highest in scenario 7 with high nutrient losses). The deficit is smallest in the more extensive scenarios and the scenarios importing forage from external sources. Hence, in all scenarios, soil N will be depleted, negatively affecting forage production capacity, unless additional fertilizer or legume N is introduced into the system.

Figure 3 Annually available N, P and K per cow for application on land for scenarios 1-8. For abbreviations see Table 7



4 Discussion

4.1 Scenario's

The scenario approach aims at exploring the consequences of varying livestock and manure management practices on nutrient and manure availability. In most of these scenarios, cattle positively contribute to the external nutrient balance and crop nutrient availability because they trigger import of external nutrients through either outside grazing or purchased feeds. However, the first can only be sustained as long as land is not limiting, while the latter will only be initiated if economic conditions are favorable (De Ridder et al., 2004). In the improved scenarios also legume N contributed, no fertilizer N was used on forage crops. The estimated "net" contribution of cattle to the N balance however, after taking into account losses during manure collection and storage (excluding manure application!), is much less favorable. Only in the improved scenarios for Mbeere and Kibichoi with N import in feeds and rather good-quality manure storage practices is the "net" N balance positive.
The relative contribution of cattle to the net P balance is higher, because of the lower risk for P losses and the higher P input in purchased mineral mixtures (0 to about 3 kg per cow per year, depending on the scenario). K losses are relatively high, with a very negative K balance in scenario 7 with poor manure storage methods. In the calculations, K losses are somewhat overestimated, because it is assumed that all K is excreted in urine.
Estimated N content in solid manure only is highest in the improved scenario for Mbeere (with urine N, intermediate N losses). Nitrogen contents are lower in the improved scenarios for Wakiso and Kibichoi, because of separate urine storage! Except for the baseline scenario in Mbeere, N contents in the scenario calculations are higher than found in actual farming practice (Onduru et al., 2008), and would be still higher if urine N was accounted for in scenarios 4, 6 and 8. However, manure storage practices, organic matter additions, for example from feed refusals, and soil content can vary strongly in reality. Moreover, the basis for calculation of carbon and dry matter losses is rather weak (see Section 2.2). In case of green manures, criteria like N content are suggested to indicate the rate of N release (preferably over 2.5%; Palm et al., 2001). Feed digestibility and/or N contents of manure sometimes relate rather well to N utilisation from manure (Kyvsgaard et al., 2000; Sørensen et al. (2003), Reijs et al., 2007), in particular for slurries with higher (ammonia) N contents. Rufino et al. (2006) however, indicate that criteria used for green manure cannot be directly applied to (solid) animal manures. Visual and sensory characteristics used by farmers (like texture and colour) for forages (feeds), manures (Lekasi et al. 2001a;b; 2003) and soil could possibly be linked to risks for nutrient losses and for improving manure handling and livestock management.
The low manure availability per CU in the Mbeere scenarios is due to outside grazing, breed and manure management. The large variation in the estimated manure and nutrient availability corrected for stocking rates (see Section 3.3.2) indicates the scope for changes/improvements through livestock and manure management. Differences between rations or between the rainy and dry seasons can be large as well (Powell, 2004).
It should be considered still, that the nutrient balances in the grazing scenarios for Mbeere are better than indicated by results, because nutrients in excreta deposited during outside grazing (58 % of excreta) are in reality not fully lost, but (partly) contribute to soil productivity on communal land, depending on management (sward and root conditions) and soil and weather conditions.
Results from some other scenarios (not given) indicate (much) higher risks for nitrogen losses if the quality of cattle rations improves without improvements in manure handling, in particular during the rainy season. However, in combination with improved systems of manure handling, manure and N availability for land application can be relatively high during the rainy season compared to the dry season.

4.2 N cycling and soil N deficit

In Box 1 and in the scenarios in Section 3.3, SF was set at an "intermediate" value of 0.5. Declining soil nutrient stocks will eventually result in lower (forage) yields. The soil deficit of 38 kg N in scenario 6 could be reduced to 17 kg if SF increases from 0.5 to 0.65, in combination with low N losses during manure storage. It should be noted that in scenarios 1, 2 and 8 a part of ingested forage is derived from outside the farm boundary, requiring (much) lower inputs from home grown forage N (Table 7 and 9). Improved manure application methods (higher SF) are potentially more effective if N losses during manure collection and storage are low (high MS; more N available).
In reality, utilization by crops of N from applied organic (animal and green) manures (Nyamangara et al., 2003, Cherr et al., 2006; Rufino et al., 2006; Tonnito et al., 2006) and fertilizers (Cassman et al.,

2002; Crews and Peoples, 2005) can vary widely, depending among others on the quality of organic material and soil characteristics (Kimetu et al., 2004; Vanlauwe et al., 2005) and precipitation. Recovery increases if residual effects are included (Lekasi et al. 2001b; Mutiro and Murwira, 2004; Schröder, 2005; Reijs et al., 2007). In a series of experiments with elephant grass with variable application of fertilizer N and varying cutting intervals, N recovery averaged 50% (average per experiment from 30-61%; calculated from data from Schreuder et al., 1993). The variation was much larger for individual cutting intervals. In another experiment with cut elephant grass, recovery of manure N (from slurry) was 33 % after 5 years of bi-annual applications, being equivalent to 61% of that of fertilizer N (slurry with 0.26% total N and only 0.06% ammonium N in DM; Snijders et al., 1992). Aerobically stored manures release N more slowly than (more) anaerobically stored manures like slurry (and chemical fertilizers), but residual effects are larger. Combinations of organic manures and fertilizer may lead to higher nutrient recoveries from fertilizer (Nyamangara et al., 2003; Vanlauwe, 2004; Kimetu at al., 2004).

4.3 Scenarios and farmers situations

The risk for high N losses is lower in the more extensive scenarios. Intensive scenarios require (more) measures to conserve nutrients. It is insufficiently known to which extent N losses used in the scenarios reflect (the potential to reduce) on farm N losses. Rufino et al (2007) indicate high losses on small farms in Western Kenya. They measured strongly reduced losses in an experiment by covering manure heaps with a simple plastic film. Realising low losses of urine N (before collection and during storage) may be particularly (labour) demanding (Lekasi et al., 2001b; Rufino et al, 2007). However, a farmer in Wakiso for example, frequently removes dung pats from the barn and drains urine quickly over a sloping (concrete) floor into a closed pit, and dilutes urine with water. Solid manure is stored in a covered soil pit. Losses have not been measured, but are probably relatively low (compare also to scenarios 4, 6 and 8 with separate urine collection). Some farmers tend to apply urine liquids or wetter season excreta to demanding crops like banana or other crops grown nearby the homestead. Urine utilization might be improved through dilution with water and good distribution, or, in case of grazing, through the use of rotating kraals (Lekasi et al., 2001 a;b; 2003; Powell et al., 1998; Hansen et al., 2006), also depending on weather conditions. It might then become a substitute for chemical fertilizer.

In identifying options for manure storage in extensive situations, with relatively low N excretion in urine, more aerobic systems of manure storage in covered heaps/pits may be preferred. If intensification leads to (much) higher N excretion in urine, more organic material is required to conserve/absorb urine N. Alternatively, depending on the situation, solid manure and urine may be collected, stored and used separately, for example in a proper compact and covered pit or above-ground storage facility. Use of slurry (mixture of faeces and urine), is possibly more feasible on relatively intensive (larger) dairy farms. If slurry is used for biogas production, soluble N content increases. However, liquid systems and composting are more capital- and labor-intensive.
Cutting forage at an earlier stage, as in the improved scenarios, can improve animal production and manure quality and quantity, also depending on stocking rates. However, if intensification is poorly managed, with poor forage and manure management and too low nutrient inputs, a cycle of decreasing forage supply (and weed invasion), animal productivity and nutrient excretion could be started. “Over-cutting” may increase short term nutrient extraction (also due to a lower return of nutrients in crop residues such as from dead leaves) and nutrient losses (due to for example a more open sward and/or shallower rooting system). Similarly, although imported feeds have a positive effect on the nutrient balance of receiving farms, imports may deplete soils on farms supplying forage without a proper (local) exchange mechanism for feed and manure and/or appropriate use of fertilizer and/or legumes.
More quantitative information is required on both nutrient and manure availability and nutrient losses of different livestock and manure handling systems on smallholder farms under various conditions, in particular on innovative and intensive farms.

5 Concluding observations and tentative conclusions

Information on the efficiency of nutrient use from livestock manure under smallholder conditions in the tropics is limited, due to the wide variation in farming conditions and livestock and manure management, in particular in relation to housing of livestock and manure collection and storage. Thus there is a need for more knowledge on the consequences of various manure management practices under various smallholder conditions, with particular focus on improved practices adopted by innovative farmers.
Manure quality strongly varies, due to variation in feed supply and intake, ration quality, addition of organic material to excreta, losses during collection and storage and contamination with soil. If N excretion in urine is relatively low, aerobic (cheaper) comprehensive storage systems of all excreta combined may be preferred. Deep litter systems are feasible if supply of litter and labor is abundant, and if litter characteristics are favorable. Anaerobic (solid and liquid) systems may be feasible for more intensive farming systems and rations with higher protein contents, leading to excretion of relatively large quantities of N (and S and K) in urine. Seasonal differences in manure availability, management and quality probably require more attention. Nitrogen loss (directly) after excretion, before manure is collected and stored, also requires further attention.

Tentative conclusions

- Total nitrogen content of manure on a dry matter basis ranges from below 0.5 to over 4%. Soluble nitrogen content also strongly vary.
- Nutrient losses during manure collection and storage vary substantially, depending on cattle and manure management. Nitrogen losses for example may vary from less than 10% to about 90% and tend to be lower for more compact and anaerobic manure storage systems and for manures with higher carbon to nitrogen ratios.
- In the scenario study, the contribution of cattle to the external farm nutrient balance varies from 0 to 56 kg N per Cattle Unit, while the “net” nitrogen balance, taking losses during manure collection and storage into account, varies from –39 kg to + 29 kg.
- Estimated annual nitrogen and manure availability vary from 5 to 77 kg and 0.4 to 1.8 Mg manure DM per Cattle Unit respectively. Differences become smaller if expressed per TLU, but larger if converted to differences in stocking rates (TLU ha^{-1}) recorded on participating farms.
- More aerobic deep litter systems with more or less regular removal of deep litter become more applicable if supply of organic material (such as from feed refusals) and labor are sufficient. But with higher N excretion in urine, higher amounts of suitable (dry) bedding material are required to limit nitrogen losses.
- With intensification and/or higher N excretion in urine, more liquid, anaerobic systems of manure storage become probably more feasible, such as compact and covered/closed facilities for separate storage of solid manure and urine in pits.
- More quantitative information is required on innovative farms to asses manure availability, its quality and nutrient losses in relation to variation in livestock and manure management practices, and variation among seasons, housing systems and socio-economic conditions.

References

Amon, B., Amon, T., Boxberger, J., Alt, C. (2001) Emissions of NH3, N2O and CH4 from dairy cows housed in a farmyard manure tying stall (housing, manure storage, manure spreading). Nutrient Cycling in Agroecosystems, 60, 103-113.

Anonymus (1997) Handbook Dairying (in Dutch). Praktijkonderzoek Rundvee, Paarden en Schapen, Lelystad, the Netherlands.

Barrington, S., Choiniere, D., Trigui, M., Knight, W. (2002) Effect of carbon source on compost nitrogen and carbon losses. Bioresource Technology 83, 189–194.

Bannink, A., Valk, H., Van Vuuren, A.M. (1999) Intake and excretion of sodium, potassium, and nitrogen and the effects on urine production by lactating dairy cows. Journal of Dairy Science 82, 1008–1018.

Bussink, D.W., Oenema, O. (1998) Ammonia volatilization from dairy farming systems in temperate areas: a review. Nutrient Cycling in Agroecosystems 51, 19-33.

Broderick, G.A. (2003) Effect of varying dietary protein and energy levels on the production of lactating dairy cows. Journal of Dairy Science 86, 1370-1381.

Cassman, K.G., Dobermann, A., Walters, D. (2002) Agroecosystems, nitrogen-use efficiency and nitrogen management. Ambio 31, 32-140.

Chadwick, D.R. (2005) Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. Atmospheric Environment 39, 787-799.

Cherr, C.M., Scholberg, J. M. S., McSorley, R. (2006) Green Manure Approaches to Crop Production: A Synthesis. Agronomy Journal 98, 302–319.

Crews, T.E., Peoples, M.B. (2005) Can the synchrony of nitrogen supply and crop demand be improved in legume and fertilizer-based agroecosystems? Nutrient Cycling in Agroecosystems 72, 101–120.

De Jager, A., Onduru, D.D., Gachimibi, L.N., Muchena, F., Gachini, G., Van Beek, C.L. (2007) Farmer Field Schools for Rural empowerment and Life-long Learning in Integrated Nutrient Management: Experiences in Central and Eastern Kenya. In: Practice makes perfect, PhD Thesis, Wageningen University, Wageningen, The Netherlands.

De Ridder, N., Breman, H., van Keulen, H., Stomph, T.J. (2004) Revisiting a cure against land hunger: soil fertility management and farming systems dynamics in the West African Sahel. Agricultural Systems 80, 109-131.

Delve, R.J., Cadisch, G., Tanner, C., Thorpe, W., Thorne, P.J., Giller, K.E. (2001) Implications of livestock feeding management on soil fertility in the smallholder farming systems of sub-Saharan Africa. Agriculture Ecosystems and Environment 84, 227-243.

Dewes, T., Schmitt, L., Valentin, U., Ahrens, E. (1990) Nitrogen losses during the storage of liquid livestock manures. Biological Wastes 31, 241-250.

Ebanyat, P., Bekunda, M., De Jager, A. (2003) Ground Working: Participatory diagnosis of Constraints and Opportunities for soil fertility management in Keria, Chelekura and Onamudian villages, Pallisa District, Uganda East. Available at http://www.inmasp.nl/files/31a46c7ea8555c3abcd2133f26db80ff.pdf

Elias, E., Morse, S., Belshaw, D.G.R. (1998) Nitrogen and phosphorus balances of Kindo Koisha farms in southern Ethiopia. Agriculture, Ecosystems and Environment 7, 93-113.

Elias, E. (2002) Site characterization for INMASP in Ethiopia. Available at http://www.inmasp.nl/files/fbf0c9ca6f9d0fa92377a05ec4fb70bb.do. Accessed 5.02.03.

Eghball, B., Power, J.F., Gilley, J.E., Doran, J.W. (1997) Nutrient, carbon and mass loss during composting of beef cattle feedlot manure. Journal of Environmental Quality 26, 189–193.

FAO (Food and Agriculture Organisation) (2001) Mixed crop-livestock farming, FAO Animal Production and Health Papers 152. FAO, Rome Italy.

Gachimbi, L.N., Gachini, G.N., Onduru, D.D., Maina, F., Muchena, F.N., De Jager, A. (2004) Smallholder farming and rural livelihoods in Ngaita village, Kiambaa division, Kiambu ditrict, Kenya: a baseline survey report. INMASP Report 14, Kenya. Available at http://www.inmasp.nl/files/aedbe4e590664641bb41aa5f7035374c.pdf

Gupta, P.K. (2000) Handbook of soil, fertilizer and manure. Agra Botanica, New Delhi.

Hansen, M.N., Henriksen, K., Sommer, S.G. (2006) Observations of production and emission of greenhouse gases and ammonia during storage of solids separated from pig slurry: Effects of covering. Atmospheric Environment 40, 4172-4182.

Hao, X., Chi, C., Larney, F.J. (2004) Carbon, nitrogen balances and greenhouse gas emission during cattle feedlot manure composting. Journal of Environmental Quality 33, 37-44.

Harris, F. (2002) Management of manure in farming systems in semi-arid west Africa. Experimental Agriculture 38, 131-148.

Hiddink, B. (1987) Manure recycling within the zero-grazing system in Kenya. Department of Field Crops and Grassland Science, Wageningen Agricultural University, Wageningen, the Netherlands.

Hutchings, N.J., Sommer, S.G., Andersen, J.M. and Asman, W.A.H. (2001) A detailed ammonia emission inventory for Denmark. Atmospheric Environment 35, 1959-1968.

Jackson, H L and Mtengeti, E. J. (2005) Assessment of animal manure production, management and utilization in Southern Highlands of Tanzania. Livestock Research for Rural Development 17 (10). Available at http://www.cipav.org.co/lrrd/lrrd17/10/jack17110.htm.

Ketelaars, J.J.M.H., Van der Meer, H.G. (2000) Establishment of criteria for the assessment of nitrogen content of animal manures. Report 14, Plant Research International, Wageningen University and Research centre, Wageningen, the Netherlands.

Kimani, S.K. and Lekasi, J.K. (2004) Managing manures throughout their production cycle enhances their usefulness as fertilisers: A review. In: Bationo A. (Ed.) Managing Nutrient Cycles to sustain Soil Fertility in Sub-Saharan Africa. CIAT-TSBF, Nairobi, Kenya.

Kimetu, J.M., Mugendi, D.N., Palm, C.A., Mutuo, P.K., Gachengo, C.N., Bationo, A., Nandwa, S., Kungu, J.B.

(2004) Nitrogen fertilizer equivalencies of organics of differing quality and optimum combination with inorganic nitrogen source in Central Kenya. Nutrient Cycling in Agroecosystems 68, 127–135.

Kirchmann, H. and Lundvall, A. (1998) Treatment of solid animal manures: identification of low NH3 emission practices. Nutrient Cycling in Agroecosystems 51, 65-71.

Kolenbrander, G.J. and De La Lande Creemer, L.C.N. (1987) Farmyard manure and urine (in Dutch). Veenman en Zonen, Wageningen, the Netherlands.

Kűlling, D.R., Menzi, H., Kröber, T.F., Neftel, A., Sutter, F., Lischer, P., Kreuzer, M. (2001) Emissions of ammonia, nitrous oxide and methane from different types of dairy manure during storage as affected by dietary protein content. Journal of Agricultural Science 137, 235-250.

Kűlling, D.R., Menzi, H., Sutter, F., Lischer, P., Kreuzer, M. (2003) Ammonia, nitrous oxide and methane from differently stored dairy manure derived from grass and hay-based rations. Nutrient Cycling in Agroecosystems 65, 13-22.

Kyvsgaard, P., Sørensen, P., Møller, E., Magid, J. (2000) Nitrogen mineralization from sheep faeces can be predicted from the apparent digestibility of the feed. Nutrient Cycling in Agroecosystems 57, 217-214.

Lekasi, J.K., Tanner, J.C., Kimani, S.K., Harris, P.J.C. (2001a) Manure Management in the Kenya Highlands: Practices and potential.HDRA. Kenilworth, UK.

Lekasi, J.K., Tanner, J.C., Kimani, S.K., Harris, P.J.C. (2001b) Managing manure to sustain smallholder livelihoods in the East African Highlands. HDRA, Kenilworth, UK.

Lekasi, J.K., Tanner J.C., Kimani, S.K., Harris, P.J.C. (2003) Cattle manure quality in Maragua District, Central Kenya: effect of management practices and development of simple methods of assessment. Agriculture, Ecosystems and Environment 94, 289-298.

Liang, Y, Leonard, J.J., Feddes, J.J.R., McGill, W.B. (2006) Influence of carbon and buffer amendment on ammonia volatilization in composting. Bioresource Technology 97, 748–761.

Martins, O., Dewes, T. (1992) Loss of nitrogenous compounds during composting of animal wastes. Bioresource Technology 41, 103-111.

Misselbrook, T.H., Powell, J.M. (2005) Influence of bedding material on ammonia emissions from cattle excreta. Journal of Dairy Science 88, 4304–4312.

Murwira, H.K. (2004) Linking Research Results with Rural Development Projects: Experiences from Southern Africa. In: Bationo A. (Ed.) Managing Nutrient Cycles to sustain Soil Fertility in Sub-Saharan Africa. CIAT-TSBF, Nairobi, Kenya.

Mutiro, K., Murwira, H.K. (2004) The Profitability of Manure Use on Maize in the Smallholder Sector of Zimbabwe. In: Bationo, A. (Ed) Managing Nutrient Cycles to sustain Soil Fertility in Sub-Saharan Africa. CIAT-TSBF, Nairobi (608 pp)

Nhamo, N., Murwira, H.K., Giller, K.E. (2004) The Relationship Between Nitrogen Mineralization Patterns and Quality Indices of Cattle Manures from Different Smallholder Farms in Zimbabwe. In: Bationo A. (Ed.) Managing Nutrient Cycles to sustain Soil Fertility in Sub-Saharan Africa. Nairobi, Kenya: CIAT-TSBF.

Nyamangara, J., Bergström, L.F., Piha, M.I., Giller, K.E. (2003) Fertilizer use efficiency and nitrate leaching in a tropical sandy soil. Journal of Environmental Quality 32, 599-606.

NRC (National Research Council) (1989) Nutrient requirements of dairy cattle, 6th revised edition. National Academic Press, Washington DC.

Nzuma, J.K., Murwira, H.K. (2000) Improving the management of manure in Zimbabwe. Managing Africa's Soils No 15. IIED (International Institute for Environment and Development), London.

Onduru, D.D., Gachimbi, L.N., De Jager, A., Gachini, G.N., Maina, F., Muchena, F.N. (2002) Smallholder farming and rural livelihoods of Central Kenya: a baseline survey in Kiambu district. INMASP Report 6, Kenya. Available at http://www.inmasp.nl/files/4b8ac556a3367c307d693fb1a826b66a.pdf

Onduru, D.D., Snijders, P., Muchena, F.N., Wouters, B., De Jager, A., Gachimbi, L., Gachini, G.N. (2008) Manure and Soil Fertility Management in sub-Humid and Semi-arid Farming Systems of sub-Saharan Africa: Experiences from Kenya. International Journal of Agricultural Research 3 (3), 166-187

Palm, C.A., Giller, K.E., Mafongoya, P.L., Swift, M.J. (2001) Management of organic matter in the tropics: translating theory into practice. Nutrient Cycling in Agroecosystems 61, 63-75.

Parkinson, R., Gibbs, P., Burchett, S., Misselbrook, T. (2004) Effect of turning regime and seasonal weather conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. Bioresource Technology 91, 171-178.

Powell, J.M. (2004) Crop-Livestock interactions in the West African Drylands. Agronomy Journal 96, 469-483.

Powell J.M., Williams, T.O. (1995) An overview of mixed farming systems in sub-Saharan Africa. In: Powell, J. M., Fernández-Rivera, S., Williams, T. O., Renard, C. (Eds) Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of sub-Saharan Africa. Volume II: Technical Papers. Proceedings of an International Conference held in Addis Ababa, Ethiopia, 22–26 November 1993. International Livestock Centre for Africa, Addis Ababa (568 pp)

Powell, J.M., Ikpe, F.N., Somda, Z.C., Fernandez-Rivera, S. (1998) Urine effects on soil chemical properties and the impact of urine on pearl millet yield. Experimental Agriculture 34, 259-276.

Reijs, J.W., Sonneveld, M.P.W., Sørensen, P., Schils, R.L.M., Groot, J.C.J., Lantinga, E.A. (2007) Effects of different diets on utilization of nitrogen from cattle slurry applied to grassland on a sandy soil in The Netherlands. Agriculture, Ecosystems and Environment 118, 65-79.

Rotz, C.A. (2004) Management to reduce nitrogen losses in animal production. Journal of Animal Science 82, (E. Suppl, E119–E137)

Rufino, M.C., Rowe, E.C., Delve, R.J., Giller, K.E. (2006) Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. Agriculture, Ecosystems and Environment 112, 261–282.

Rufino, M.C., Tittonell, P., van Wijk, M.T., Castellanos-Navarrete, A., Delve, R.J., de Ridder, N., Giller, K.E. (2007) Manure as a key resource within smallholder farming systems: Analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. Livestock Science 112, 3, 273-287

Schiere, J.B, Ibrahim, M.N.M., Van Keulen, H. (2002) The role of livestock for sustainability in mixed farming: criteria and scenario studies under varying resource allocation. Agriculture, Ecosystems and Environment 90, 139–153.

Schröder, J.J., Aarts, H.F.M., Ten Berge, H.F.M., Van Keulen, H., Neeteson, J.J. (2003) An evaluation of whole-farm nitrogen balances and related indices for efficient nitrogen use. European Journal of Agronomy, 20: 33-44.

Schröder, J.J. (2005) Revisiting the agronomic benefits of manure: A correct assessment and exploitation of its fertiliser value spares the environment. Bioresource Technology 96, 253-261.

Schreuder, R., Snijders, P.J. M., Wouters, A.P., Steg, A., Kariuki, J.N. (1993) Variation in organic matter digestibility (in vitro), yield, crude protein and ash content of Napier grass (Pennisetum purpureum), and their prediction from chemical and environmental parameters. Kenya Agricultural Research Institute, Naivasha, Kenya (62 pp)

Shepard, M., Philips, L., Bhogal, A. (2000) Manure management on organic farms: to compost or not to compost? In: Alfouldi, T., Lockeretz, W., Niggli, U. (Eds) Proceedings 13th International IFOAM Scientific Conference Basel. VDF Hochschulverlag AG ETH, Zürich, Switzerland.

Smits, M.C.J., Valk, H., Elzing, A., Keen, A. (1995) Effect of protein nutrition on ammonia emission from a cubicle house for dairy cattle. Livestock Production Science 44, 147-156.

Snijders, P.J.M., Orodho, A.B., Wouters, A.P. (1992) Effect of manure application methods on yield and quality of Napier grass. Kenya Agricultural Research Institute, Naivasha, Kenya (50 pp)

Snijders, P.J.M., Wouters, B. (2003) Livestock and Soil Nutrient Management. Contribution to the Development of a Curriculum for Farmer Field Schools on Integrated Nutrient Management in East Africa. Available at http://www.inmasp.nl/files/9937ac05134a9512244c8d8afca24b60.pdf. Accessed 19.12.03.

Snijders Paul, Davies Onduru, Joshua Zake and Bram Wouters (2008) Livestock model explanation (Livestock and Integrated Soil Nutrient Management tool). http://www.lei.dlo.nl/inmasp/files/1cd8aea6ae03d0785a522215e90bdc25.pdf Accessed 2009

Sommer, S.G. (2001) Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. European Journal of Agronomy 14, 123–133.

Sørensen, P., Weisbjerg, M.R., Lund, P. (2003) Dietary effects on the composition and plant utilization of nitrogen in dairy cattle manure. Journal of Agricultural Science 141, 79-91.

Staal, S.J., Chege, L., Kenyanjui, M., Kimari, A., Lukuyu, B., Njubi, D., Owango, M., Tanner, J., Thorpe, W., Wambugu, M., 1998. Characterisation of Dairy Systems Supplying the Nairobi Milk Market, A Pilot Survey in Kiambu District for the Identification of Target Groups of Producers. International Livestock Research Institute, Nairobi.

Steinfield, H., De Haan, C., Blackburn, H. (1996) Livestock-Environment Interactions. European Commission, Brussels.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., De Haan, C. (2006) Livestock's long shadow, environmental issues and options. FAO, Rome.

Thompson, I.K. (2000) C and N transformations in ^{15}N cross-labelled solid ruminant manure during anaerobic and aerobic storage. Bioresource Technology 72, 267-274.

Tiquia, S.M., Richard, T.L., Honeyman, M.S. (2002) Carbon, nutrient and mass loss during composting. Nutrient Cycling in Agroecosystems 62, 15-24.

Thorne, P.J., Tanner, J.C. (2002) Livestock and nutrient cycling in crop–animal systems in Asia. Agricultural Systems 71, 111-126.

Tonitto, C., David , M.B., Drinkwater, L.E. (2006) Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agriculture, Ecosystems and Environment 112, 58–72.

Vanlauwe, B. (2004) Integrated Soil Fertility Management Research at TSBF: The Framework, the Principles, and their Application. In: Bationo, A. (Ed) Managing Nutrient Cycles to sustain Soil Fertility in Sub-Saharan Africa. CIAT-TSBF, Nairobi (608 pp)

Vanlauwe, B., Gachengo, C., Shepherd, K., Barrios, E., Cadisch, G., Palm, C. A. (2005) Laboratory Validation of a Resource Quality-Based Conceptual Framework for Organic Matter Management. Soil Science Society of America .Journal 69, 1135–1145.

Walaga, C., Zake, J., Nagawa, F. (2003) Wakiso Sub-County, Agriculture Sector Baseline Study Report, Uganda Central report No 1. Available at http://www.inmasp.nl/files/32328167ca27196f80ac4199f5351e9d.doc. Accessed 12.5.03.

Zaaijer, D., Noordhuizen, J.P.T.M. (2002) Dairy cow monitoring in relation to fertility. International Dairy Topics 1, 5.

Zemmelink, G., Brouwer, B.O., Subagiyo, I. (1992) Feed utilisation and the role of ruminants in farming systems. In: Ibrahim, M.N., de Jong, R., van Bruchem, J., Purnumo, H. (Eds.) Livestock and feed development in the tropics. International Seminar in Malang, Indonesia, Wageningen Agricultural University, Wageningen, the Netherlands; Brawijaya University, Malang, Indonesia; Commission of European, Brussels, Belgium Communities.

Zemmelink, G., Ifar, S., Oosting, S.J. (2003) Optimum utilisation of feed resources: model studies and farmers' practices in two villages in East Java, Indonesia. Agricultural Systems 76, 77-94.