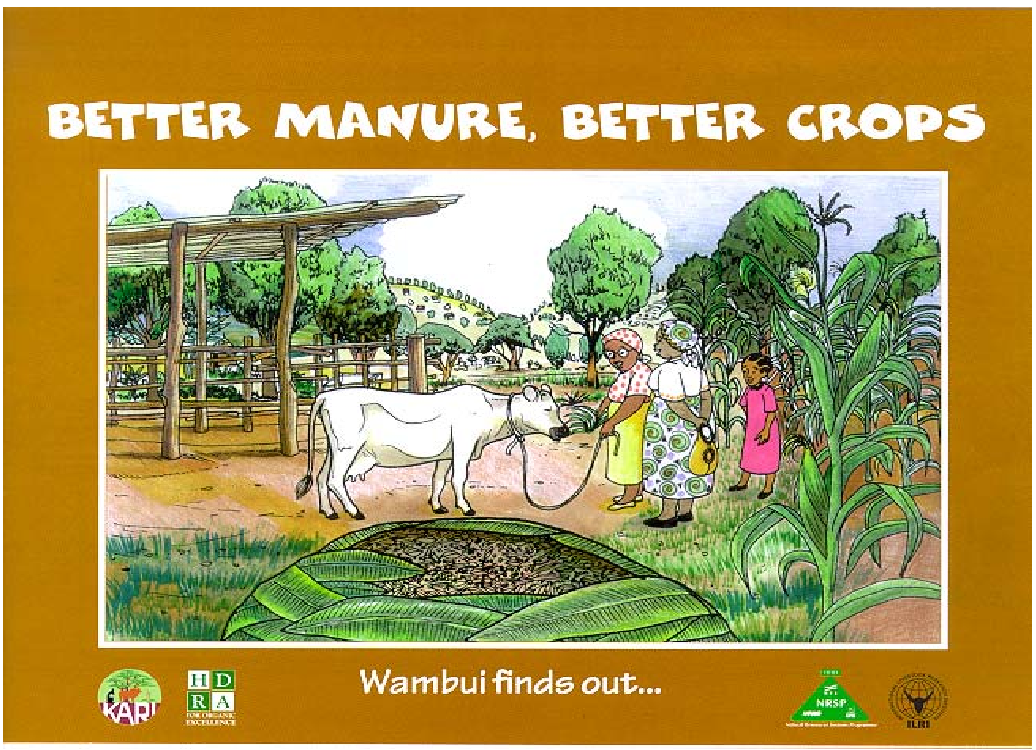
Department for International Development

Strategy for Research on Renewable Natural Resources

NATURAL RESOURCES SYSTEMS PROGRAMME
High Potential Systems

FINAL TECHNICAL REPORT

R6731: Manure Management in the Kenya Highlands: Collection Strategies to Enhance Fertiliser Quality and Quantity



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DFID Project Number: R6731

Project Title: Manure Management in the Kenya Highlands: Collection Strategies to Enhance Fertiliser Quality and Quantity

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NRSP Production System: High Potential

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Background

Identification of Demand

As human populations continue to grow towards an anticipated figure of over 8 billion by the year 2020 there is considerable anxiety that the food inequalities prevalent in the world today will worsen over the next 20 years (Pretty, Thompson & Hinchcliffe, 1996). Optimists calculate that, in absolute terms, the planet should be able to sustain this huge population through increases in crop production. It is predicted that in developing countries, two-thirds of the increase in food output will in fact come from rising crop yields, the rest will be achieved through expansion of the arable area (20%) (mainly into marginal and degraded lands) and from increased cropping intensity (13 %) (Alexandratos, 1995). However, these advances will have a disappointing impact upon mitigation of the impending crisis if disparity of access to food is not resolved for the poorest households.

Amongst strategies for improving access to food is ensuring that local capacity for staple food production is retained or, better still, enhanced (Pretty, Thompson & Hinchcliffe, 1996). This may seem an obvious suggestion but is becoming increasingly difficult to attain. Rising population densities in rural areas render the average size of agricultural landholding too small even for subsistence crop production. The risk that rural families will lose access to a viable land units providing a year-round food supply is very real. Already in India livelihood strategies of the poor in dry-land areas encompass seasonal or permanent migration to urban areas seeking paid employment but inevitably finding urban destitution (Kumar & Singh, undated). Such dismal examples fuel the common paradigm that it is rising rural population creating increased pressure on land that threatens the fundamental bio-physical factor underpinning food security – soil fertility (Donovan & Casey, 1998).

The evidence that soil fertility is in decline in sub-Saharan Africa is purportedly incontrovertible (Smaling, Nandwa & Janssen, 1997). Grandiose schemes for nutrient replenishment have been proposed and tested on pilot scales (Sanchez *et al*, 1997). However, conservative voices exist amongst the hyperbole. Scoones & Toulmin (1999) for example, point the scientific world to reasons why doom-ist evidence needs to be carefully interpreted. Weak methodologies for scaling up plot/single season soil fertility and crop productivity data to supra-national levels lie at the heart of the problem.

There is little doubt that in some areas "nutrient mining" is prevalent and action to slow or reverse this process is required. Constructive approaches have sought solutions in indigenous knowledge and practices. To this end some authors have documented examples where centuries of population pressure have seen farmers to engage in a range of strategies for sustainable intensification of food production. These examples pervade the "grey literature". Experiences have been brought to the international arena through organisations such as the Information Centre for Low-External-Input and Sustainable Agriculture and through mainstream publications including Tiffen, Mortimore & Gichuki, 1994, Reij, Scoones & Toulmin, 1996 and Mortimore, 1998.

Many traditional approaches for raising local food production though better soil fertility management have one particular strategy in common – the integration of crop and livestock production (Ruthenburg, 1980). In mixed-farming systems, livestock play a key role in energy and nutrient cycling as well as providing a diverse range of outputs (Mearns, 1997). Mixed farming appears to have had particular appeal to poor farmers in locations where external fertility inputs are not available (Winrock, 1992).

The research described in this report considers the importance of livestock and their excreta in the processes of nutrient cycling in smallholder production systems. It presents evidence for the positive contribution that livestock make to the nutrient status of highly intensive smallholder farms in the Central Highlands of Kenya. The sites chosen for the research are benchmark sites within the African Highlands Ecoregional Programme and so contain farming systems operated by the majority of poor households in the densely populated East African highlands.

The informed reader will be aware that at the beginning of the previous century authors expounded the virtues of livestock in the attainment of greater land productivity (Hall, 1909). They still do today (Staal, Ehui & Tanner, 2000). However, expounding the merits of mixed farming in an attempt to foster policies that support livestock development using western donor finance currently faces a major hurdle: the public sentiment embodied in the following statement:

"Rings of barren earth spread out from wells on the grasslands on Turkmenia. Heather and lilies wilt in the nature reserves of the southern Netherlands. Forests teeming with rare forms of plant and animal life explode in flame in Costa Rica. Water tables fall and fossil fuels are wasted in the United States. Each of these cases of environmental decline issues from a single source: the global livestock industry" (Durning and Brough, 1991).

Livestock production systems are currently undergoing stringent international scrutiny with regard to their environmental impact (de Haan, Steinfeld and Blackburn 1997) but at the same time are also globally recognised for their major contribution to the income and welfare of the poorest people (Livestock In Development, 1999). The present research contributes evidence that livestock enterprises on intensively managed mixed-farms actually make a positive contribution to livelihoods of the poor and also help sustain the "health" of agro-ecosystems.

Researchable Constraints

The highlands of Central Kenya present a situation of high population densities (in excess of 800 persons per km^2 (Imbernon, 1997)) operating small, mixed farms (<1ha, 70-80% of farms with dairy cattle) under almost continual cropping using very little inorganic fertiliser. In these farming systems the conservation and efficient use of nutrients is paramount to ensuring their productivity. There is evidence to suggest that livestock are the major conduit for nutrient flow on to farms though feed collected/purchased and brought onto holdings (Shepherd & Soule, 1998). To ensure that the maximum benefit to the whole farm is derived from expensive imported nutrients requires effective use for milk and meat production coupled with efficient transfer of any excreted nutrients to arable land.

The present research seeks to develop simple strategies for improving the quality of excreta-based organic fertilisers through better capture and conservation of faeces and urine. The aim of the research is to investigate scope for making simple improvements in animal and excreta management, which make significant and sustained impact upon crop growth and help avoid the negative environmental impacts which can also occur.

Summary of significant previous research

Overview

Some of the earliest research into systematic animal and feed management strategies to improve excreta quality for use as fertiliser is reported by Roberts (1919). However, long before the beginning of the 20^{th} century, animal management practices had already been adopted to improve excreta quality. Jones (1961) reports (of England in the 1840s):

"*the practice of fattening cattle on arable farms was continued not from a view to profit in the sale of meat, but the production of dung, and the consequent increase in the corn crop. ………. The* *liberal feeding of oilcake to stock for the sake of better manure for the land under cereals was the great distinction of English agriculture*"

Manure (usually faeces only) research has a long history in East Africa (Pereira & Jones, 1954). However, reflecting the nature of manure research elsewhere between 1950 and 1980, excreta had ceased to be regarded as a "product" of livestock that could be manipulated in terms of its quality. In fact, quite the contrary, manure was considered to be an organic fertiliser of fixed nutrient and physical composition. Many fertiliser experiments report using farmyard manure (FYM) as a treatment without even considering it necessary to present the chemical composition!

More recently, researchers in East Africa have acknowledged the nutrient heterogeneity of manure and recognised the major contributions that manure makes to the maintenance of soil organic matter (Woomer and Muchena, 1993). However, emphasis of contemporary investigations are now preoccupied with characterisation of quality, particularly with respect to nutrient release (often in combination with inorganic fertilisers) (Cadisch & Giller, 1997; Woomer and Swift, 1994). Inspite of this, it is concerning that in Kenya-wide trials manure is still treated as an nutrient resource of static nutrient status and unvaried composition (Smaling, Nandwa, Prestele, Roetter & Muchena, 1992). Further, that Government of Kenya manuring recommendations for the central is 5 t/ha despite the fact that soil types vary considerably over short distances (FURP, 1994).

Kihanda & Wood (1996), working in Central Kenya, clearly demonstrate that manure quality has significant impact on crop production. Although, the agronomic value of manure relates to both its physical and chemical composition results from Zimbabwe show that even seemingly small increases in nutrient content (N content rise 0.5% to 1%) can double biomass yields of crops (Mugwira and Murwira, 1997). Mugwira and Mukurumbira (1984) showed that poorly-fed animals in smallholdings in Zimbabwe and better-fed commercial feedlot animals produced faeces with a two- and seven-fold difference in nitrogen and phosphorus content respectively.

The evidence that farmers can accurately assess the quality of organic fertilisers and use this knowledge strategically is building. Garforth & Gregory (1997) document evidence for astute indigenous soil management knowledge from across the world. Probert, Okalebo, Simpson and Jones (1992) show that manure application rates in semi arid Kenya range from 38 – 168 t/ha. One presumes that these applications are based upon perceived needs or, alternatively, the value of the crop in question (Motavalli & Anders, 1991).

The question remains, if farmers do appreciate the variation in quality of organic fertilisers, particularly manure, then what scope do they have for manipulating it. Indications from research conducted in Indonesia suggest that farmers implement management regimes specifically aimed at influencing manure quality. These management regimes however are complex; start with the animals themselves, their feeding, housing and finally the storage of excreta (Tanner, 1995). Where researchers have singularly failed in the past is in comprehending the link between livestock, their management and ultimately, soil fertility.

Although the science of livestock and nutrient management is still in its infancy, the the International Livestock Centre for Africa, ILCA (latterly the International Livestock Research Institute, ILRI) took a lead in the research. ILCA/ILRI's research programme recognised that the decisions owners take concerning animal management has profound impact upon the nutrient status of the whole farming system. The research programme in outlined in the next section and Appendix 1.

Livestock and Nutrient Cycling in sub-Saharan Africa

In the mid-1980's ILCA embarked upon a research programme to investigate the role of livestock in the supply and turnover of nutrients in a range of farming systems. The following sections make no attempt to report the findings of this programme as these are detailed elsewhere (see below for references). Instead, the research programme (which includes this project) is outlined with the objective being to reveal the similarity of contributions that livestock bring to nutrient cycling processes in very different mixed farming systems.

*Livestock and nutrient cycling in extensive farming systems – **livestock-mediated** nutrient cycling*

Figure 1 is a schematic representation of a mixed farming system in the semi-arid tropics at low population density. Village livestock provide the means for nutrient collection, concentration and transport back to arable land. Grazing rangeland by day and tethering on cropland by night is the mechanism by which nutrients are transferred from rangelands to fields through faeces and urine. The major research issues addressed by the ILRI programme based in Niger include:

- Scale of nutrient transfer from rangeland to arable land (mass of nutrients transferred).
- Patterns of nutrient deposition on arable land
- Scale of nutrient losses and turnover through stover/stubble grazing
- Diet and its impact upon excreta quality
- Sustained impact of faeces and urine upon crop productivity
- Effect of livestock-ownership upon patterns of nutrient deposition

Overall the results show that livestock excreta has a significant and lasting impact upon crop productivity (results summarised in Powell & Williams, 1995; Powell *et al*, 1996; Powell & Valentin, 1998). Concerns that too little excreta is produced in order to manure all of the arable land adequately have been raised (Williams, Powell & Fernandez-Rivera, 1995) are partially addressed through strategies that complement farmer's knowledge of within-field variability in soil quality (Brouwer and Bouma, 1997). Excreta can by used more sparingly by, *precision tethering* (depicted in Figure 1), where animals are tethered in order to concentrate excreta on patches of poor soil within any one field or by *rotational tethering*, where fields are manured every one year in three. Both strategies rely on residual fertility effects of excreta to sustain higher yields over the remaining two years.

The key sustainability challenge to this system is the capacity of rangelands, as a common property nutrient resource, to sustain food crop production through these mechanisms of manuring. This technical question also has socio-economic dimension since access to nearby rangeland grazing is increasingly being denied to poor households due to (illegal) privatisation of land.

*Livestock and nutrient cycling in intensive farming systems – livestock-**motivated** nutrient cycling*

Figure 2 presents the scenario of a small, intensively managed mixed farm such as that found in the highlands of Central Kenya. A dairy enterprise typically composed of one cow and a follower is operated in conjunction with maize (main staple crop), vegetables with trees for fruit and timber. Cattle are raised in confinement all year due to lack of suitable grazing land. Besides the obvious flow of nutrients between these enterprises (as depicted) there is a substantial flow of nutrients onto the farm. These nutrients are mainly in the form of purchased fodder and concentrates flowing into the dairy enterprise. Poor farmers typically purchase very little inorganic fertiliser and no organic materials sourced on- or off-farm are used directly as a soil amendment but first channelled into the dairy unit as fodder or bedding. Thus, nutrients are moved onto the farm primarily for use by livestock (hence "***livestock-motivated***" nutrient transfers. Off-farm sources of fodder for poor households inevitably emanate from common-property land (eg roadside grasses).

In intensive smallholder production systems manure is, again, the main input to crop production. The key question here (as above) is the capacity of soil fertility inputs from stall-fed livestock to sustain intensive cropping not just in terms of quantities of manure provided but also with regard to the rate of turnover of nutrients.

The research conducted in Central Kenya by ILRI, KARI and other partners consider important processes affecting nutrient flows involving 1) the animal (ingestion and digestion), 2) its management (housing, bedding, drainage) and 3) the management of its waste. The overall research programme (which includes this specific project) addresses the following:

- Farmers' perceptions of the contribution of livestock to sustainable agriculture
- Range of livestock and manure management systems currently employed in the Kenya Highlands
- Impact of livestock feeding on the quality of excreta
- Impact of livestock and manure management systems on the quality of manure-composts
- Contribution of livestock to nutrient turnover and total quantity of nutrients supplied (N and P)
- Implications of intensification for food/feed supply from smallholdings
- Impact of characterised manure on the growth of staple crops.

The research programme draws attention to the much overlooked fact that the animal, its physiological status and management system are important dictates of nutrient supply and turnover within intensive smallholder production systems. These factors influence the quantity and quality of organic matter available to farmers and so, to a significant extent, are important determinants of whole system viability. The ongoing research programme attempts to validate this claim both quantitatively and qualitatively.

Project Purpose

The project was designed to contribute to Output 2 of the Natural Resources Systems Programme, High Potential Production System. Its Purpose may therefore be stated as:

"Appropriate and sustainable methods to increase nutrient supply and satisfy crop nutritional demands developed and promoted."

Research Activities

Implementing the Project

Demand for research into the issues covered by this Project (R6731) was identified following research into livestock and nutrient cycling in intensive smallholder farming systems of upland Java, Indonesia (Livestock Production Programme (LPP) Project R5193). The major findings of this project were that farmers purposefully managed livestock for the production of manure compost and employed strategies to manipulate the quality of the manure compost depending on the target crop. LPP Project R5690, looking at the seasonal allocation of feed resources to stall-fed livestock in Nepal, subsequently found evidence that some of the organic materials being supplied to livestock in the mid-hills of Nepal were unpalatable and were being supplied to livestock for the specific purpose of compost making. Thus livestock in intensive upland systems in Nepal and Indonesia were both apparently being used as a means of "nutrient processing". It was considered that investigation into the basic principles underlying this strategy warranted further investigation so that techniques for sustainable intensification could be extended elsewhere.

A pair of projects were therefore proposed for Nepal (one submitted to LPP the other to NRSP). One to examine the impact of diet (particularly the influence of secondary plant compounds) on excreta quality and the other to look at the influence of excreta management on the final quality of organic fertilisers. Despite, being ranked "project in greatest demand" in a research planning workshop meeting between RNRRS Programme Management and the Nepal Agricultural Research Council the project was rejected by NRSP Hillsides Production System.

The project was later funded by the NRSP High Potential System (HPS). Since Nepal was not a target country for NRSP-HPS the project location shifted to Kenya where there were indications that the same challenges faced farmers and it was suspected that producers seek similar production objectives to those in Nepal and Indonesia. Administrative problems ensued in Nepal and so LPP Project R6283 (*Implications of livestock feeding management for long-term soil fertility in smallholder mixed farming systems)* also moved to Kenya to operate in partnership with the present project, R6731. (The executive summary from the Final Technical Report of Project R6283 can be found in Appendix 2).

The Manure Management Project (R6731) was implemented through the International Livestock Research Institute (ILRI) in collaboration with the Kenya Agricultural Research Institute (KARI) and Henry Doubleday Research Association (HDRA). The project has made a major contribution to ILRI's research theme on livestock and nutrient cycling (described above). Perhaps more importantly, the project entered the East African soil science arena broadened the perspective of regional soils researchers from soil-only to whole farm analyses of nutrient management. Projects R6731 (and LPP R6283) have re-kindled interest in manure research in the Region to the extent that the African Highlands Initiative has created a "Manure Working Group" drawn from the National Agricultural Research Systems of seven East African countries.

The research was conducted by a PhD student, Mr J.K. Lekasi, from KARI National Agricultural Research Centre – Muguga. Mr Lekasi was supervised in-country by Drs S.K. Kimani (KARI) and J.C. Tanner (ILRI) and registered at the Coventry University, supervised by Prof P.J.C. Harris (HDRA/Coventry University). The submission date for the thesis is mid-2000.

The Experimental Programme

Overview

The research was conducted over three years (1996 – 1999) in Murang'a, Muragua and partly in Kiambu Districts of Kenya's Central Province (See Map 1. The programme of field activities was divided into four phases: 1) PRA, 2) structured surveys, 3) on-station and 4) on-farm experimentation. The following detail of activities and outputs do not necessarily flow in this manner but have been rearranged into a more logic order.

Figure 3 outlines the on-station and on-farm research in the context of on-going soil fertility research in East Africa. Stall-fed livestock produce a range of outputs. However, they apparently yield inadequate quantities on manure to sustain soil fertility as the sole input (Williams *et al,* 1995). Soil scientists in East Africa are investigating several solutions to the problem: better, or more strategic placement of manure (spatially and temporally) and combinations with inorganic and other organic fertilisers.

A popular soil fertility research area in East Africa (but not shown in Figure 3) is the direct incorporation of plant biomass into soils (Myers et al, 1994). Experiences from Indonesia, Nepal, Zimbabwe and Kenya (Tanner, 1995; Thorne, Tanner & Gurung, (in press); Campbell *et al*, 1998; Jama, Swinkels & Buresh, 1997) point to direct routing of biomass into soil as an opportunity foregone (and uneconomic) compared to routing through livestock prior to use as a soil ameliorant or nutrient source.

Project R6731 dissects the "livestock route" for nutrient cycling on smallholder farms and looks at consequences of and strategies for 1) routing more palatable and non-palatable biomass through the livestock unit (Experiment 1), 2) improving the quality of the small quantities currently produced through better feeding and management (Experiment 2) and 3) improving strategies for storage of excreta (Experiment 3). All experiments feed into the final box "Strategies for use" since in practice all excreta produced from experiments was passed to KARI's soil scientists and agronomists for field evaluation.

PRA Phase: *Intensification of farming on smallholdings in the Central Kenya Highlands discussions with Embu communities.*

Embu District is located in Kenya's Eastern Province on the south-western slopes of Mt. Kenya (Map 1). Most of the District is described as being of high agricultural potential. Soils are dominated by the humic nitisol soil type and rainfall in the range of 1200 and 1500 mm per annum. Intensive, small-scale agriculture is the main source of household income. Two major cash crops are grown: tea at high altitudes and coffee lower down the mountainside. Macademia nuts and vegetables are fairly recent additions to the range of cash crops. Maize and beans are the major staples grown. Dairy cattle production is widespread amongst farms with 70% of households owning cattle (Kihanda, Tanner & O'Neill, 1998, unpublished data).

Whilst intensive, mixed farming currently maintains populations of up to 800 persons per square km (Imbernon, 1997) there is concern amongst development NGOs (eg IT-Kenya) that this is reaching an upper limit. The consequence of reaching "saturation" is that there is now a steady flow of poor people out of the high potential areas to the low potential, semi-arid areas is search of land to sustain livelihoods.

Despite observation that out-migration is occurring, the high population density supported in Embu today (mainly through agriculture) is a contrasting scenario to the situation predicted in the late 1960's where:

- collapse of soil fertility over time because of continuous cultivation of smallholdings with food crops and…………..

- continued fragmentation and diminuation of land holdings to such scattered and miniscule plots……

would no longer supply a family's sole income and lead to a general decline in smallholder agriculture (Moris, 1998).

These gloomy predictions echo those of the colonial government in Kenya in the 1930's concerning the Akamba farming systems of Machakos District (Tiffen, Mortimore & Gichuki, 1994). As in the Akamba systems, Moris (1998) attributes the situation in Embu today of productive farming and high human carrying capacity to a number of factors which have raised household incomes: off-farm income and remittances, cash cropping, adoption of extension packages (hybrid seeds etc) and smallscale dairying.

The purpose of this research activity was to document the discussions with Embu communities in which we learned, first-hand, how they currently sustain their livelihoods and how they anticipate doing this in the future. A specific objective of this exercise was to see whether and how *livestock* are perceived to contribute towards the "health" and productivity of high potential farming in Embu. The reason for this specific question was in response to Moris' (1998) statement that " In Embu, in 1967......... by seeing livestock as purely a problem, we failed to recognise their critical role in nutrient transfers and in maintaining the fertility of heavily cropped home fields".

Methodologies

Group discussions were held with three farming communities in Mbeti North and Gatituri Sub-Locations, Embu District. On each day, 16 to 21 farmers gathered. The groups were mainly composed of members of women's home economics groups although some men also attended. The groups had no prior knowledge of the objective/purpose of the meetings.

The group sessions lasted around 3 hours and used mapping, time lines, sub-group discussions, brainstorming and question/answer. To gain the confidence of the groups an NGO (Intermediate Technology (IT) – Kenya) collaborated in the exercise. Their considerable experience of interaction with poor communities in the area permitted frank and focused discussions to take place. The following exercises were conducted at each of the group meetings:

Exercise 1 – Timelines describing general changes in the community
Exercise 2 – Mapping to describe changes on farms
Exercise 3 – Farmers' observations on changes
Exercise 4 – Farming strategies to cope with growing population pressure and decreasing farm size
Exercise 5 – How do you maintain 2 cows on half an acre?
Exercise 6 – Why is it important to maintain cattle on a small farm?

Structured Survey 1: *Manure management in the Kenya Highlands: a survey of current practices and potential*

There is great concern over soil fertility decline on arable land in the East African Highlands (Swift et al, 1994). In Kenya, it is estimated that 64% of the population resides in the highlands with population densities in some areas of over 1000 persons/km^2 (Braun et al, 1997). Losses of N and P were estimated at 42 and 3 kg/ha/yr respectively in the period 1982 to 1984 (Stoorvogel et al, 1993). The long-term decline is, in part, related to increased cropping intensity on shrinking smallholder farms (most households subsist on less than 1 ha) and to the limited use of inorganic fertiliser. Smaling et al (1992) estimated N and P fertiliser use in Kenya was only 6 and 3 kg/ha/yr in 1981.

Use of inorganic fertilisers on smallholdings in the Kenya Highlands has been reducing steadily since the 1960's when heavy promotion and subsidisation of fertiliser coincided with the release of improved maize varieties and the creation of co-operatives such as the Kenya Grain Growers Co-operative Union (Smaling *et al*, 1992).

In recent years, with increasing cost of inorganic fertilisers, scientific interest has turned towards the evaluation of organic fertilisers based on locally-available resources including green manures and mulches (Reijntjes *et al*., 1992). Research has focused on the quality, quantity and methods of application of biological materials (Myers *et al*, 1994). These studies now complement a wealth of research conducted over the last half century in East Africa demonstrating the positive responses of crops to livestock manure (eg Pereira & Jones, 1954).

From the 1960's, when the use of organic fertilisers, particularly livestock manure, was at a nadir, manure is now used by over 95% of all smallholder farmers in the Kenya Highlands (Karanja *et al*, 1997; Harris *et al*, 1997). Manure is highly valued and its price is increasing as the cost of inorganic fertilisers rises and the long-term (residual) benefits of using manure are realised by farmers.

The objectives of the present study in the high potential areas of Central Kenya were to:

- estimate the potential for ruminant livestock to supply manure;
- gain an appreciation of farmers' perceptions of the value of manure;
- assess the potential for improving manure supply and quality.

Methodologies

The study, a structured survey of 60 mixed farms (crop/dairy) in February 1997, was conducted in Kiambu and Murang'a Districts, Central Province, Kenya (Map 1). Most of the land area in these districts is described as having high agricultural potential and is agroecologically representative of much of Kenya's other high potential land areas (Jaetzold & Schimdt, 1983). These Districts have the following general characteristics (Table 1).

Sixty households were randomly selected, 30 in Kiambu District and 30 in Murang'a District. The households were selected at random from lists of farms known to be operating dairy/arable farms. The survey took place over a period of three weeks in February 1997.

The survey instrument took the form of the questionnaire directed at the household head taking 1.5 hours to administer in the local language, Kikuyu. The survey relied upon the farmer's capacity to recall farm productivity (crop yields, animal numbers etc.) for 1996. It should be noted that 1996 was a year of prolonged drought.

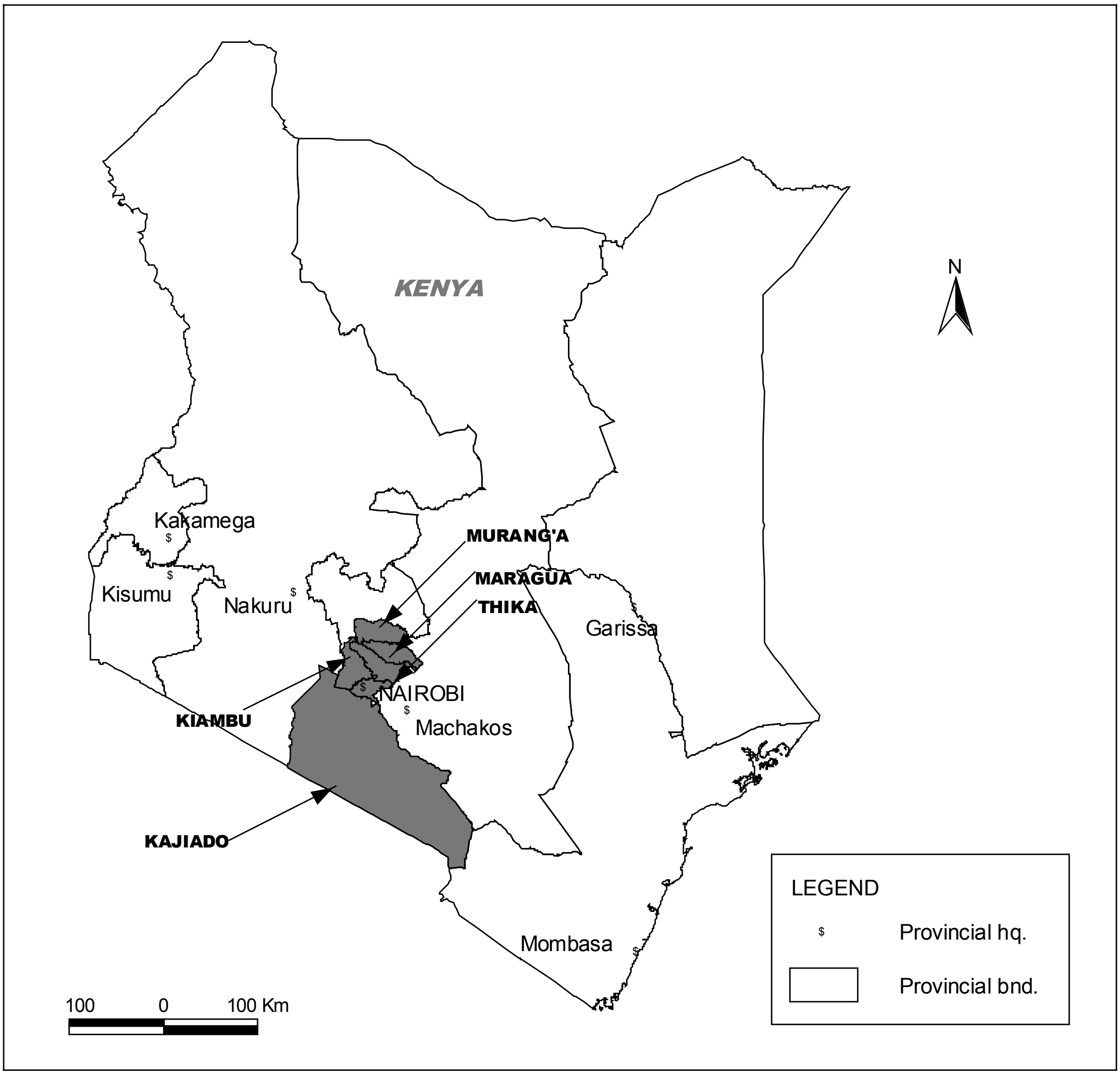
Classification of manure: Manures were classified on the basis of the animal(s) producing them. The major groups of animals encountered during the survey were, cattle, sheep, goat, rabbit, poultry (local, layers and broilers) and pigs. It was often found that cattle and goat/or sheep manures were stored/mixed together. Cattle manure was further classified according to the state at which it was taken to the field. Some farmers would apply it as fresh dung , others as slurry and others as a manure based compost, a composted mixture of dung, urine, feed refusals and bedding.

Table 1. General characteristics of high potential areas in Kiambu and Murang'a Districts, Central Kenya

District	Annual rainfall range (mm)	Mean annual temp (^oC)	Main soil type	Main land-use systems	Overall population density(km^2)*	Market access
Kiambu	1000 – 1800	18-19	Nitisol	Tea/dairy; Coffee/dairy; Marginal coffee/maize	353	Good
Murang'a	1000 - 1800	18-19	Nitisol	Tea/dairy; Coffee/dairy; Marginal coffee/maize	340	Medium

**CBS, 1995. Note that this population density includes people in the lower potential areas in each District. Recent figures for the high potential areas of Embu District give a population density of 800 persons/km^2(Imbernon, 1997) whereas CBS (1995) gives 132 persons/km^2 for overall Embu District. (Table source: Jaetzold & Schmidt, 1983)*

Map 1. Districts in which the research was conducted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Manure sampling and analysis: On each farm visited manure was scooped from four random spots on the manure heap to a depth of about 30 cm. The four samples were mixed together and a subsample of approximately 1 kg was taken and stored in plastic bags. The manures were air dried and then ground to pass through 2 mm screen openings.

Carbon was analysed by the loss on ignition technique described by Okalebo *et al* (1993). A 10 g sample was taken and ignited at 550^{o} C for 8 h and the ash weighed on a fine balance. The percent organic matter content was converted to total C by dividing by 1.74 (Stevenson, 1986). Total nitrogen was analysed by the modified Kjeldadhl oxidation method where salicylic acid is added during digestion so as to include nitrate-N and nitrite-N. A sample weighing 0.3 g was placed in a clean dry digestion tube and, after addition of the oxidising reagents, sulphuric acid + salicylic acid + catalyst, the tubes were placed in a digestion block at 360 °C for 3 h until the remaining digest was sand white. The tubes were removed and left to cool and diluted to 50 ml. 10 ml of the digest was taken for N determination by the distillation and titration method. The rest of the digest was used for P and K analysis. P was determined by the ascorbic acid/molybdate blue colour method while K was determined by flame photometry.

Structured Survey 2: *Influence of manure management on variability of manure chemical and physical characteristics in Kariti Location*

The general survey of manure management practices (Structured Survey 1) encountered some factors that appeared to affect the quality of manure and yet were not investigated conclusively due to the limited number of farms involved in the survey. Factors emerging with an influence on manure quality included the capture of urine in the manure heap and the use of bedding. The present survey investigates these parameters more comprehensively within a small area in Kariti Location. By limiting the survey to one Location the variability in manure quality is more likely to be influenced by the management rather than the geographical location

The previous survey also found that farmers showed some ability to assess manure quality. However, it was uncertain whether perceptions of quality influenced application rate. During the present survey the relationships between manure quality and its physical consistency colour, smell and biological activity were investigated. The aim was to see if obvious visual and olfactory indicators have significant correlation with manure quality. Simple quality indicators that could be used to determine application either of manure alone or manure in strategic combination with inorganic fertilisers could help improve the efficiency with which limited nutrient inputs are used.

A survey comprising a one-page questionnaire was conducted in Kariti Location, Kandara Division, Maragua District within a 5 km radius from the trading centre. The survey was conducted in the same season as the first survey (February-March). An enumerator (2^{nd} year horticulture student) from the Location was engaged to perform survey in the local Kikuyu language. Three hundred farmers were chosen at random by visiting every 5^{th} household along roads/paths radiating out from the trading centre. At each farm approximately 1 kg of manure was sampled from the farm's manure heap at a depth of 45 cm from the surface of the heap. The samples were stored in plastic bags and kept at the student's home in a cool store. The manure was collected weekly and taken to the KARI Muguga laboratories where it was air dried, ground through 2 mm sieve and analysed for nutrient content according to methods described by Anderson and Ingram (1996).

The questionnaire was subdivided into the following three sections:

1. Cattle management - this involved all aspects of animal housing such as type of animal enclosure, roofing, floor type, drainage, bedding and use of concentrate feeds;

2. Manure management – including the way waste is handled and stored prior to utilisation

3. Manure characteristics that could be assessed visually such as the consistency, colour, smell and biological activity (since these are subjective assessments only one enumerator was used to ensure consistency in manure appraisal).

Experiment 1: *Collection and Composting Strategies to Enhance Fertiliser Quantity and Quality and the impact on maize growth over two seasons*

This experiment was conducted in part at the Kenya Agricultural Research Institute (KARI), National Agricultural Research Center (NARC) Muguga, Kenya. This station in located 25 km west of Nairobi at latitude S 1^{o} 13' 53.0" and longitude 36^{o} 38' 1.1" East at an altitude of 2500 m above sea level. This study ran between October 1997 and February 1998.

Twenty Friesian/Ayrshire steers were used for production of faeces, urine and rejected fodder (feed refusals) during the *Collection Phase* of this experiment. Four animals (balanced for similar group weights) were allocated to each of the following treatements.1). The five methods of manure collection were:

1. Faeces + urine + feed refusals mixed on the floor of the cow shed by the animal (Stable)
2. Faeces + urine + feed refusals mixed systematically by hand (F+U+FR)
3. Faeces + feed refusals mixed by hand but without urine (F+FR)
4. Faeces and urine only, mixed by hand (F+U)
5. Faeces only, without urine or feed refusals (F)

The steers were offered maize stover dry matter (DM) at 2.5% liveweight and 2 kg dairy concentrate split into two 1 kg rations fed in the morning and afternoon. The steers were provided with minerals and with water *ad libitum*. Steers used in Treatments F+U+FR and F+U were kept in metabolism pens where faeces and urine could be collected separately. Steers on treatment Stable were enclosed in cubical sheds where feed refusals (maize stover) were applied daily as bedding over a concrete floor. On Treatments F+FR and F steers were kept as in Stable but not provided with bedding. Faeces were collected separately and recombined with feed refusals in heaps away from the animal pens. The Collection Phase lasted for 60 days.

At the end of the Collection Phase the accumulated waste from each steer was weighed, pooled by treatment and subdivided into four approximately equal heaps for composting. The Composting Phase lasted 84 days after which manure-compost were used in agronomic experiments.

Composting was carried out on concrete floors of roofed cowsheds. The manure heaps were stored in 1m^3 chicken wire cages mounted on steel frames. On the inside, a finer plastic netting with 2 mm openings was used that would retain collected waste, preventing the manure-composts coming into contact with the metal frames, and yet still allowing free circulation of air. The concrete floor below the cages was lined with non-porous plastic sheet, extending 20 cm up the sides of the cages, to minimise leaching from the heaps.

Measurements

Collection Phase: The masses of feed offered and refused were recorded daily. Composite samples of the feed offered and refused were obtained daily and, at the end of each week, this was bulked and ground for nutrient analysis. No other measurements were possible for treatment "Stable" until the end of the Collection Phase. For all other treatments, additional measurements included, mass of faeces and the volume of urine produced by the animal daily and the amount of feed refusals that went into the composting heap.

Samples obtained daily and stored in a freezer before bulking as weekly samples. All solid components were dried at 72 °C and ground before analysis.

Composting Phase: At the beginning of this phase the amount of manure-compost going into the replicate compost heaps was weighed. A sample was taken from each replicate at 0, 3, 6 and 12 weeks after making the heaps. The samples were analysed for DM, total organic carbon, total nitrogen and total phosphorus. At the end of the Composting Phase, nutrient mass balances were calculated for C, N and P to ascertain losses occurring during accumulation and composting.

Analyses for C, N, P and K were carried out as described by Okalebo *et al* (1993). Carbon was analysed by the wet oxidation by acidified dichromate technique as described by Nelson and Sommers (1982). A sample of 0.01 ± 0.0005 g of ground manure was placed in a test tube and acidified potassium dichromate was added. The tube was placed in a preheated digestion block and heated at 150 °C for 30 min. The heated sample was transferred to a 100 ml conical flask and 0.3 ml of 1:10 phenanthroline molybdate-ferrous sulphate (Ferroine) indicator was added. Using a magnetic stirrer, the sample was titrated against ferrous ammonium sulphate solution. The end point was a change in colour from greenish to brown. Two reagent blanks were used for background correction.

Total nitrogen was analysed by the modified Kjeldadhl oxidation method where salicylic acid is added during digestion so as to include nitrate-N and nitrite-N. A sample weighing 0.3 g was placed in a clean dry digestion tube and, after addition of the oxidising reagents, sulphuric acid + salicylic acid + catalyst, the tubes were placed in a digestion block at 360 °C for 3 h until the remaining digest was sand white. The tubes were removed and left to cool and diluted to 50 ml. Ten ml of the digest was taken for N determination by the distillation and titration method. The rest of the digest was used for P and K analysis. P was determined by the ascorbic acid/molybdate blue colour method while K was determined by flame photometry.

Sub-Experiment 1a: *Agronomic Experiment*

The five manure-composts were used in this field trial conducted at two different sites. Two other treatments were also included for comparative purposes: manure-compost obtained from a Masaai kraal in Kajiado District (semi-arid location) and, at one site only, manure-compost obtained from the farmer on whose farm the experiment was conducted. A control where no manure was applied was included at both sites. Masaai manure is often trucked up to the Kenya highlands for use on small farms. It commands a high price.

Before the application of manure-composts, soils were analysed for C, N, P and K. The experimental design was a randomised complete block design with four replicates. With the exception of the farmer's manure, all manure-composts were applied at a rate equivalent to 75 kg N ha^{-1}, evenly broadcast in the plots and then incorporated into the soil. The farmer's manure was applied at the same rate as the Masaai manure, 13.7 t (fresh weight) ha^{-1}, and analysed after application, when N application rate was calculated to have been 121 kg N ha^{-1}. The plot size was 4 x 6 m and maize was planted at a spacing of 30 cm (inter-row spacing) x 75 cm (intra-row spacing) giving a population of 43,000 plants ha^{-1}.

Both sites were planted with maize in the first week of April 1998 and harvested in the third week of August 1998. Two seeds were planted per hill and thinned to one plant per hill 4 weeks after planting. Routine agronomic practices, such as weeding and pest control, were carried out according to the recommendations of local MoA Extension Department. At maturity, an area of 9 m^2 in each plot was harvested and cobs and stover weighed. Sub-samples of ten cobs and six plants were taken for moisture and nutrient analysis.

Statistical analysis: Data were analysed by single factor analysis of variance using MS Excel Version 5.0 with calculation of LSD at p=0.05 using Tukey's t for all pairs comparisons. Percentage data were arcsine transformed before analysis of variance. Before and after composting values for individual treatments were tested by paired two-sample t-test for means.

Sub-Experiment 1b: *Nitrogen availability of composted cattle manure by laboratory and greenhouse incubation techniques*

Brief: It is a widely accepted that synchronising nutrient release from organic fertilisers with periods of maximum demand by growing crops is the key to improving nutrient use efficiency on smallholdings (Woomer & Swift, 1994). This experiment evaluated the manure-composts used in the experiment above in terms of their nitrogen-releasing capability. Net nitrogen mineralisation, is considered to be a measure of the availability of organically-bound N in soils. The objectives of this laboratory/greenhouse study were use aerobic and anaerobic soil incubations to predict nitrogen-availability of composted cattle manureand to correlate these by regression analysis with dry matter production and total nitorgen uptake by finger millet (*Eleusine coracana*).

Experimental: Aerobic incubation. Treatments for this experiment comprised the five manure-composed derived from Experiment 1 plus the Maasai manure described above. The six manures were ground to pass through a sieve of 2 mm mesh openings. Top soil (0-20 cm) was obtained from the farms in Gatuanyaga and Kariti where the agronomy experiements were carried out. The soils were air-dried in a greenhouse and ground to pass through a sieve of 5 mm mesh openings. 50 g of soil were weighed into 200 ml plastic bottles. Manure was applied at the rate of 10 mg N 50 g^{-1} soil. Bottles containing no manure were added as controls. Water holding capacity of the soil had been predetermined by the method described by Anderson and Ingram (1989).

The bottles containing soil and manure were stoppered and shaken on an end-to-end shaker for 15 min to ensure a homogenous mixture. They were removed and allowed to stand for 1 h for the dust to settle before gently applying distilled water to 60 % of water-holding capacity. The bottles were loosely closed so as to allow gaseous exchanged and yet maintain the same level of moisture. The bottles were incubated at 25 ^{o}C. The moisture was checked and adjusted weekly. At the end of 1, 2, 4, 8, 12 and 16 weeks of incubation, duplicates of each treatment and the controls were withdrawn for mineral-N (NH_3-N+NH_4-N and NO_3-N+NO_2-N) analysis. 10 g of the moist soil was extracted for mineral-N in 50 ml 0.5 M K_2SO_4 solution. Mineral-N analysis was done by the calorimetric methods described by Anderson and Ingram (1989).

Experimental: Greenhouse bioassay. Soils were air-dried and sieved through a 5 mm screen. 2 kg of soil was weighed into each pot. Manure-composts were air-dried and then mixed well into the soil, without prior grinding, at rates equivalent to 0, 25, 50 and 100 kg N ha^{-1}. In addition to the six manures mentioned earlier, a treatment with direct urine application was included. The volume of urine applied was adjusted to give the same rates of N as those applied in the manures. About 10 seeds of finger millet were sown into each pot. Soils were watered to 60% moisture holding capacity and this level was maintained throughout the growing period. After germination the plants were thinned to four plants per pot which were allowed to grow for 60 days. The shoots were then harvested and dried at 65 ^{o}C for 72 h and ground to pass through a 2-mm sieve. The shoots were analysed for total N by the method of Anderson and Ingram (1989). Correlation was sought between the N mineralised during the laboratory incubations, initial manure characteristics and shoot dry matter and N uptake of the above ground biomass production of the finger millet. ANOVA was determined and LSDs calculated using Turkey’s t for all pair comparisons at 5% significance level.

Experiment 2: *The effects of composting on quality of cattle manure-compost derived from napier grass/concentrate/poultry litter diets*

Brief: As dairy production systems become more market-oriented and/or smaller in land area they depend to a larger extent on off-farm, purchased feed resources. KARI/ILRI/MoA Smallholder Dairy Project studies in Central Kenya show that these diets can contain concentrated feeds such as commercial dairy meal, cereal milling by-products and poultry litter fed at rates of between 1 to 4 kg per head per day. Despite feeding higher quality diets milk production is still comparatively low. It is suspected that nutrients may instead be used for maintaining live-weight with a proportionately higher level of nutrients actually being excreted than on lower quality diets (see Kebreab et al, 2000).

It would be premature to deem these feeding systems uneconomic until it is demonstrated that the higher nutrient levels excreted do not contribute to better crop growth. This experiment tests the impact of higher quality diets on excreta quality and also if higher nutrient concentrations in excreta can be retained during storage. The experiment features poultry litter, a commonly used supplementary feed high in non-protein nitrogen. The "high concentrate" diet used in this experiment is not unlike those used on farms in the area and is designed to give a protein/energy imbalance in the diet. Diets that are unbalanced in protein and energy can result in excessive levels of nitrogen in urine. The challenge in this experiment (and therefore on-farm) is to effectively capture urinary nitrogen.

Experimental: The experiment was conducted at KARI Muguga between third week of August 1998 and fourth week of February 1999. The study was conducted in two phases; a 60-days *Collection Phase* and a 90-days *Composting Phase*. Friesian/Ayrshire cross-bred steers were used for the production of faeces and urine. The experiment comprised six treatments in a 2 x 3 factorial design. Concentrated feeds were offered at two levels and excreta derived from these diets handled in three different ways (Table 2). Treatments including urine were obtained from steers housed in metabolism pens where faeces and urine could be collected separately and measured. Steers for faecal collection (without urine) were housed in a roofed, concrete floored barn where urine quickly drained away.

This experiment differed from Experiment 1 with respect to the basal diet. Steers were fed on Napier grass (*Pennisetum purpureum*) as opposed to maize stover. Bedding (in this case barley straw) was added to the heaps of excreta and to the Stable treatment at the rate of 1% of liveweight as straw DM every second day (steers were weighed every two weeks). Bedding was included, as this is a widespread practice amongst smallholders. Barley straw was used a fairly homogenous crop residue instead of maize stover in this case following failure of the maize crop in the highlands.

Sampling of feeds, bedding and excreta was conducted as per the previous experiment.

Table 2. The experimental design for production of cattle manure.

	High concentrate diet	Low concentrate diet
Plus urine	Hand mixed (HC+U)	Hand mixed (LC+U)
Minus urine	Hand mixed (HC-U)	Hand mixed (LC-U)
Stable	Animal mixed (Stable HC)	Animal mixed (Stable LC)

The steers were fed a basal diet of Napier grass offered at 2% liveweight (as dry matter). Steers receiving high concentrate diets were offered a mixture of 0.5% liveweight (as dry matter) of commercial concentrate plus 0.5% liveweight (as dry matter) of poultry litter sieved to pass a 5-mm screen. This mixture (not unlike diets used on smallholdings locally) was intended to produce high urinary nitrogen. Steers for the low concentrate treatments were provided with 0.5% livewight (as dry matter) of commercial concentrate only. The steers were provided with mineral supplements and water *ad libitum*. Some quality parameters of napier grass, commercial concentrate and poultry litter used in the study are given in Table 3.

Statistical analysis: ANOVA was carried out using statistical programme MS Excel version 5.0. All the LSDs were calculated at 5% significance level using Turkey's t, adjusted for making all pair-comparison except where mentioned otherwise.

Table 3. Chemical composition of feeds and straw used in the experiment.

	DM[1] (g kg^{-1} fresh weight)	Chemical composition (g kg^{-1} DM)		
		N	P	K
Napier grass	340±11.6	11.5±0.87	0.58±0.167	23.7±1.62
Concentrate	900±15.2	17.6±0.63	6.60±0.433	10.6±1.01
Poultry Litter	880±18.5	23.6±0.10	6.23±0.018	16.7±0.00
Barley straw	910±41.1	7.2±0.12	0.36±0.031	24.8±1.93

[1]DM = dry matter

Experiment 3: *The Effects of Barley Straw Addition and Covering on the Quality of Composted Cattle Manures*

Brief: The previous experiments indicated that addition of barley straw to manure heap assisted in conservation of nitrogen whereas this was not the case with more coarse-stemmed maize stover. This positive attribute of barley straw was tested again in the present experiment but with an added treatment to see if covering (an internationally well-accepted method for improving compost quality but not widely adopted in the project area – See Structured Survey 1)) could improve N conservation.

Experimental: The study was carried out between the third week of July 1998 and the fourth week of February 1999 at KARI Muguga. This experiment comprised the familiar *Collection* and *Composting* Phases. In the Collection Phase, faeces (only) were collected from 14 Boran steers (*Bos indicus*) enclosed in roofed sheds with well-drained concrete floors. The steers were fed on a daily basal diet of 20 kg of fresh napier grass per head per offered in two equal meals per day. They were also fed 2 kg fresh weight of commercial concentrate. Water and minerals supplements were provided *ad libitum*. Some quality measurements of napier grass, dairy meal and straw are given in Table 4.

Daily feed intake, feed refusals and faecal production were recorded. A sub-sample of about 500 g of the faeces produced by each animal each day was collected and stored under refrigeration, and then bulked weekly to provide one sample for nutrient analysis. After sub-sampling, the remaining faeces were heaped in cages measuring 1x1x1 m in a roofed shed with a concrete floor. Collection took place over 60 days into two large heaps of faeces (seven animals contributed to each heap). To one heap was added barley straw at the rate of 1% of the total mass of DM in the heap and left covered but undisturbed for 4 weeks allowing the "straw heap" to settle. Each heap was then thoroughly mixed and sub-divided into 8 smaller heaps (total: 16 heaps of equal weight) They were located in the open in two rows separated by a 1 m path and with 1 m between individual heaps. Four heaps were selected at random from the two manure types (with or without straw), and covered with clear plastic sheets. The remaining four from each category were left uncovered. The ensuing Composting Phase lasted 120 days.

Table 4. Chemical composition of feeds and straw used in the experiment.

		Chemical composition (g kg^{-1} dry matter)		
	DM[1] (g kg^{-1} fresh weight)	N	P	K
Napier grass	340±11.6	11.5±0.87	0.58±0.167	23.7±1.62
Concentrates	900±15.2	17.6±0.63	6.60±0.433	10.6±1.01
Straw	910±41.1	7.2±0.12	0.36±0.031	24.8±1.93

[1]DM = dry matter

Outputs

The Experimental Programme

PRA Phase: *Intensification of farming on smallholdings in the Central Kenya Highlands - discussions with Embu communities in Mbeti North and Gatituri Sub-Locations*

Small-scale agriculture is the predominant land-use type in both sub-Locations. Farms are between one half and five acres in size. Maize, beans, sweet potatoes, potatoes, vegetables and pawpaw are grown. With bi-modal rainfall, the intensity of cropping is high with very little arable land without crop-cover throughout the year. Coffee is the dominant cash crop. Others include macadamia nuts and bananas.

Livestock are dominated by exotic dairy cattle (Friesian and Ayrshire) and their crosses with local zebu types kept in small herds of between one and five head. The cattle are kept in permanent confinement throughout the year and stall-fed. By comparison, very few sheep and goats are kept. Pigs, dairy goats, improved poultry and rabbits have been introduced by NGOs but have not been widely adopted.

- *Exercise 1: Timelines describing general changes in the community*

Farmer-groups were asked to verbally recall changes since settling land in each sub-location at Independence in 1963. Changes in farm size, livestock keeping, farming practices, market access, income sources and farm labour were investigated. Findings are summarised as follows:

Changes in farm size: Land was demarcated in 1963. Families were allocated land holdings of between 5 and 15 acres. The size depended upon the standing of the person in or with the "Adminstration" at that time. Leaders were given larger parcels. Despite being issued up to 15 acres most farmers cultivated only one acre leaving the rest as fallow for grazing herds of 5 to 20 zebu cattle. Today most landowners have sub-divided their farms amongst their sons and the majority of them remain with very few acres. A poor household will typically be farming less that 1 acre.

Changes in livestock keeping: In the 1960s people kept large herds of local zebu cattle and small ruminants because grazing land was plentiful on each farm. Now livestock holdings per farm are significantly lower due to small farm size. There has always been a large demand for milk in the area. Many farmers therefore took up loans from the Ministry of Agriculture to more productive, exotic dairy cattle. Permanent stall-feeding of dairy cattle started in the 1980's. Today, over 70% of the farmers keep their animals in confinement.

Changes in farming practice: In 1963 families cultivated only one acre out of a total landholding of 5 to 15 acres. Families were small with few children. This made cultivating large portions of land unnecessary. They grew coffee, maize and bananas. Yields were poor. The seeds planted were homegrown. As farms became smaller the need to improve productivity per hectare through the use of hybrid seeds. Fertiliser was quickly adopted in the 1970's as it was recognised that hybrid plants required higher levels of fertility. Manure was the only soil fertility amendment used prior to fertiliser. To date, farmers still prefer to use manure as opposed to regular application of fertiliser as they have observed that that sustained use of the latter leads to a decline in soil fertility.

New varieties of crops were introduced in the 1970s such as macadamia, pawpaw and bananas. Since the 1970's trees have been planted on farm boundaries as a source of firewood and construction timber. *Grevillia robusta* is the most popular species planted. The groups felt that the environment has improved with the advent of the trees and associate the increase in frequency and quantity of rainfall with better tree cover. In the 1970s bench terracing was introduced in an effort to reduce soil erosion.

Changes in agricultural markets: In the 1960's people were walking long distances to buy simple household goods. Whilst Embu Town is a major market for farm products, each village now has a number of kiosks where goods can be bought and sold. From a system based on barter in the 1960's, village economies are now based on cash. The communities thought that prices for agricultural produce are now better than in the past because of a steady increase in the number of wholesale buyers of farm output. Groups agreed that they "cannot produce enough to satisfy the demand".

In the 1970s over two thirds of the women said that they hand-carried all produce to market. Today marketing of products is facilitated by the use of ox carts and motorised vehicles. However, road quality seriously reduces the viability of these transport options in some parts of the sub-Locations.

Changes in income from the farm: Despite decreasing land sizes there has been a real increase in household income from farming since 1963. High demand from nearby urban areas has contributed to the rise in commodity value. Since incomes derived from farming small areas are still perceived to be good few of the participants in the three farmer-groups mentioned engaging in other income generating activities such as kiosks or other off-farm employment.

Changes in farm inputs: In 1963 no purchased inputs were used for crop or livestock production. Soil fertility was maintained by fallowing/manure, seeds were saved from the previous year's crop and livestock were fed by grazing. Today the majority of farms are using hybrid seeds, fertiliser and manure; growing diverse cash crops; owning grade cattle and planting fodder (Napier grass). The groups perceived these changes as necessary so as to ensure family livelihoods.

Changes in on-farm labour: In the early 1970's there was no shortage of labour. Hiring rates for farm labourers were small, around KSh 30 / month. Not all children attended school so they were therefore available to do farm work. Education (at least at primary level) is now compulsory and this is considered to have seriously reduced the supply of labour. Communities also felt that schooling has raised children's aspirations beyond farming. However, parents considered that a dearth of employment opportunities for their children existed off the farm.

Labour has thus become scarce and expensive. Traditional communal working groups no longer function and so farms have become almost entirely dependent upon family labour. It was agreed that lack of labour was currently the main constraint to agriculture in the sub-Locations.

- *Exercise 2: Maps of farm changes*

Each of the three farmer-groups was asked to map changes on a typical farm in the immediate area. The groups drew maps depicting a farm from belonging to one member of the group. Maps were drawn to show the farm in 1963, the early 1980's, 1998 and then what they think the farm would look like in 10 years' time (2008). The mapping exercise was actively facilitated to ensure participation of the whole group. The maps shown in Figure 4 are examples of the deliberations from one of the groups.

Major changes to Njanga's farm since 1961:

- In 1961 the farm occupied 15 acres. The family (six members in total) only cultivated 1 acre and left the rest of the farm as bush grazing for 20 cattle and 50 goats.

- By 1981 the 15 acre farm had been divided into six holdings, Njanga retained 3 acres as a homestead plot, had opened a kiosk and had given 3 acres to his two eldest sons and 2 acres to his other three sons. The land now sustained 20 people all deriving a livelihood from the land.

- By 1998 Njanga had sold his 3 acres of land at the bottom of Figure 4 (below the road). The total land area remaining (12 acres) was then re-allocated amongst the five sons and himself leaving all six households with 2 acres each. The land now sustains 60 people. The kiosk no longer functions.

- In 2008 the family anticipated that each of the 2 acre holdings would be split again as the third generation inherited land. The last map of Figure 4 shows detail of how one of the holdings would be split in order to give each of the two grandsons ½ acre each. It was estimated that the land would then be required to support 100 people.

Population density on Njanga's farm from 1961 to 1998 has changed from 0.4 to 5.0 persons per acre, a 1150 % increase. In 2008 the family anticipated that the population density would rise to 8.3 persons per acre.

- *Exercise 3: Farmers' observations on changes.*

The farmers' groups were asked to describe the major changes in farming over the period 1961 – 1998 and predict changes to 2008. They are presented below:

Between 1961 and 1981

- Major period of land sub-division
- Widespread terracing of land was carried out in these specific sub-Locations
- Maize planting changed from broadcasting to row planting
- Arable areas on each farm increased
- Crop diversity increased
- Loss of grazing land

- Stall feeding of cattle became more prevalent
- Farms owned more poultry

Between 1981 and 1998

- Further sub-division of land
- Pure stands of crops on separate patches of land (ie not intercropped)
- New varieties of food and cash crops (eg Macademia)
- Stall-feeding improved breeds of dairy cattle
- Boundary planting of trees (eg *Grevillia robusta*)
- Planting Napier grass on terrace edges

(1998 map gives prominence to coffee. The traditional *"boma"* depicted in 1981 has been replaced by a stall-feeding unit in 1998)

Projections to 2008

- Houses will improve further
- Land will be partitioned to even smaller plots
- Even greater variety of crops grown
- Better methods of keeping cattle to yield more manure and milk will be devised.

(2008 map show that farmers anticipate horticultural crops will become more important, intensive goats and poultry are in evidence and the farm will diversify to various businesses such as a shop, hotel, bar etc.)

- *Exercise 4: Farming strategies to cope with growing populations and decreasing farm size.*

The farmers' groups were asked to look at the farm maps and to describe the most important farming strategies that have allowed farms to compensate for increases in population pressure in the face of reducing farm size. They are as follows:

Crop-related:

- Use irrigation and grow horticultural crops for market
- Diversify farm enterprises
- Use improved seeds
- Use pesticides
- Weed early

Livestock-related:

- Increase soil fertility through use of manure
- Establish more fodder for livestock
- Adopt better management of livestock (AI, zero grazing)
- Buy fodder
- Keep a minimum of 2 cows on half acre

Other strategies:

- Seek off-farm employment

It was clear from the discussion that in the absence of opportunities for off-farm employment the way to sustain the increasing population in the future was through greater farm diversity and productivity. Subsistence agriculture, ie the growing of food crops was not seen as a priority, quite the contrary, the consensus was that diversification into market-oriented products such as horticultural crops and dairy was regarded as the key to improving food security.

If dairy cows are considered to make a critical contribution to sustaining the productivity of shrinking smallholdings in the future the question raised is how these animals will be maintained on a decreasing, homegrown forage base?.

- *Exercise 5: Maintaining dairy cows on small farms.*

The Kenya National Dairy Development Project (NDDP) recommend that at least one acre of Napier grass is required to sustain a dairy cow and her follower. This recommendation was discussed with the groups. They were specifically asked how, if dairy cattle are to become so crucial to future livelihoods, does one maintain 2 cows on a half acre farm? (The scenario under discussion was suggested by the groups)

The following practices were considered necessary:

- Stall-feed the cattle (no grazing possible)
- Establish fodder (Napier grass) on terraces
- Buy cereal bran, milling by-products and vegetable waste etc
- Collect roadside grass
- Feed crop residues
- Rent land to grow fodder

Observations: Maintenance of dairy cattle hinges upon importation of forage and concentrated feeds. Home-grown forage is limited to the margins of fields (terraces). Even though the groups were asked to consider a land-scarce/high population density scenario they felt that land would be available for rent upon which fodder could be grown. Groups considered that higher population densities would mean that more labour (cheaper) would be available for forage collection. Common property is the main source of fodder.

Why is it important to maintain cattle on small farms?

Each group was asked to list and then rank the various products of cattle the results are as follows:

Product	Rank
Manure	1
Milk	2
Income	3
Investment	4
Prestige	5
Dowry	6
Meat	7=
Skin	7=

Whilst the groups considered that the “health of people is due to milk” they considered that, more importantly, "farms without livestock are not as healthy as those with livestock”. The means to attain better “farm health” was through regular application of manure to soils.

What manuring strategies are used to maintain "farm health"?

To answer this question farmers were asked to draw an *average* farm and then to say how much manure/fertiliser should be applied each season to sustain good yields. (Note that in Embu there are two main growing seasons).

Figure 5 shows a 1 3/8 acre farm (size chosen by farmers) with two cows. The following table shows the seasonal application rates of manure and fertiliser to each plot.

Table 5: Hypothetical seasonal application of manure/fertiliser to a 1 3/8 acre farm

Crop and plot area sown (acres)	Manure (debes*)	Fertiliser (kg of DAP)
Beans (0.25)	12	4
Maize (0.25)	12	6
Potatoes (0.125)	20	10
Bananas (0.125)	3	0
Horticulture (0.125)	9	5
Coffee (0.25)	126	0
Sweet potatoes (0.125)	0	0
Napier grass (0.125)	6	3
TOTAL	182	28

* One debe of manure (as applied to field) weighs approximately 16 kg (@ 40% dry matter - I. Kariuki, KARI RRC Embu, pers. comm. 1998 – from NUTMON dataset)

Coffee is considered the major income earner for the group and so receives the majority share of the manure. For many of the farmers present, the credit to purchase fertiliser comes from the coffee cooperative. It is interesting therefore that coffee receives no fertiliser but, instead, it is used on all other crops.

Will two cows produce sufficient manure to sustain this manuring strategy? Table 5 indicates that the requirement is around 2.9 tonnes of manure (182 x 16) are required per season. This is equivalent to 1.2 tonnes of dry manure per season (based on an average manure dry matter content of 40% at time of application) or 2.4 tonnes of dry manure per year.

This Project found that cattle produce 0.8 % of liveweight each day in faecal dry matter. Adult cows in the Central Kenya achieve average liveweights of around 350 kg (B. Lukuyu, KARI NARC Muguga, pers. comm. 1998). Thus, on this hypothetical farm two cows would thus produce around 5.6 kg of manure dry matter per day or just over 2 tonnes of dry manure per year.

Thus the manure application rates proposed by farmers are almost feasible as long as two cows are kept and all their manure is collected and stored. The deficit of 0.4 tonnes of dry manure may of course not occur in practice where manure heaps are supplemented with rejected feeds, bedding and household waste.

It is important to note that farmers considered that maintenance of crop productivity on this hypothetical farm required use of 28 kg of di-ammonium phosphate (DAP) in addition to the application of manure. A manure-only scenario was not proposed

Alternatives to the manuring strategy: Farmers were asked what they would do to sustain soil fertility if they had i) too little or ii) no manure? The following strategies were suggested:

i) too little manure:
- Alternate manure applications between plots.
- Exchange fodder for manure

- Buy manure from those who have livestock
- Bring in organic material from outside the farm to be trampled on by cattle and then added to the manure heap

ii) no manure:
- Make compost from plant material collected off-farm

Application of manure to alternate plots was considered as a feasible alternative to regular manuring of the whole land area because manure has a residual fertility effect, to quote: *"we use manure more than fertiliser because it stays longer and is cheaper"*.

Making manure-less compost was not a particularly attractive alternative because it was considered a tedious process. It was better, if the farmer was going to collect plant matter for subsequent use as organic fertiliser, to use an animal to "process" it. Plant matter used as bedding absorbed urine and this was seen as advantageous because urine was thought to accelerate the breakdown of the organic matter.

Discussion

The farmer-groups presented a scenario of continued diminution of land holdings to the extent that households would, within the space of the next 10 years, cultivate only 0.5 acre. The derivation of a living from such small areas was considered to still be feasible although the impression gained was that 0.5 acre represented a threshold below which the arable plot became non-viable.

Livelihoods based on the cultivation of very small land areas is of course not unprecedented in other high potential regions of Kenya such as Kisii District (Rees *et al*, 1998). However, farmers pointed out that the viability of small arable plots is contingent upon the capacity to diversify into a variety of intensive, market-oriented enterprises (market-gardening, dairy and local business were the three specific examples given) and having good input/output market access. An alternative was to seek employment in nearby urban centres (eg Embu town), except that, currently, the employment market is reported to be limited.

It is somewhat puzzling that, in this area of high population density with a (reportedly) limited urban employment market, rural labour shortages should exist. Equally baffling is that a random survey in the same location found less than one percent of households owning no land (Kihanda, Tanner & O'Neill, unpublished survey data). Further studies are required to find out what is happening to those households that inevitably become disenfranchised of land as families expand and ownership of the remaining viable land parcel passes to only one child. It is a possibility that at present landless families are not a numerous social grouping and/or, for whatever reason, do not function as land-labourers. Local NGOs suspect that one possible reason for the relatively low frequency of landless families in the Embu area is that they are either migrating permanently or seasonally to more marginal (dryland) areas to farm or moving to more distant urban centres.

For households still occupying smallholdings in the Embu area it is clear that strategies to sustain "*farm health*" under more intensive farming activities are considered as central pillars supporting livelihoods. Although not reported in detail above, farmers regard the condition of the soil as the quintessential element of farm health. Farmers suggest that the main diagnostic indicator for assessing the state of farm health is the darkness of the soil – "dark soils give rise to large maize cobs and heavy banana yields". This emphasis on soil fertility maintenance as a core factor determining the viability of smallholdings is apparently prevalent across the East African Highlands (AHI, 1997).

In meetings the farmers eloquently portrayed trends in farming systems over the past 40 years. During this dialogue, and against the backdrop of acute awareness of the state of the soil, no mention was made of a discernable, negative change in soil fertility. This is perhaps not surprising given that a number of studies elsewhere contend that where land is intensively used so greater attention is paid to maintaining soil fertility (eg Tiffen, Mortimore and Gichuki, 1994). Worthy of note in the present study however is the direct linkage made between between livestock, particularly dairy cattle and soil fertility.

The fact that manure was ranked the most important output from cattle despite the proximity to a local milk market reflected some of the more fervent statements made by older members of the group concerning the use of manure - "my land was very infertile in 1965 so I bought cattle to improve my land through manure" and "without livestock many things will not move or grow". This latter reaction arose in response to the notion that as farm sizes reduced so would the opportunities for keeping cattle. There was general consensus that the communities would continue to keep cattle despite land pressure.

The suggestions given by the groups when presented with the dilemma of how to maintain cattle on a small farm hinged upon the purchase of feeds. The main feature to note about the "diet of the future" is that forage still plays a significant role. Home-grown forages such as napier grass are still anticipated to be in use perhaps grown on the edges of terraces instead of pure stands in the main body of the plot. However the bulk of home-grown forages will emanate (seasonally) from crop residues. It is assumed then that for the greater part of the year the bulk of forage will be sourced from common property land such as roadsides. The extent to which access to this source of forage will remain a "common property" given the great demand on this biomass remains to be seen. It is possible to envisage a scenario where loss of access to these common feed resources threatens the existence of the livestock enterprise on the smallest farms and thereby undermines the viability of the farm-based livelihoods of the poor.

It is clear that for poor households purchasing very limited quantities of fertiliser the livestock enterprise is the main conduit for importation of crop nutrients onto the farm in the form of purchased concentrates and forage. The exercise performed during the meeting showed that by maintaining two cows and purchasing minimal quantities of fertiliser the nutrient requirements of a ½ acre intensively managed farm can just be met as long as total collection of cattle faeces is possible.

Conclusion

It is evident that an intensive dairy enterprise is considered to offer more than medium-term financial viability to small farms. The presence of cattle underpins strategies for the sustainable intensification of smallholdings. Cattle permanently confined to kraals are the primary conduits for the importation of nutrients on to farms and accelerate the breakdown of more recalcitrant plant biomass through trampling.

It would be erroneous to conclude that as long as cattle are present on smallholdings acting as "biomass processers" then the biological sustainability of these particular smallholder farming systems is ensured. Clearly this can occur when the nutrient inter-relations between crops and livestock are operating as effectively as possible and as long as the farm has the number of animals to supply sufficient manure. To be confident of the former requires the examination of nutrient flows into and between farm enterprises whilst the latter depends upon the financial and labour endowment of the household.

The challenge to research arises in recognition that as farm sizes decrease and poverty levels rise this may lead to a decline in the number of cattle per holding. Thus, there is an urgent need to continue research into improving the management of the confined animal as a conduit for nutrients. The objective being to develop strategies to maximize the quantity and quality of manure-based organic fertiliser emerging from the animal unit.

Structured Survey 1: *Manure management in the Kenya Highlands: a survey of practices and potential*

Household characteristics All sample households in Murang'a District were headed by males with an average age of 50 years (range: 30–70) and with 30 years farming experience (range: 4–60). Farm sizes in the district ranged from 0.4 to 12.5 ha with an average size of 1.8 ha. Thirty-three percent of farms were less than 1 ha. Twenty-five percent of households in Kiambi District were female headed with an average an average age of 53 (range: 30–80) with 28 years of farming experience (range: 2–60). Farm size averaged 1.4 ha (range: 0.1-4.3 ha). Fifty-two percent of farms were less than 1 ha. These findings agree with those of Staal *et al* (1997) who found that 28% of households in Kiambu were female headed and mean land holding in the district was 1.1 ha.

Average household size for the sample was 7 individuals which is close to the 6.2 persons per household found by Staal *et al* (1997) from a survey of households in Kiambu District. Household size was independent of farm size, as categorised in 3.2 below. Small farms had a mean of 7 persons per farm (range 3-15); medium farms 6.4 persons per farm (range 1-7); and large farms 7.7 persons per farm (range 2-17). This resulted in highly significant ($p<0.001$) differences in mean farm population density between farm sizes (small farms 18 persons/ha; medium farms 6 persons/ha; large farms 3 persons/ha). The very high farm population density on small farms does not represent a 'carrying capacity', since it is not known what proportion of income in any of the farm size categories is derived from off-farm activities, but does not indicate the incentive for highly intensive management of natural resources on these farms to maximise both food production and income generation.

Categorisation of farms In the tables below, farms are disaggregated according to size (Table 6). This has been done because the central hypothesis of this study is that as farm size decreases so the intensity of cropping will increase as farmers strive to maintain crop outputs to meet basic family food needs. The level of cropping intensity and hence nutrient extraction will be a major influence on farmer decision- making with respect to soil nutrient management, particularly use of manures. Cropping intensity is defined as total cropped area /year/ total cultivated area (Byerlee, 1990).

Table 6. Division of farms into land classes

Farm size	n*	Mean land area (ha)	s.d.	Range (ha)
Small	14	0.45	0.15	0.1-0.6
Medium	22	1.08	0.31	0.7-1.8
Large	21	2.82	0.99	2.0-5.2

**Three farms were removed from the dataset, one because of an abnormally large landholding (12.5 ha) and two because of unusually large small ruminant numbers per farm (> 50 head).*

Crop production

All farms grow a mixture of food crops. Higher altitude farms in the sample grow coffee as a cash crop. Vegetables such as potatoes (*Solanum* and *Ipomea*), kales, french beans, tomatoes, citrus fruit and bananas are grown partly for home consumption and partly for sale. Maize and beans (*Phaseolus*) are grown ostensibly for home consumption (sometimes as an intercrop) although, depending on market access, some of the maize crop is harvested at the dough stage and sold for roadside roasting.

Maize: Maize is a staple crop grown by almost all households (Table 7). Small farms sowed the largest proportion of land to maize in the long rains of 1996 and also obtained the highest yields. The yields obtained, based on farmer recall, were low but around the average of 1.7 t/ha reported by Karanja et al (1997) from a survey of 190 farms in the Central Kenya Highlands. Whether the maize was grown as a sole or intercrop was not recorded in the present survey. The proportion of land sown to maize in the current survey is similar to those found on other farms in Kiambu growing no perennial crops (tea or coffee) (Staal et al, 1997).

Beans: Small farms sow the largest proportion of their farm to beans but fewer small farms than medium and large producers grow beans (Table 8). This may reflect the need during this drought year to re-plant sole maize crops on smaller farms to reduce purchases of this expensive grain (Dr J. Chui, KARI NARC Muguga. pers. comm, 1998). Yields did not differ between farms of varying size.

Table 7. Cultivation of maize in long rains of 1996 (April – August)

Farm size	Percentage of farms growing maize	Percentage of farm sown to maize	Mean yield (t/ha (range))
Small	93	38	2.1 (0.4 – 5.8)
Medium	100	27	2.0 (0.6 – 4.5)
Large	90	20	1.6 (0.2 – 4.2)

Table 8. Cultivation of beans in the short rains of 1996 (October – November)

Farm size	Percentage of farms growing beans	Percentage of farm sown to beans	Mean yield (t/ha (range))
Small	0.78	0.24	0.9 (0.07 – 1.8)
Medium	0.91	0.20	0.7 (0.1 – 1.8)
Large	0.86	0.15	0.9 (0.1 – 3.6)

Table 9. Cultivation of potatoes (Solanum) in the long rains of 1996

Farm size	Percentage of farms growing potatoes	Percentage of farm sown to potatoes	Mean yield (t/ha (range))
Small	0.50	0.13	25 (8 – 48)
Medium	0.68	0.15	13 (2 – 40)
Large	0.67	0.09	25 (4 – 56)

Potatoes: Potatoes (*Solanum*) are cultivated by over 50% of the farms in each category of farm size (Table 9). Large farms allocate the lowest proportion of land to the cultivation of potatoes.

Napier grass: Napier grass (*Pennisetum purpureum*) is a planted forage used by farmers to feed dairy cows. It is also an effective means of controlling soil erosion when planted in rows along contours. Napier is present on 64, 73 and 43% of small, medium and large farms and occupies 27, 28 and 21% of the farm area respectively. This is higher than the average of 14% (range: 4-23%) for Kiambu farms reported by Staal et al (1997). Yields of Napier were not reliably obtained from the present survey. Other survey work in the districts has shown, however, that yields are less than 10 t DM/ha/yr (D. M. Mwangi, KARI Muguga. pers. comm, 1998).

Bananas: Approximately half of the farmers in each category grow bananas (Table 10). Small farmers only allocate 11% of their farm to growing bananas. This reflects the normal cultural practice of growing bananas along field boundaries and around the homestead/cattle shed. On small farms this amounts to a very limited area. Despite this, yields/ha are twice those of the bigger farms at 5.2 t/ha (banana bunch weight about 25 kg - Muriithi, 1996).

Coffee: Coffee was present on 28, 41 and 33% of small, medium and large farms respectively, mainly those between an altitude of 1500 and 1700 m.a.s.l. Farms of increasing size in the coffee zone plant 42, 37 and 20% of the farm area to the crop, figures that lie near the 36% reported for coffee farms in Kiambu by Staal et al (1997). The present survey did not adequately capture the yield of coffee in 1996.

Vegetables: The main vegetable types: sweet potatoes, kales, carrots, cabbages and french beans are grown in various combinations on 43–45% of all farms (Table 11). Small areas are allocated to the crops, usually next to the homestead. The crops are grown mainly for home consumption with any surpluses for sale. Owing to the diversity of products in this category yield weights were not captured in the survey.

Table 10. Yield of bananas in 1996

Farm size	Percentage of farms growing bananas	Percentage of farm sown to bananas	Mean yield (t/ha (range))
Small	50	11	5.2 (4.5-6.0)
Medium	50	19	2.2 (1.0-3.0)
Large	57	13	2.3 (0.7-6.0)

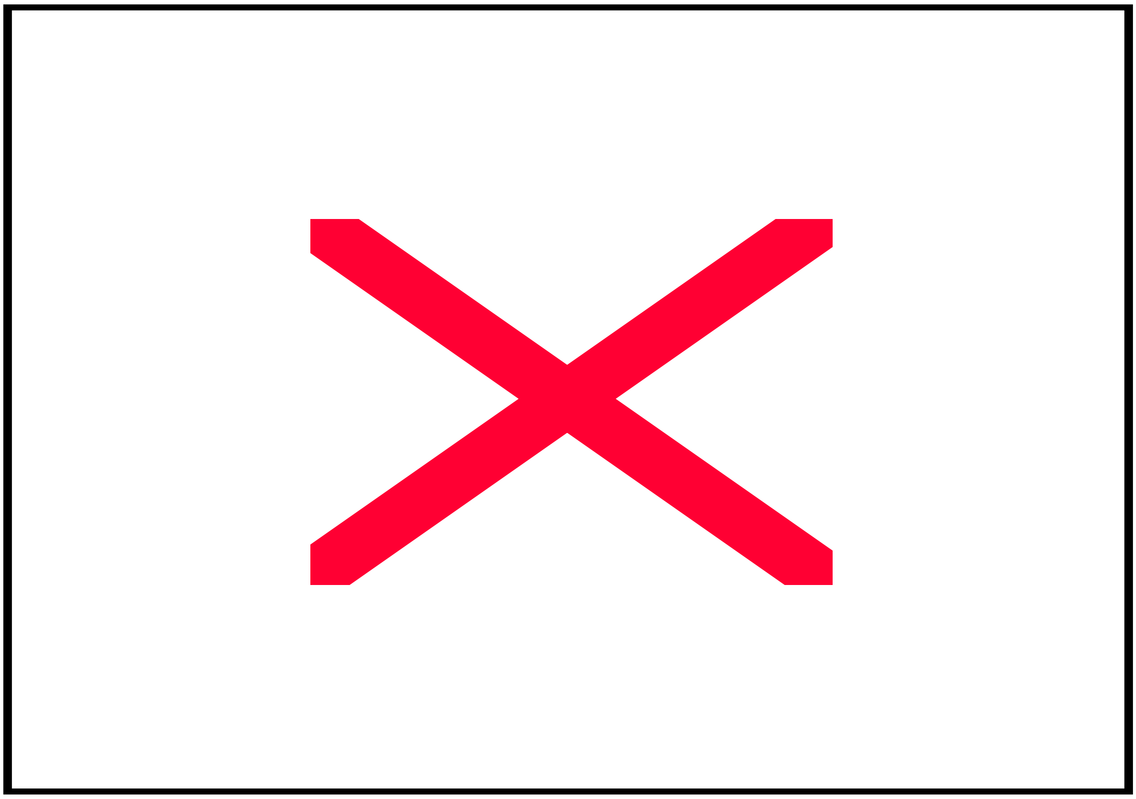
Table 11. Cultivation of vegetables in 1996

Farm size	Percentage of farms growing vegetables	Percentage of farm sown to vegetables
Small	43	11
Medium	45	17
Large	43	8

Livestock production

Dairy cows were owned by all households in the survey since this was one of the criteria for inclusion in the sample (Figure 3). Local dairy genotypes were owned by 27 and 10% of farmers in Murang'a and Kiambu respectively. The most common exotic dairy breeds are Friesian, Ayrshire and Guernsey. All dairy cows on farms in the sample are kept in permanent confinement and fed by cut-and-carry. Replacement dairy stock; heifers and immatures, were owned byaround only half of the households.Local poultry are owned by 70 to 80% of all households in the survey in flocks numbering from 1 to 10 birds. Goats are more frequently owned than sheep and small ruminant ownership tends to be a feature of larger farms. Sheep, bulls, pigs, broilers and layers are the least frequently owned livestock categories. Broilers are kept in large numbers by only a few producers.

Figure 6. Percentage of farms of different size owning livestock categories



Herd/flock size by farm size: Table 12 shows that average cow herd size increases between small farms and large farms by a multiple of 1.7, although considerable variation within categories occurred. The biggest herd of cows in each of the farm categories was; small 4, medium 6 and large 25. The average cow herd size did not increase in proportion to the increase in farm size. There is clearly not a simple relationship between land holding and cattle herd size. This is explained below.

Bulls are a more significant feature of larger farms. Ownership of heifers, immatures (including calves) and goats did not differ significantly between categories of farm. Sheep, layers, broilers and pigs were owned by not more than one third of households in each category. However, these households tend to own large numbers of these stock.

Staal *et al* ‘s (1997) study of cattle owning households in Kiambu report that households in Kiambu District had on average 0.2 bulls, 1.5 cows, 0.7 heifers and 3.0 calves. These figures only contrast with the present study for heifer and calf (immature) numbers.

Table 12. Average livestock numbers and farm size

Farm size	Livestock type									
	Bull	Cow	Heifer	Immatures	Goat	Sheep	Layer	Broiler	Local hen	Pig
Small	0.0	1.9	1.2	1.5	1.3	0.2	48.0*	24*	5.0	1.4
Medium	0.2	2.2	1.1	2.3	1.2	1.1	55.0*	14*	14	5.0*
Large	0.6	3.2	1.6	1.2	1.7	2.9	76.0*	0.0	12	1.2

** Data influenced by a few larger producers of pigs and poultry.*

Ranking the uses of livestock products on farms.

Only cattle and goat products are considered in this section because these livestock species occurred on the majority of farms in both Districts. Free-range local poultry, although also owned by a large proportion of farms and therefore, through sales, making an important contribution to livelihoods, were not considered because they would not contribute to manageable manure production. Broiler/layer units and pigs produce larger quantities of manure, of high quality, but ownership is limited to few farms. Owing to skewed ownership, these livestock categories are also excluded from the following analysis.

Farmers, including those not keeping that category of livestock, were asked to rank products from 1 (high value) to 5 (no value) and a mean taken of the total scores in each farm size class.

Cattle products: Results indicate that milk and manure are almost equally ranked on small farms (Table 13). Calves are ranked lower than these products on all farms. Meat was not mentioned as an important output from the dairy enterprise.

Use of cattle products: Only 14% of small farmers produce milk solely for home consumption. Over 50% sell part or all of the milk. Thirty-six percent of households did not respond to this question.

Milk solely for home consumption is produced by only 10% of medium households. Almost 60% produce milk exclusively for sale.

Fourteen percent of large farms produce milk solely for home consumption whilst 43% produce milk for sale only.

Sixty-seven percent of farms in each category were using their own cattle manure for crop production. Thirty-three percent did not respond to this question. No farms, small, medium or large, reported sale of manure.

The immediate fate of calves on over half of small farms was sale.

Only 6% of medium scale farmers said that they would keep home produced calves as dairy replacements or fatten them for beef.

Two thirds of large farms said the calves produced were sold soon after birth. Only 13% said they would rear the calves as dairy replacements or for beef.

Table 13. Ranking of cattle products (1=high, 5=low)

Farm size	Cattle products		
	Milk	Manure	Offspring
Small	1.4	1.6	3.6
Medium	1.5	1.9	3.4
Large	1.6	2.0	3.4

Goat products: Consumption of goat milk was not reported by any of the households and so received a low ranking by respondents (Table 14). Offspring received an equal and low ranking by all categories of farm. The products valued marginally higher were manure (by large and medium farms) and meat (by large farms).

Uses of goat products: Goat products generally received low ranking by all farmers but with manure being the most useful product for medium and large farmers. This may reflect that few goat products are actually consumed on farm, it being more likely that they are sold in times of need. Conceptually then, the goat itself is valued as a capital asset rather than for any one product *per se*. However, if this is the case it is unclear why kids are not ranked more highly in the ranking of goat products in Table 10. For this reason it was decided not to detail any uses of goat products.

The relationship between ruminant livestock numbers and farm size

This relationship was investigated for two reasons: (1) it is hypothesised that the limit on stock numbers may be dictated by land available to grow forage (Napier and crop residues) and (2), the density of ruminant livestock will indicate the availability of manure per hectare. If the former hypothesis is true then livestock density should be similar across farm size or possibly decrease on smaller farms as limited available land is preferentially used for food production.

A significant positive linear relationship (R^2 = 0.15, p = 0.003) was found between land holding and the density of sheep and goats indicating that larger farms had a higher density of sheep and goats per hectare than small farms (Figure 7). However, there was a strong negative relationship (R^2 = 0.176, $p < 0.001$) between land holding and cattle density (Figure 8), which was better described by a logarithmic (R^2 = 0.36) than by a linear equation. Similarly, there was a significant negative relationship between land holding and total ruminant density (R^2 = 0.16, p = 0.001), again better described by a logarithmic equation (R^2 = 0.28) (Figure 9). Thus, the density of cattle and, as a result, also of total ruminants was higher on small farms. This suggests that livestock numbers, especially cattle holdings, are apparently not constrained by farm size and indicated greater manuring potential for the smaller farms.

Table 14. Ranking of goat products (1=high, 5=low)

Farm size	Goat products			
	Milk	Meat	Manure	Kids
Small	5.0	4.8	4.5	4.4
Medium	4.8	4.1	3.7	4.4
Large	4.9	3.9	3.7	4.4

Figure 7. The relationship between land holding and sheep/goat density

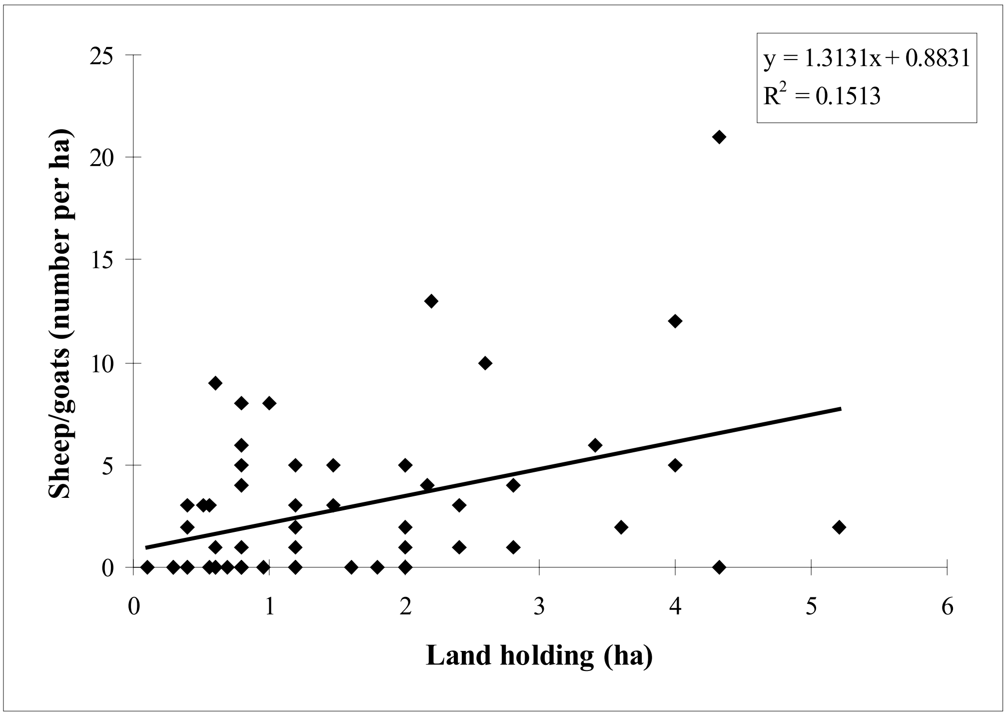


Figure 8. The relationship between land holding and cattle density

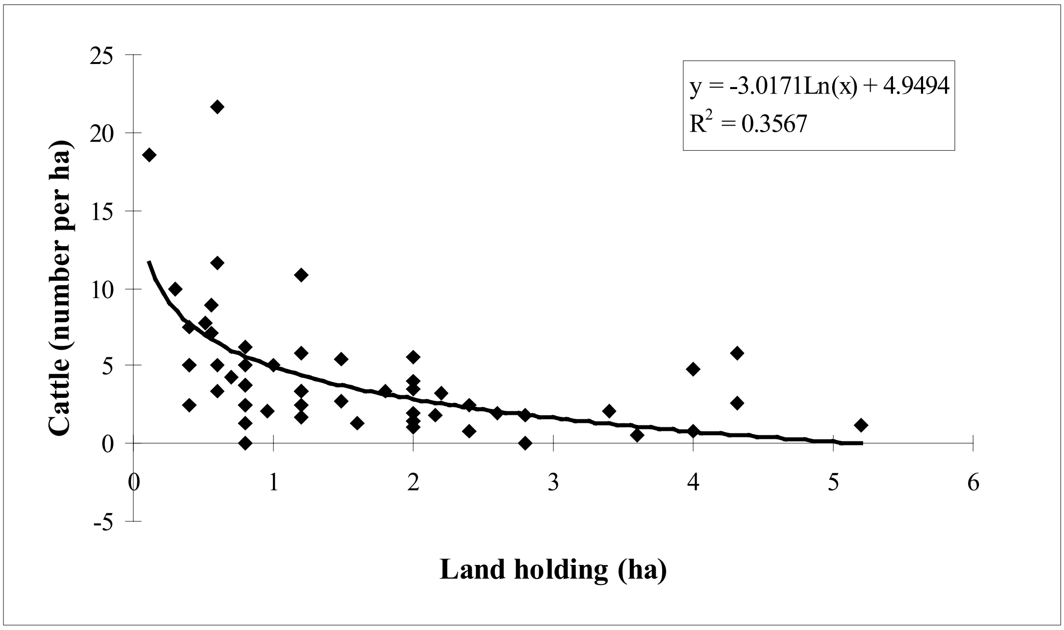
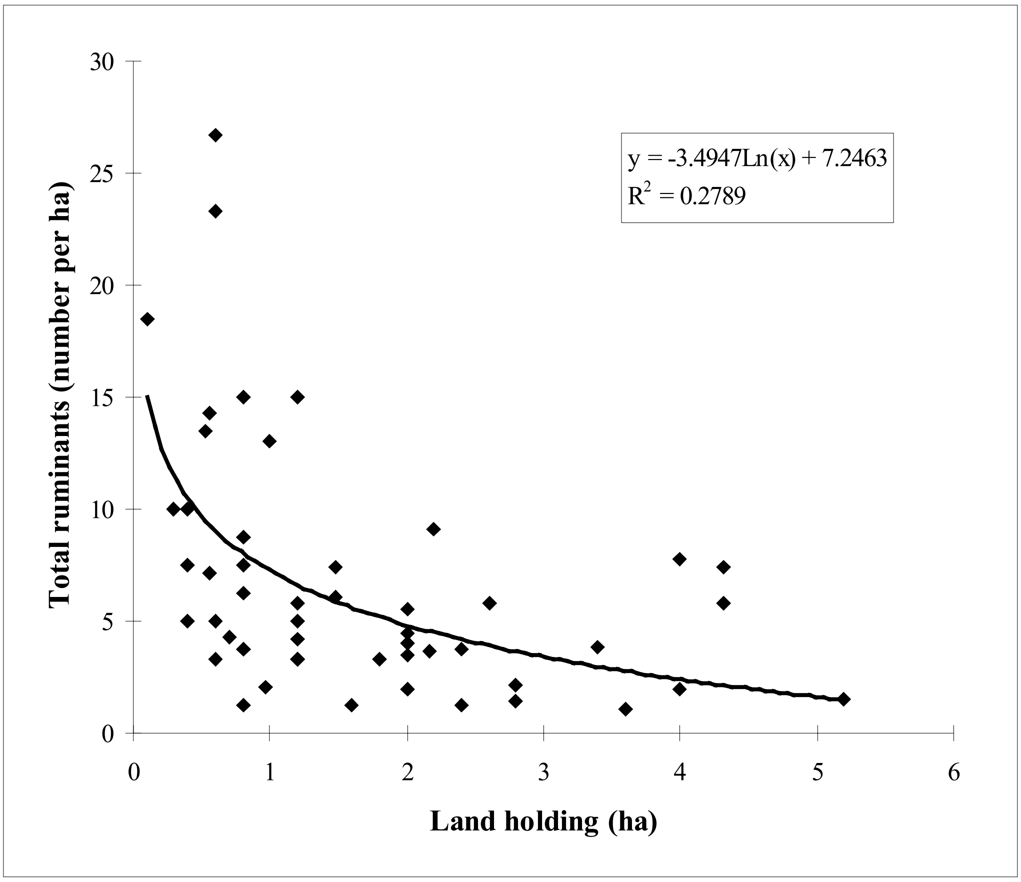


Figure 9. The relationship between land holding and total ruminant density



Factors affecting manure production

The greatest manure producing potential obviously emanates from owning the largest livestock species, cattle. All farms in the sample owned cattle. More importantly, all farms in the sample reported keeping cattle in permanent confinement throughout the year allowing, therefore, maximum opportunity for manure collection. The completeness of manure collection depends very much upon the way in which livestock are housed and the type of feeding they receive.

The following sections examine cattle housing, feeding, manure management practices and strategies to enhance the quantity and quality of manure produced on small, medium and large farms..

Cattle housing: Fifty seven, 68 and 71% of large, medium and small farms kept cattle in 'zero grazing' units. These are pens featuring distinct lying and standing areas for cattle with partial or complete roofing, feeding and water troughs. The rest of the farmers in each class kept cattle in traditional 'bomas'. These are pens with soil floors where litter (bedding and feed refusals) is allowed to accumulate across the whole floor area. They may be roofed, with feeding and watering facilities. All cattle in the two districts are kept in permanent confinement throughout the year.

Around 70% of all farms in each category with zero grazing units had concrete floors with good drainage. Those with soil floors in zero grazing units or traditional bomas reported poor drainage.

Feeding strategies for cattle

On small farms: Most farms indicated a fodder shortage in the long dry season (Table 15). No farms had access to grazing. So to compensate, 36% of farmers purchased fodder during the long dry season. Fifty percent of farmers did not report any forage compensation strategy.

Eighty percent of farms obtain some fodder from their own land all year (Napier and crop residues) and the same proportion used concentrates (dairy meal, maize germ, brans, wheat pollard) all year. Twenty-eight percent feed purchased poultry waste all year and all those that have larger poultry units (21%) feed the waste.

On medium farms: Seventy percent of farms experienced a long dry season feed shortage. No farms used grazing. Ninety percent of farms use home produced fodder all year but only 28% of all farms purchase fodder in an attempt to alleviate long dry season forage shortages. Eighty-six percent of farmers use concentrates all year. Twenty percent of farms purchase poultry waste to feed all year in combination with concentrates and the same proportion feed their home-produced poultry litter, again in combination with concentrates.

On large farms sixty-seven percent of farms experienced a shortage of feed during the dry season. All farms stall-feed year-round with only 10% of farms employing roadside grazing in addition to this. All farms, except one, used their own land as a source of cut fodder, this one farm routinely purchased fodder. Sixty-two percent fed concentrated feeds all year but 20% only used concentrates in the dry seasons. The rest (18%) did not use concentrates. Twenty percent of farms fed purchased poultry manure routinely throughout the year, 14% fed home produced poultry manure. All fed poultry waste in combination with concentrates.

Manure management

Manure collection: Few small farms actually report collecting cattle faeces, only (14%) compared with 40 and 45% respectively of medium and large farms (Table 16). Small farms are more likely to add feed refusals to the heap/pit and, together with medium farms, are more likely to purposefully collect foliage/litter from on or off the farm (eg *Grevillia* or *Eucalyptus* foliage) to add to the manure heap. Very few farms drain urine into a purpose-built collection sump. Most channel liquid draining from the animal pen directly to the base of the manure heap. Twenty percent of small farmers clean the cattle pen every day and store the manure. All other farmers clean less frequently.

Table 15. Cattle feeding strategies (% of households)

Farm size	Experience dry season fodder shortage	Use grazing	Use own land as source of fodder all year	Purchase fodder in dry season	Use concentrates all year	Use purchased poultry waste all year	Use own poultry waste all year
Small	80	0	80	36	80	28	21
Medium	70	0	90	28	86	20	20
Large	67	10	95	5	62	20	14

It appears, therefore, that a greater proportion of small farmers are attempting to maximise manure production by adding biomass to the manure heaps/pits and to reduce manure loss. Some are cleaning the pen on a daily basis. Fifty to 73% of farmers simply drained urine into the manure heap/pit as their means of urine collection. This may not be the most effective technique for urinary nutrient collection. However, only a few farmers employed the potentially better technique of collecting urine in a drainage sump and then transferring it directly to crops.

Manure management techniques: Having collected manure, around one third of small and medium farmers afforded no further management to the pit or heap (Table 17). Only a quarter of larger farms did not manage the manure further. Four distinct management strategies were identified; covering, turning, adding ash or adding water. Only the small and medium farmers practiced single strategies, the most notable being covering, by one third of small households. Seventy-five percent of large farms employed combined techniques.

Table 16. Cattle manure collection strategies (% of households)

Farm size	Collect faeces only	Add feed refusals to manure heap	Add collected foliage/ litter	Purpose-fully collect urine	Drain urine directly into manure heap	Clean animal pen every day	Clean animal pen less frequently	Take solid waste directly to field each day
Small	14	54	21	7	73	20	80	0
Medium	40	25	35	9	50	0	100	0
Large	45	33	14	5	50	0	94	6

The majority of farmers in each category saw that there was benefit to be gained from 'managing' the manure heap. For smaller farms, covering was the single most important technique, presumably because this required low inputs of limited labour resources. Seventy-five percent of large farms used two or more of the four techniques listed. Large farms tend to be better resource-endowed with greater access to labour for manure turning or can afford to divert water from essential domestic/livestock uses to improving manure (Table 17).

Covering manure heaps/pits is a less labour intensive technique than turning to physically manage the manure, and a technique which could therefore be promoted if shown to improve manure quality. All farmers were asked why it was important to cover manure. Small farmers said that covering would speed decomposition and conserve nutrient status. Speeding decomposition was the only reason given by medium farms whereas a range of reasons and multiple reasons were given by large farmers the most important of which was to stop evaporation of water (Table 18).

Storage periods are short on small farms but longer on larger farms. This may indicate the intensity of manure use on small farms but could also be a factor of limited storage space and/or proximity to land requiring manure on small farms.

Manure quality: Table 19 shows the summary analysis of manure samples collected from farms during the survey. From the standard deviation and ranges given it can be seen that very considerable variation in the content of the major nutrients occurred among manure samples of the same type as well as between types. Large variations in nutrient contents among manure samples are not unexpected and have been reported previously for large scale surveys of manure quality in temperate farming systems (Dewes & Hünsche, 1998). To explore this further, farmers perceptions' of manure quality and their views on how to increase manure quantity and quality were recorded.

Table 17. Manure handling techniques (% of households)

Farm size	Non managed heap/pit	Covered heap/pit	Turned heap	Added ash	Added water	Employed two or more techniques
Small	30	33	14	0	0	17
Medium	36	9	9	5	5	36
Large	25	*	*	*	*	75

Table 18. Manure storage (% of households)

Farm size	Why do you cover manure?				How long do you store? (months)		
	Speed decomposition	Conserve/ improve nutrient status	Stop evaporation of moisture	Prevent excessive wetting	0-2	3-6	>6
Small	60	36	28	7	65	1	-
Medium	55	-	-	-	67	33	-
Large	33	33	52	24	20	50	30

Table 19. Mean, (s.d.) and range of N, P, K and C content and C:N ratio of collected manures.

Manure type	n	N (%)	P (%)	K (%)	C (%)	C:N ratio
Cattle	55	1.4 (0.35) 0.5-2.0	0.60 (0.34) 0.19-1.61	0.59 (0.28) 0.02-1.21	35 (8.8) 17-52	26 (8.4) 17-56
Cattle + compost	10	1.3 (0.46) 0.8-2.1	0.44 (0.21) 0.21-0.90	0.36 (0.23) 0.02-0.74	25 (5.6) 18-35	21 (5.6) 11-30
Cattle + goat	1	1.3	0.29	0.51	27	20
Cattle: dung + urine	3	1.5 (0.22) 1.2-1.7	0.65 (0.36) 0.30-1.01	0.39 (0.12) 0.25-0.46	35 (6.5) 29-42	24 (0.78) 23-25
Cattle: fresh dung	2	1.5 (0.36) 1.2-1.8	0.54 (0.28) 0.35-0.74	0.64 (0.01) 0.63-0.65	39 (11) 32-47	26 (0.98) 25-27
Cattle: slurry	2	1.3 (0.40) 1.0-1.6	0.36 (0.04) 0.33-0.39	0.14 (0.17) 0.02-0.26	34 (14) 24-44	25 (2.8) 23-27
Goat	9	1.5 (0.51) 0.9-2.3	0.40 (0.19) 0.18-0.83	0.53 (0.17) 0.30-0.83	32 (9.3) 20-46	22 (3.4) 15-26
Goat + chicken	2	0.9 (0.10) 0.8-0.9	0.24 (0.06) 0.20-0.29	0.23 (0.07) 0.18-0.28	18 (0.4) 17-18	21 (2.0) 19-22
Goat + sheep	1	0.9	0.74	0.40	27	32
Pig	8	2.0 (0.23) 1.5-2.2	1.19 (0.44) 0.74-1.82	0.49 (0.11) 0.35-0.69	40 (8.0) 24-48	21 (3.5) 16-27
Poultry: broiler	2	2.4 (0.21) 2.3-2.6	1.60 (0.18) 1.50-1.75	0.41 (0.01) 0.40-0.42	41 (7.1) 36-46	17 (1.5) 16-18
Poultry: layers	8	1.8 (0.47) 0.9-2.4	1.27 (0.44) 0.29-1.73	0.37 (0.10) 0.26-0.56	41(6.7) 28-48	23 (5.6) 16-33
Poultry: local	1	1.2	0.91	0.26	22	19
Rabbit	4	1.6 (0.33) 1.2-1.9	0.40 (0.11) 0.29-0.55	0.50 (0.21) 0.23-0.76	33 (11) 28-48	20 (5.1) 14-27
Sheep	1	1.5	0.33	0.44	33	22

Are there differences in the quality of manures?
Around 80% of small and medium farmers said that there were differences between manures in their quality as soil amendments. Differences in manure quality were reported to occur between different livestock species and also as a result of different management techniques. Only 40% of larger farms said a difference could be detected.

Fifty percent of small farmers ranked cattle manure as "best". Medium farmers ranked poultry manure as best whereas larger farmers were undecided which was best out of cattle, sheep/goat, poultry and pig manures. The criteria used for ranking were a combination of quality factors combined with the quantities that could be produced from each species.

What makes manure from one livestock species better than from others?
Few farmers could answer this question. Of the four small farmers who answered, three commented on the residual fertility effects of cattle manure on soils and one said it gave her good effects on soil fertility. One medium and one large farmer said cattle manure gave the best residual effects and two large farmers said it was good because large quantities could be produced.

No small farmers had experience of using poultry manure as fertiliser but six medium and two large farmers commented that it should have an "instant" soil fertility effect. This confirms the view of farmers reported in Harris *et al* (1997). Nobody could comment on what the benefits were to using small ruminant manure.

How do you know what a good manure looks like?
Thirty percent, 20% and 50% of farmers in the large, medium and small categories respectively said a good manure is one that is "fully decomposed". The remainder (ie the majority of farmers) said that the quality of the manure could only be known by applying it to a crop.

How could you increase the quantity of the manure that you produce?
Eighty percent of small farmers said that the way to increase the quantity of manure produced was to increase the use of crop residues, particularly maize stover, as fodder and bedding. Seventy percent and 60% of medium and large farmers agreed that this was the best strategy. However, of the remaining 40% of larger farmers, half said they would offer larger quantities of a variety of feeds to their cattle and the other half said they would simply buy more cattle.

Almost all of the small farms (86%) and 55–60% of large and medium farms respectively reported using bedding for their cattle. All used fodder refusals as bedding, especially rejected maize stover, except one quarter of small farms and 40% of large farms that used sawdust from local saw mills as the main bedding type.

How to increase the quality of the manure that is produced?
By feeding: Twenty-five percent of small farmers and 30% of large farmers thought that it was possible to improve manure quality by providing better feeds to livestock (note that most farmers fed concentrates).

By capturing urine: Sixty, 50 and 40% of small, medium and large farmers respectively said that the capture of urine was important to overall manure quality. Specifically, it assists in the decomposition of the waste heap said 43, 27 and 14% of the same farmers. Only 10% of medium farmers recognised urine as a source of plant nutrients. The rest were not aware of its influence on the nutrient content of manure.

By mixing manures: Eighty, 40 and 50% of small, medium and large farmers said that they thought mixing cattle manure with manure from other species, particularly poultry, would be beneficial to overall quality.

By composting: Thirty percent and 20% of small and medium farmers said that longer composting periods would improve quality.

By storing in a covered pit: Thirty-six percent and 20% of small and large farmers said that storing in a covered pit would enhance manure quality.

By adding ash and inorganic fertiliser: This would improve manure quality said 30% of medium farmers.

By adding green biomass: Said 14% of large farmers.

By collecting and storing faeces alone: Said 20% of large farmers.

By roofing the whole cattle pen: Thirty percent of farmers in each category said that this was good idea. These farmers were actually practising complete roofing.

All farmers in the small and medium categories could suggest one or several strategies to raise manure quality. However, just over 20% of large farmers declared that they had no idea how improvements in quality might be attained.

The findings reported here do not necessarily agree with those in Tables 17 and 18. Farmers demonstrated an understanding that management could affect manure quality but this does not mean that they necessarily employ these techniques.

Factors influencing manure quality: A statistical analysis of variance was carried out to examine ten factors which were considered by farmers/researchers to influence the quality of the cattle manure (N, P and organic C) which was sampled during the survey.
Whether the farmer:

Fed concentrates
Had a zero grazing unit or a traditional boma
Had a concrete or a soil floor
Had an animal unit with a sloping floor (ie collecting urine effectively)
Had a completely covered animal unit
Stored the manure in the open
Shaded the manure heap
Covered the manure heap
Turned the manure heap regularly
Composted the cow manure with other materials

Nitrogen: Factors which significantly increased N concentration were feeding of concentrates (1.4% versus 1.2%, p = 0.042, n = 12, 43); zero grazing unit rather than a traditional boma (1.4% versus 1.2%, p = 0.043, n = 36,11); concrete rather than soil floor (1.5% versus 1.3%, p = 0.024, n = 27, 20). Regular turning reduced the N content (1.2% versus 1.4%, p = 0.021, n = 35, 14).

Phosphorus: The phosphorus concentration of cattle manure was significantly increased by feeding of concentrates (0.64% versus 0.43%, p = 0.041, n= 43, 11); concrete rather than soil floor (0.71% versus 0.42%, p = 0.002, n = 27, 19). The phosphorus concentration was significantly reduced by covering the heap (0.42% versus 0.68%, p = 0.009, n = 15, 33).

Organic Carbon: The organic carbon concentration of the manure was significantly increased by feeding concentrates (36% versus 31%, p = 0.041, n = 43, 12); concrete rather than soil floor (38% versus 30%, p = 0.0004, n = 27, 20); shading the heap (36% versus 29%, p = 0.022, n = 8, 41); and covering the heap (39% versus 33%, p = 0.016, n= 15, 34).

Estimated quantities of manure produced in 1996

Farmers were asked to estimate yearly production of manure from their ruminant stock using local units of measure (sacks, pick-up truckloads, 7 t truckloads etc) which had been calibrated by Muriithi (1996). In parallel, an estimate was made of ruminant faecal production theoretically possible from the livestock present on farm (Table 20).

Table 20. Ruminant holdings on farms of varying size and estimated annual production of faeces/ha

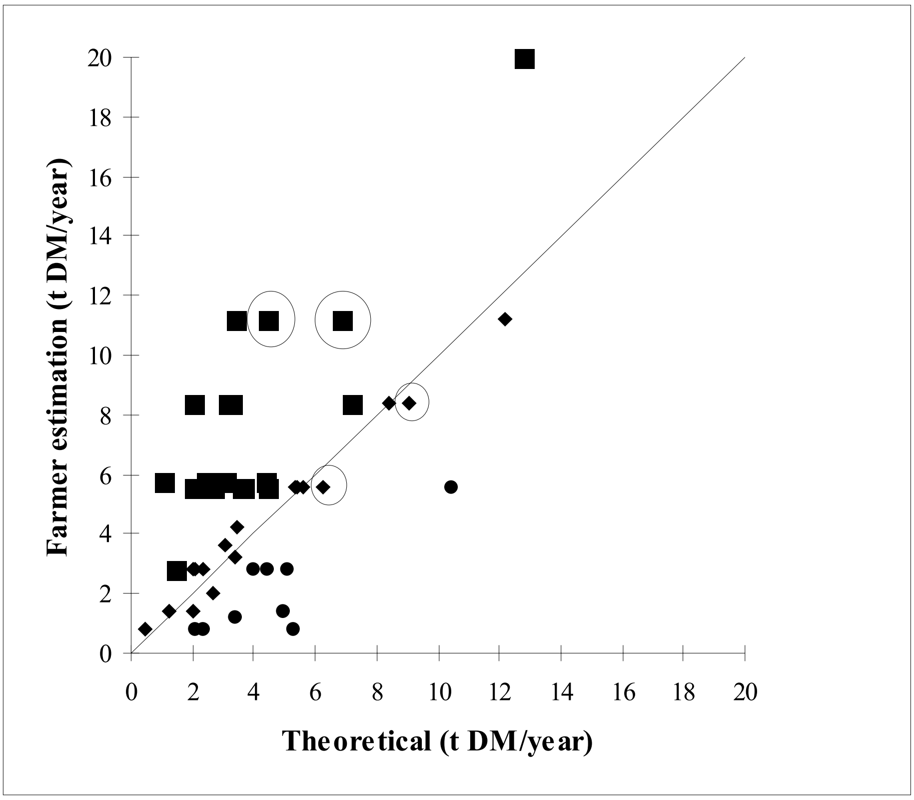
Farm size*	Mean (and range of) ruminant livestock numbers			Mean (and range of) estimated production of faeces (t DM/ha/yr)
	Large cattle	Small cattle	Small ruminants	
Small	3.1 (1-9)	1.5 (0-9)	1.5 (0-9)	8.2 (3.1-18.9)
Medium	3.5 (1-11)	2.3 (0-8)	2.3 (0-8)	3.6 (0.5-10.2)
Large	5.4 (0-20)	1.2 (0-5)	4.6 (0-21)	2.2 (0.1-5.1)

*Three farms were removed from sample, one with large land holding and two others with very high small ruminant numbers on limited land.

The generally accepted figure that a ruminant produces 0.8% of its liveweight as faecal dry matter (DM) in a day (Fernandez-Rivera *et al*, 1995, confirmed for the Kenya Highlands by Delve, unpublished data, 1998; Lekasi, unpublished data, 1998) was used to calculate faecal DM output. It was assumed that the DM of cattle faeces is 40% and that of small ruminants 50%, average figures derived from measurements taken from ruminant manure sampled during the survey Appendix 3.

Figure 10 shows how farmer estimations of manure production compared with theoretical values of faecal output based on the liveweight and number of animals present on the farm at the time of the interview.

Figure 10. Relationship between theoretical annual ruminant faecal production levels on farms compared to farmers' estimations of annual manure DM yields



See text immediately below for key to symbols

Forty-five farmers estimated yearly manure production (1996) from cattle, sheep and goats. Seventeen farms lay above the line x=y (marked), where theoretical manure waste production is less than that estimated by the farmer (large squares), 9 farms below, where theoretical manure production is greater than the farmers' estimate (large circles) and 19 close to the line, where theoretical manure production matched the farmers' estimates (small diamonds).

The reason why some theoretical values are lower than the farmers' estimate may be because the calculation does not take into account the unknown quantities of additional organic amendments added to the manure heap. For example, the two farms circled (large squares) reportedly added feed refusals and weeds to their heaps, whereas the two farms (small diamonds) circled near the line x=y collected only faeces in the manure heap. Theoretical values higher than farmers' estimates could be due *inter alia* to changes in herd size over 1996, rapid dry matter loss from the manure heap during decomposition, loss of manure or inaccurate assessment of manure production by the interviewee.

On only 20% of the farms was manure production overestimated by the theoretical calculation. It is more likely therefore that manure production would be underestimated or predicted correctly. For this reason it was decided that the total ruminant livestock liveweight present on farm could be used as a valid predictor of total yearly manure output (faeces only).

Maximum theoretical production of manure (faeces only): In Table 12, the average ruminant herd in each farm category has been divided into large cattle (bulls, cows and heifers) and small cattle (immatures and calves). Liveweights for large cattle were arbitrarily taken as 350 kg M, small cattle 100 kg M and sheep/goats as 25 kg (B. Lukuyu, KARI Muguga pers.

comm). It is assumed that ruminants produce 0.8% of their liveweight as faecal DM daily (see above).

Table 20 (above) shows that small farms have the greatest faeces availability per hectare with approximately twice and four times that available on medium and large farms respectively. This calculation of course assumes no DM losses during storage. The extent of DM loss is currently under investigation.

Evidence reported above suggests that the small cattle population on the farm is transient over the year because of frequent sales and purchases. Small ruminants are more likely to be fed through grazing. Thus, estimating the year-long contribution of manure from these animals as if they were stall-fed may be incorrect. It is worth noting however that the contribution made to total faecal DM production by the ‘less mobile’, large cattle, population is between 81 and 89% across the three categories of farm.

Nutrients potentially available in faeces and urine produced on farms

The survey sampled stored manure on all farms and found the average N content of cattle manure to be 14 g/kg DM. Small ruminant manure was measured to contain 15 g/kg N (Table 19). For the following calculation, since cattle are the largest and predominant livestock on farms, it is assumed that manure N content was 14 g/kg N. Phosphorus content of stored manure was also analysed and was estimated to be 5 g/kg DM.

Lekasi (unpublished data, 1998) estimated that steers produce 25 g urine/kg liveweight/day, a figure which agrees with that given for ruminants by Sundstøl & Owen (1993). Urine is assumed to contain 10 g N and 10 g K/l (Sundstøl & Owen, 1993). If it is assumed that all faeces and urine are captured and that no N, P or K is lost in the course of a year, then if all excreta is conserved the following application rates of N, P and K could theoretically be achieved (Tables 21 and 22).

Table 21. Theoretical N application rates to farmland from ruminant excreta produced on farms

Farm size	Mean (and range of) N application rates (kg/ha/yr)		
	Faeces	Urine	Total
Small	114 (43-265)	289 (97-696)	403 (140-939)
Medium	50 (8-142)	121 (17-355)	171 (25-498)
Large	30 (1-71)	78 (3-185)	108 (5-256)

In the East African Highlands it is estimated that a 4 t DM/ha maize crop requires an input of between 16 and 24 kg P/ha and around 100 kg N/ha (Sanchez *et al*, 1997). The estimates above indicate that as long as nutrient losses from manure are minimised the smallest farms could easily achieve these nutrient application rates. The nutrient constraints for larger farms through the use of manure only are obvious and on these farms there appears a need to supplement with inorganic fertilisers.

It is important to note that the cost currently incurred by farmers who do not effectively conserve/use urine is high. Approximately 80-95% of the N and P consumed by livestock is excreted. Whereas most P is voided in faeces (Ternouth, 1989), N is voided in both urine and faeces (Powell *et al*, 1998). It has been estimated that urine contains more than twice as much N as faeces and values of 10 g N per litre of urine have been recorded in this study. Up to two-thirds of the urine-N is in the form of urea (Bristow *et al*, 1992) which is easily lost if poorly managed. The N loss from stored faeces is unknown and is currently being measured.

Again, present practices which inadequately conserve urine result in almost complete loss of considerable quantities of K. Faecal P is less labile than faecal N compounds and so it is expected that less will be lost during manure storage.

Estimation of the monetary value of nutrients in faeces and urine

In this section an estimate is made of the value of total excreta (faeces and urine) production both on an inorganic fertiliser equivalent rate (N in urea and P in triple superphosphate (TSP), inorganic value) and on the current market rate for manure in the highlands of Kenya (organic value). Since P and N are the major limiting nutrients in highland soils the value of K was not considered here.

Nine farms in the two districts reported purchasing cattle manure in 1996. The average price of KSh 5.3 /kg of dry manure is the figure used here to estimate the 'organic' fertiliser value of home produced manure. Thus, using data above, the following estimates of value can be made (Table 23).

Table 22. Theoretical P and K application rates to farmland from ruminant excreta produced on farms

Farm size	Mean (and range of) P and K application rates (kg/ha/yr)	
	Faecal P	Urinary K
Small	41 (16-95)	347 (116-835)
Medium	18 (3-51)	146 (21-427)
Large	11 (1-25)	93 (4-222)

Table 23. Estimated monetary value of animal waste potentially produced on farms

Farm size	Mean (and range of) monetary value of nutrients in faeces (KSh)*		Mean (and range of) monetary value of nutrients in urine (KSh)*
	Inorganic equivalent (N and P) as urea and TSP	Organic value based on manure DM	Inorganic equivalent (N) as urea
Small	3,800 (1,350-11,300)	18,400 (6,600-55,300)	4,400 (1,350-14,500)
Medium	4,200(470-13,200)	25,200(10,800-64,600)	4,600 (480-4,800)
Large	6,800 (300-23,750)	37,100 (1,550-116,100)	7,800 (300-27,800)

**1997: KSh 90 = £1. Daily minimum wage rate = KSh 70-90 per day.*

The organic fertiliser value of faeces is approximately five times that of its inorganic fertiliser (urea and TSP) equivalent. This presumably reflects perceptions on the effect of manure on the physical properties of soil as well as its role in plant nutrient supply as reported by Harris *et al* (1997).

Conclusions

Livestock, particularly dairy cattle, are an important enterprise in the Central Kenya Highlands. Staal *et al* (1997) and Harris *et al* (1997) estimate that 77 and 85% respectively of agricultural households in rural areas around Nairobi own dairy animals. Whilst dairy cattle numbers are greatest on larger farms, the keeping of exotic dairy animals is not the exclusive preserve of wealthier households. On the contrary, Staal *et al* (1997) found that 28% of crop/dairy producing households in Kiambu were headed by women. Female-headed households tend to be resource deficient indicating that dairy production supports the livelihoods of the poorest farm households. Baltenweck & Staal (1998) also point out that the smallholder dairy industry is a significant employer of non-family labour, often itinerant labourers or landless members of the community.

Milk production for sale ranked highest as the reason for keeping dairy cows on medium and large farms. However, on small farms milk and manure were ranked almost equal in importance. Use of milk for home consumption was a much stronger feature on small farms indicating the subsistence nature of farming on the smallest units.

The survey found that farms were allocating 20-38% and 21-28% of their land to growing maize and Napier grass respectively. With maize yielding around 4-5 t DM/ha of low quality fodder (J. Methu, KARI Muguga, *pers comm*, 1998) and Napier yielding no more than 10 t DM/ha/yr (D. Mwangi, KARI Muguga, *pers. comm*, 1998), few farmers can depend upon farm feed resources to maintain herds throughout the year. Staal *et al* (1997) report that nearly half of farmers in Kiambu used purchased fodder as their main source of feed and that 70% fed concentrates on a regular basis. Regular purchase of feed thus represents a major route for the importation of nutrients onto the farm. Ineffective conservation of excreta quality could equally represent a pathway for considerable nutrient loss on farms.

Manure capture: All cattle in the survey were kept in permanent confinement. This is a management strategy common to the high potential areas of Kenya. Zero-grazing units were used by over half of all farms with small farms being the main adopters of this housing strategy (71%). Almost three-quarters of all farms with zero-grazing units had concrete floors with good drainage. Thus, by adoption of this system most farmers have already gone some way to maximising collection of faeces.

The estimates of faeces production in Table 20, particularly on small farms, are impressive and might be considered with some scepticism given that lack of manure is a commonly reported limitation on smallholder farms. However, of the 45 households which reported their assessments of yearly manure production, in only 25% of cases did the calculation of manure production from herd theoretical faecal DM yield actually overestimate the farmer's assessment of manure production. For 40% of farms the calculation actually underestimated total manure production because it was impossible to account for the contribution that feed refusals and bedding make to the total 'manure' yield. Thus the cattle confinement system already adopted by farmers yields large quantities of solid, organic fertiliser (faeces, feed refusals and bedding).

The survey shows that very few farmers were making an effort to trap urine separately, instead letting it drain to nearby soil or, more likely, directly into the manure heap/pit. Why this is so is discussed later. Suffice it to say that inadequate urine collection probably represents a major source of nitrogen and potassium loss along the nutrient transfer pathway. Current on-station research is estimating the scale of N and K loss through the urine route and also quantifying N and P loss in faeces during storage.

Manure use: Kagwanja (ILRI Addis Ababa, pers comm, 1996) studied manure use on 196 small farms in high potential Embu District, Kenya. She found that in 1993, 27% of farms had used no manure, 23% used 2.5-7.5 t fresh weight (FW)/ha, 32% used 10-15 tFW/ha and 18% used over 17.5 tFW/ha. Average application rate, 11 tFW/ha, was high compared with recommendations (5-8 tFW/ha). Otieno et al (1995) working in Busia District, Western Kenya, also found application to be highly variable between farms in similar locations.

Kagwanja (*pers. comm*., 1998) asked local extension workers to assess whether they thought that the application rates were adequate for soil conditions on each farm. Only 10% of farms were considered to be using inadequate levels of manure whereas 68% were using levels considered more than adequate in that year. Despite this, lack of manure was considered by farmers to be the major limiting constraint to manure use.

Otieno *et al* (1995) found that in Vihiga District, where population density is over 1,000 persons/km^2 and average farm size is 0.6 ha, two cattle in a zero grazing unit produce around one wheelbarrow of manure each day which is approximately 25 kg/day; just over 15 t/ha/yr. The authors note that farmers clean their zero grazing units twice each day so as to avoid manure loss. This again exemplifies the manure yield potential of the zero grazing unit and how, in highly intensive cropping areas such as Vihiga, manure collection is extremely thorough.

So, with evidence that small farms can produce large quantities of manure per unit area, why do farmers in the survey complain of insufficient manure? Kagwanja (*pers. comm*, 1998) suspects that this is because farmers feel that soils can never receive too much manure and so demand appears insatiable. However, this phenomenon might be related to the fact that high manure applications are still not meeting the thresholds of certain limiting nutrients (perhaps P in the case of acidic highland soils, or micronutrients). There is an obvious need to pursue this aspect further, particularly looking at manuring rates and application strategies compared with nutrient extraction through crops, labour cost of manuring in relation to crop yield increases and farmers' perceptions of manuring requirements.

Increasing manure supply: All farmers in the survey wanted to increase manure supply. No households used organic materials, eg plant foliage, other than manure, directly as a fertiliser. Plant material is more likely to be fed to livestock or used as animal bedding than to be directly applied to soil. This is not surprising. Jama et al (1997) reported that Calliandra calothyrsus foliage was much more economically attractive as a protein supplement for dairy cows than as a fertiliser on smallholdings in high potential areas.

In the present study farmers felt that manure supply would be best increased by the greater supply of bedding or forage. A minority of farmers in each farm size category considered adding unpalatable biomass (such as *Grevillia* and *Eucalyptus* foliage) directly to the manure heap. Most farmers considered it important however that the biomass be channelled through the animal (as feed) or through the animal unit (as bedding). Thus livestock play the role of biomass 'processor'; accelerating biomass decomposition by microbiological (digestion) and physical (treading + urine) processes.

Boosting manure supply by purchasing was not common in 1996. Only five large farms bought manure, from semi-arid areas such as the Rift Valley. However, Harris *et al* (1997) estimated that 60% of peri-Nairobi farmers buy manures, mainly from the Rift Valley. It is uncertain why so few of the sample farmers were buying manure. On-going manure marketing studies as part of this study suggest that there is indeed a thriving market for manures being imported into the highland areas from drier areas. Preliminary results show that these dryland manures are receiving around a 400% mark-up by agents who collect from the Rift Valley and deliver to highland farms.

Perceptions of manure quality: The basis for efficient use of manure hinges upon recognising differences in quality and adjusting application rates and timing of application accordingly. Mwarasomba *et al* (1995) report that in Kiamathare Catchment, Kiambu District the preference ranking for manure was as shown in Table 24.

Similarly, the present study found that around 80% of medium and small farmers were well aware of quality differences between manures from each species. However, only between a quarter to one third of farmers in each category of farm size thought it possible to influence the quality from a particular livestock species by better feeding. This could be related to farmers' limited experience of using quality feeds at a level where they would have an observable impact on manure quality.

If farmers think that there was little to be done to influence manure quality emanating from the animal itself, the survey showed that the majority thought raising manure quality was possible *post*-animal through better collection and storage techniques.

Capturing urine more effectively was reported to make the biggest difference to manure quality for farmers in all three categories. However, hardly any farmers made efforts to capture urine separately, feeling that incorporation into bedding in bomas or running it into the manure heap from zero-grazing units was sufficient. Concrete floors in the zero-grazing unit did have an impact upon N content of manure. This is presumably because fast drainage of urine into the manure heap/pit leaves less opportunity for evaporation of urine and concrete floors reduce leaching, even though leaching would still occur in the unlined pits.

Table 24. Preference ranking of manures in Kiamathare Catchment, Kiambu District

Type of manure	Crop response	Residual value	Moisture retention	Susceptibility to worms
Poultry	1*	4	4	0
Goat/sheep	2	2	2	0
Cattle	3	1	1	1
Compost	4	3	3	0

**1 = best , 4 = worst , 0 = not susceptible*

One third of farmers in each category also thought that completely roofing the cattle pen would make a positive impact on quality, presumably by reducing the evaporation of urine and preventing infiltration by rain.

Farmers in all categories were affording some management to their manure heaps on the premise that this would improve quality. Covering the manure heap seemed to be the most widely accepted means to enhance or maintain quality.

Evidence therefore exists that some farmers already practice strategies that they perceive will enhance manure quality. Small farmers, who have little opportunity to purchase fertilisers, may be marginally more innovative in this respect. Variable appreciation of manure quality might explain why wide variation in manure application rate occurs within similar locations (Otieno *et al*, 1995; Kagwanja, 1996). However, on the other hand, only half of the small farmers in the present survey had an idea of what a good manure looked like and the majority of medium and large farmers had no method of assessing manure quality. Whether smaller farmers vary their application rates according to perceptions of manure quality/soil deficiencies requires further investigation.

It is concluded that whilst farmers are aware of the ‘ingredients’ and methods involved in making good manures they did not display competence in assessing the quality of purchased manures or appreciating when a home-produced manure is ready for application. Simple indices of manure quality are required that will enable farmers to combine manure more effectively with strategic quantities and placements of inorganic fertilisers and so more precisely meet the nutritional needs of crops.

Nutrient inputs through livestock: In addition to being an integral step in the nutrient cycle within farms, livestock, mainly dairy cattle, are the main reason for importation of exogenous nutrients onto highland farms (Shepherd & Soule, 1998). Farmers buy concentrates and forage on a regular basis to complement forage grown on farm.

The scale of this livestock-motivated nutrient transfer within Kiambu District alone is large. Staal *et al* (1997) estimated 150,000 t of fresh Napier (around 17% DM containing 1.4% N) to be traded amongst farms in Kiambu in 12 months spanning 1995-96. This amounts to a flow of 357 t N/yr, equivalent to 15,500 50 kg bags of urea. Since over 90% of the nitrogen ingested by ruminants appears in faeces and urine much of this could be available for return to the soil. On-going monitoring of livestock feeding strategies in Kiambu District (DFID RNRRS LPP Feeding Strategies Project) will reveal the scale of N, P and K importation onto farms in feed, compared with fertiliser purchases and nutrients re-cycled within the farm. These figures clearly show the importance of research into the role of livestock as a nutrient conduit in high potential areas. It is thus particularly important to seek ways of improving manure collection, handling and storage systems.

Value: Table 23 presents the estimated value of faeces produced on-farm each year. Based on an average milk price in 1996 of KSh 13.4/l and cow ownership in Table 12, assuming all cows are lactating throughout the year, the value of manure produced in 1996 is equivalent to 28, 33 and 34% of the annual milk production on small, medium and large farms respectively.

Issues arising from the study

Dairy cattle are the most numerous and widespread livestock species owned by farmers in the sample. Since farmers rely upon purchased fodder/concentrates to supplement home-produced fodder, livestock numbers are not constrained by size of land holdings. Therefore, on the smallest farms, large herd size to land ratios result in the production of considerable quantities of manure/ unit area each year. On larger farms, manure availability is much more constrained. However, these farms may have greater opportunity to purchase more manure and inorganic fertilisers.

All farmers felt that the quantity of manure they were producing was insufficient for their needs but could suggest strategies for increasing output. Since all animals were in permanent confinement the strategies involved raising fodder or bedding supply.

There were widespread ideas on ways to improve/conserve the quality of manure during storage and also a reasonable number actually putting theory into practice. It was intriguing to note that despite the existence of knowledge on improved manure management practices very few farmers knew how to assess manure quality. Presumably they had adopted proven techniques which had then been verified by each farmer's own experiences. This is acceptable as long as the farmer knows the 'history' of the manure but brings into question his/her ability to assess the value of an unknown, purchased, manure.

The survey raises a number of issues/questions:

- Potential manure application rates are greatest on the smallest farms because of higher livestock densities. This finding contrasts with those of Smaling *et al* (1992) who conclude that manure application is insufficient to sustain crop production in high potential Kisii District. The estimates in this report support observations of Kagwanja (*pers comm,* 1998) for Embu District that the smaller farms do actually apply considerable quantities of manure on a regular basis. There is a need to measure manure accumulation and application rates on the smallest (poorest) farms in high potential farming areas of Kenya.

- Further studies are needed to verify manure production levels, and recommended and actual application rates particularly on small farms. If small farms really do produce considerable quantities of manure, quite apart from addition of fodder refusals and bedding, why do these farmers perceive that supply is too low?

- If urine does make a difference to manure quality how can it best be captured? Taking into account the volatility of nutrients in urine, is urine then best captured separately, in collection sumps, typically constructed from concrete without lids. allowed to mix with bedding or simply directed into manure heaps as is current practice.

- What is the scale of nutrient passage through livestock? Very few organic amendments are made directly to the soil. All exogenous and endogenous nutrients on the farm pass through livestock, either through the digestive tract or the housing unit. How efficient is this routing? Losses of DM and other nutrients through this route must be measured and compared with direct application of organic materials to soils.

- How do farmers perceive manure quality? The survey indicated that some farmers do have their own perceptions/measures of quality and could suggest management techniques to improve the quality. However, further investigation into the basis of quality ranking is warranted, especially to test if these criteria influence application rate.

- What is the impact (cost/benefit) of the farmer-suggested improved manure storage methods on manure quality?

As farms intensify and become smaller through inter-generational sub-division, the need to enhance nutrient turnover will become more important. The overall impression from the survey was that the small farms in the sample already had a greater knowledge than the larger farms concerning improving the efficiency of manure management.

The study highlights that livestock are important as nutrient conduits, concentrators and converters on farms but points to the fact that there is need to: (1) validate the manure enhancement strategies reported by farmers, (2) quantify nutrient losses (eg urine losses) as a consequence of 'taking the livestock route' and (3) improve the efficiency of manure use. Outputs of research into area (3) should not only create tools to allow farmers to make better assessments of manure quality and match those with crop nutrient requirements but also provide simple criteria to enable farmers to meet manure nutrient deficiencies with strategic use of inorganic fertilisers.

Structured Survey 2: *Influence of manure management on variability of manure chemical and physical characteristics in Kariti location*

Cattle management

Table 25 provides a summary of some chemical characteristics determining manure quality. Considerable differences were observed between the highest and the lowest values of the quality parameters (see standard deviation). Although nutrient concentrations are good indicators of manure quality, these measurements do not reflect the actual quantity of nutrients that are potentially available on farms. For example, it is possible that that manure with low nutrient concentration could also have a higher heap mass. An estimate of nutrient availability from manure of farms of different livestock complements was discussed above.

Table 25. A summary of chemical characteristics of manures collected during the survey.

	Organic C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
n[1]	299	298	298	298	297	297	297	298
Mean	24.5	1.12	23.1	197	0.31	2.39	0.26	0.51
[2]Min	6.5	0.33	5.3	0.12	0.06	0.43	0.00	0.05
[3]Max	49.7	1.91	81.3	8.0	0.75	7	1.34	1.19
[4]SD	8.8	0.33	9.6	1.30	0.12	1.07	0.21	0.19

[1]n = number of farms examined [2]Min = minimum [3]Max = maximum [4]SD = standard deviation

Effect of housing and roof type on manure quality: The three categories of housing structure investigated in the study were traditional *boma* (kraal), improved *boma* and zero-grazing which represented 6, 84 and 9% respectively, of the total number of farms surveyed. Of the total housing types surveyed, 48% had no roof, 69% had partial roof and 15% had a full roof. The effect of housing and roof type on manure quality is given in Table 26.

Housing has a significant effect on the concentration of organic C, P and Ca whereas no significant effects on N, soluble C, K and Mg, and on the C: N ratio. However it was observed that even in the parameters that were not significant there was some marginal improvement in manure nutrient concentration as the housing changed from traditional to the zero-grazing type. Roof type also showed significant effects on the concentrations of manure organic C, Soluble C, P, K and Mg but not on N and Ca, and the C:N ratio.

Table 26. Effect of housing and roofing on manure chemical characteristics.

	C (%)[1]	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Housing type								
Traditional boma	21.2c	1.08	20.5	2.04	0.24b	2.19	0.15c	0.52
Improved boma	24.4b	1.12	23.3	1.92	.030b	2.39	0.25b	0.50
Zero grazing	28.3a	1.25	23.9	2.41	0.43a	2.61	0.40a	0.53
p	0.02	NS[2]	NS	NS	<0.001	NS	<0.001	NS
Roof type								
No roof	21.5c	1.07	20.9	1.81b	0.25	2.22b	0.24	0.50b
Partial roof	24.6b	1.12	23.2	1.83b	0.31	2.34b	0.25	0.49b
Full roof	27.7a	1.20	25.3	2.82a	0.35	2.83a	0.32	0.60a
p	0.003	NS	NS	<0.001	<0.001	0.009	NS	0.001

[1]Value followed by the same letter are not significantly different [2]NS = not significant

These observations suggest that housing structures that restrict animals from wandering over a large area result in manure of higher quality. In addition, roofing improves nutrient concentration probably because of reduced moisture evaporation and impact of precipitation leading to reduce leaching losses and in the case of N, reduction in excessive gaseous losses of volatilisation.

Effects of floor type, bedding and drainage on manure quality: Table 27 show the effects of type of floor, drainage and bedding on the quality of manure. 286 and 12 farms had soil and concrete/stone floor representing 96 and 4% of all farms surveyed. Concrete flooring resulted in manure of significantly higher Ca and P concentration compared with soil floor while the rest of the nutrients were not significantly affected even though they all showed marginal increases.

Table 27 Effects of flooring, drainage and bedding on manure quality.

	C (%)	N (%)[1]	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Flooring								
Soil	24.4	1.12	23.1	1.94	0.30b	2.31	0.25b	0.51
Concrete or stone	28.5	1.2	24.0	2.68	0.41a	2.52	0.40a	0.53
p	NS[2]	NS	NS	NS	0.001	NS	0.016	NS
Bedding								
No bedding	23.3	1.14	21.3b	2.06	0.33a	2.42	0.24	0.52
Bedding present	25.1	1.12	24.0a	1.93	0.30b	2.38	0.26	0.50
p	NS	NS	0.028	NS	0.028	NS	NS	NS
Drainage								
Poor	23.9	1.09b	23.4	1.85	0.30	2.31	0.24	0.52
Medium or well drained	25.5	1.17a	22.8	2.14	0.32	2.52	0.26	0.50
p	NS	0.047	NS	NS	NS	NS	NS	NS

[1]Value followed by the same letter are not significantly different [2]NS = not significant

Ninety-three farms did not use bedding in the animal sheds while 207 farms did. This represents 31 and 69% of all farms surveyed, respectively (Table 28). The main type of bedding materials used (expressed as proportions of farms that used bedding them) were: napier grass (34%), maize stover (92%), banana residues(51%), grass (45%), *Grevillea* prunings (13%). Other organic materials include avocado leaves (4%), coffee leaves (2%), mango leaves (4%), jacaranda (1%), *Lantana* (1%), bean trash (3%), reeds (15%), sawdust (3%) and weeds (6%). Most of the farms used more than one type of organic material for bedding.

Inclusion of bedding significantly increased C:N ratio but reduced P concentration while the rest of the parameters were not affected significantly even though addition of bedding resulted in marginal reduction in N, soluble C, K and Mg and increases in C and Ca concentrations. This observation suggests that inclusion of bedding acts primarily as a diluent to these nutrients instead of an additional source of nutrients contributing to increased nutrient concentration.

Farms have a variety of different drainage systems that either allowed drainage of urine away (well drained) or retained much of it in the animal sheds (poorly drained). Poor drainage was encountered in 174 farms while medium/well drainage was found in 124 farms representing 58 and 42% of total farms surveyed. Poor drainage resulted in significantly lower N concentration in manure heaps compared with medium/well drained animal sheds but did not affect other parameters significantly (Table 27). However, lower C:N ratio was observed in medium/well drained than the poorly drained manures. There was also an improvement in C, soluble C, P, K and Ca concentration in the medium/well drained manures compared to the poorly drained ones while Mg was reduced.

These observations suggest that urine inclusion was not beneficial at improving manure quality in terms of nutrient content conservation except for Mg. This could be attributed to the fact that inclusion of excessive urine may have resulted in higher nutrient leaching losses. In addition to leaching, in the case N, it might have created anaerobic conditions that may have resulted in diminishing of the more favourable aerobic composting thereby encouraging gaseous losses due to denitrification and volatilisation.

Table 28. Type and usage of bedding at Kariti Location.

		Number of farmers	% of all farmers	% of farmers using bedding	% of farmers using this bedding
Any bedding		207	69		
No bedding		93	31		
Napier	Use	70	23	34	
	1[a]	18	6	9	26
	2	17	6	8	24
	3	26	9	13	37
	4	9	3	4	13
Maize stover	Use	191	64	92	
	1	106	35	51	55
	2	56	19	27	29
	3	28	9	14	15
	4	1	<1	<1	0
Banana	Use	105	35	51	
	1	38	13	18	36
	2	43	14	21	41
	3	19	6	9	18
	4	5	2	2	5
Grass	Use	94	31	45	
	1	16	5	8	17
	2	38	13	18	40
	3	32	11	15	34
	4	8	3	4	9
Grevillea	Use	27	9	13	
	1	10	3	5	37
	2	9	3	4	33
	3	8	3	4	30
	4	0	0	0	0
Other*	Use	49	16	24	

*Others	No.	%
Avocado leaves	13	4
Bean trash	3	1
Banana leaves	1	<1
Coffee leaves	2	0
Jacaranda leaves	1	<1
Lantana pruning	1	<1
Mango leaves	4	1
Reeds	15	5
Sawdust	3	1
Weeds	6	2

[a]indicated the proportion of material in bedding, 1 = highest and 4 = lowest

Effect of concentrate feeding on manure quality: Use of concentrated feed and its effect on manure quality is shown in Table 29. It was observed that 90 farms did not use concentrate while 208 farmers fed their animals some sort of purchased concentrate. This represented 30 and 70% of surveyed farms, respectively. Only P concentration was significantly increased by concentrate feeding while the rest of the quality parameters were unaffected.

Table 29. Effect of concentrate on manure quality

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
No concentrate	23.4	1.14	22.5	2.00	0.28b	2.55	0.26	0.53
Concentrate fed	25.1	1.12	23.4	1.96	0.32a	2.32	0.26	0.50
p	NS	NS	NS	NS	0.030	NS	NS	NS

The effect of the amount of concentrate on the quality of manure was also investigated in this study. The results of regression analysis between the amount of concentrate fed to cattle and manure quality are given in Table 30. Farmers offered between 0.25 and 8.00 kg of concentrate on a whole herd basis daily. Accepting that the manure heap contains a mixture of excreta obtained from the whole herd, some of which may not have received concentrates (eg young stock, males) the link between concentrate feeding and the quality of manure in the heap was thought to be extremely tenuous. It is interesting therefore that the regression analysis showed a significant positive relationship between level of concentrate feeding and manure P and C concentrations.

Table 30. Regression between manure quality parameters and amount or concentrate fed to the animals.

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
R^2	0.017	0.002	0.007	<0.001	0.06	<0.001	<0.001	<0.001
p	0.022	NS	NS	NS	<0.001	NS	NS	NS

Animal management factors affecting manure quality: A summary of animal management factors affecting manure quality are given in Table 31. It was observed that housing and floor-type only influenced the P and Ca concentration significantly while drainage had an effect on the C:N ratio and N concentration. Bedding significantly influenced the C:N ratio and P concentration while roofing affected all the quality parameters under consideration except the C:N ratio, N and Ca concentrations. Concentrate feeding only affected the P concentration.

Table 31. A summary of single factors that affected manure quality parameters

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Housing	[1]NS	NS	NS	NS	***	NS	***	NS
Floor type	NS	NS	NS	NS	**	NS	*	NS
Drainage	NS	*	*	NS	NS	NS	NS	NS
Bedding	NS	NS	*	NS	*	NS	NS	NS
Roof	**	NS	NS	***	***	**	NS	**
Concentrate	NS	NS	NS	NS	*	NS	NS	NS

[1]NS not significant * significant p=0.05, ** significant p < 0.01, *** significant p < 0.001

Manure management

Manure management parameters studied: Manure management parameters that were investigated in this part of the study are shown in Table 32. Most farmers preferred to store their manure in heap/pit (67%) compared with deep littering (33%) and 90% did not cover the manure while 10% did. Forty-six percent of farmers kept the manure under some sort of shade compared with 54 % who did not. Farmers who did not turn, infrequently turned and frequently turned the manure during storage represented 45, 51 and 4%, respectively. Ninety eight percent of farmers included urine in the manure while only 2% did not while 95% included organic materials (usually bedding) and 5% did not.

Table 32. Manure management parameters studied and the proportion of farms employing them.

	n	%
Storage method		
Deep litter	97	33
Heap/pit	201	67
Covering		
Not covered	268	90
Covered	29	10
Shading		
Not Shaded	159	54
Shaded	138	46
Turning		
Not turned	135	45
Infrequently turned	151	51
Frequently turned	11	4
Urine		
Urine not included	6	2
Urine included	292	98
Organic materials		
Not included	14	5
Included	283	95

Effect of storage method on manure quality: This study investigated the effects of manure storage methods on the quality of manure (Table 33). The methods under considerations were pit, heap and deep litter. However only three farms were found to be using pit as a storage method and as such this category was combine with the heap method during statistical analysis. Deep littering resulted in manure of significantly lower P concentration compared with heap/pit storage while the opposite was observed for K concentration while the rest of the nutrients were unaffected.

Table 33. Effect of storage method of manure quality

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Deep litter	25.3	1.16	23.4	2.1	0.28a	2.7	0.29	0.52
Heap/pit	24.2	1.11	23.0	1.9	0.32b	2.2	0.25	0.50
p	NS	NS	NS	NS	0.02	<0.001	NS	NS

Effect of covering on manure quality: The effect of covering on the quality of manure is given in Table 34. It was observed that covering significantly increased Mg concentration and all the other nutrients were unaffected although there were some modest increases observed in the concentration of these nutrients and a reduction in C:N ratio.

Table 34. Effect of covering on manure quality

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Not covered	24.6	1.12	23.3	1.9	0.30	2.4	0.25	0.50
Covered	24.1	1.15	21.7	2.3	0.32	2.7	0.30	0.61
p	NS	NS	NS	NS	NS	NS	NS	0.002

Effect of shading on manure quality: The effect of shading on manure quality in terms of nutrient concentrations is given in Table 35. It was observed that, whereas shading resulted in reduced manure nutrient concentration for all the nutrients only soluble C and K were significantly lowered. This observation suggests that shading may result in manure retaining more moisture leading to increased leaching losses.

Table 35. Effect of shading on manure quality

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Not shaded	25.0	1.15	23.4	2.1	0.31	2.5	0.26	0.51
Shaded	24.0	1.10	22.8	1.8	0.30	2.2	0.25	0.50
p	NS	NS	NS	0.017	NS	0.021	NS	NS

Effect of turning on manure quality: Effect of manure turning during storage was also investigated where not turning, infrequently turning and frequently turning resulted is significant differences in the C:N ratio, P and Ca concentration (Table 36) while the rest of the nutrients were unaffected.

Table 36. Effect of turning on manure quality

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Not turned	24.9	1.08	25.0	1.87	0.31	2.5	0.25	0.52
Infrequently turned	24.1	1.16	21.5	2.03	0.30	2.3	0.25	0.50
Frequently turned	26.3	1.17	22.8	2.35	0.39	2.7	0.45	0.45
p	NS	NS	0.008	NS	0.045	NS	0.008	NS

The lowest C:N ratio of 21.5 was observed for the infrequently-turned manure while not turning resulted in highest C:N ratio of 25.0 and frequent turning resulted in manure of C:N ratio of 22.5. Frequent turning resulted in highest P and Ca concentration and the rest of the nutrients except Mg.

Effect of urine addition on manure quality: The effect of urine on the studied manure quality parameters are showing Table 37. It was observed that urine including urine in the manure did not significantly affect nutrient concentration. However, considerable reduction in was observed for all the nutrients except for Mg. This observation suggests that urine containing manure are more likely to incur leaching nutrient losses compared with manure with no urine inclusion and in the case of N, additional enhance gaseous losses of volatilisation and denitrification may also occur.

Table 37. Effect of urine on manure quality.

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Urine not included	26.9	1.16	23.8	1.99	0.40	2.58	0.42	0.52
Urine included	24.5	1.12	23.1	1.97	0.30	2.39	0.26	0.51
p	NS	NS	NS	NS	0.042	NS	NS	NS

Effect of adding organic materials on manure quality: During the survey some farmers reported adding organic materials directly to the manure heap rather than using it as bedding first (Table 38). One major source of these materials added directly to the manure heap is rejected fodder. As in the case of bedding, farmers were found to be adding more than one type of organic material. Maize stover was the most frequently added organic material with 87% of farmers using it. It was followed by banana residues (71%), then by napier grass (47%), roadside grass (42%), *Grevillea* leaves (34%) and others (16%) that included avocado leaves ((6%), coffee leaves, *Lantana* prunings, mango leaves and sweet potato vines, all <1%, reeds (4%) and sawdust and weeds (1%). Although these materials were reported above as also being used for bedding it is interesting that farmers distinguish between the same material used as feed or as bedding. It might be assume that bedding consisted of all rejected feed. This is evidently not always the case, and organic materials appear to selected for particular usage. An example of this would be maize leaves used as fodder whilst maize stems are used as bedding – both are classified as “maize stover”.

The effect of organic materials addition on manure quality is given in Table 39. It was observed that addition of organic materials only decreased P concentration significantly although the concentration all the other nutrients were also reduced.

Table 38. Organic material added to the manure other than originating from bedding and proportion in the heaps.

		Number of farmers	% of all farmers	% of farmer using bedding	% of farmers using this bedding
Any organic addition		286	95		
No organic addition		14	5		
Napier	Use	142	47	50	
	1	75	25	26	53
	2	29	10	10	20
	3	32	11	11	23
	4	6	2	2	4
Maize stover	Use	261	87	91	
	1	115	38	40	44
	2	87	29	30	33
	3	48	16	17	18
	4	11	<1	4	4
Banana	Use	212	71	74	
	1	28	9	10	13
	2	93	31	33	44
	3	84	28	29	40
	4	7	2	2	3
Grass	Use	127	42	44	
	1	14	5	5	11
	2	32	11	11	25
	3	69	23	24	54
	4	12	4	4	9
Grevillea	Use	101	34	35	
	1	40	13	14	40
	2	31	10	11	31
	3	25	8	9	25
	4	5	2	2	5
Other*	Use	49	16	17	

Others include	No	%
Avocado leaves	19	6
Coffee leaves	2	<1
Lantana pruning	2	<1
Mango leaves	2	<1
Reeds	13	4
sawdust	4	1
Sweep potato vines	2	<1
Weeds	3	1

Table 39 Effect of organic materials additions on manure quality.

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
No organic materials added	28.3	1.20	25.6	2.3	0.39a	2.8	0.36	0.57
Organic materials added	24.4	1.12	23.0	2.0	0.30b	2.4	0.25	0.50
p	NS	NS	NS	NS	0.009	NS	NS	NS

Manure management factors affecting manure quality: A summary of manure management factors affecting manure quality are given in Table 40. It was observed that manure storage (deep litter/heap/pit) significantly affected P and K concentrations while covering affected Mg concentration only. Shading affected soluble C and K concentrations while turning had significant influence on the C:N ratio, P and Ca concentrations. Urine had no significant effects on manure nutrient content and organic materials affected manure C:N ratio and P concentration.

Table 40. A summary of single management factors that affected manure quality parameters

	C (%)	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Storage	[1]NS	NS	NS	NS	**	***	NS	NS
Covering	NS	NS	NS	NS	NS	NS	NS	**
Shading	NS	NS	NS	*	NS	*	NS	NS
Turning	NS	NS	**	NS	*	NS	**	NS
Urine	NS	NS	NS	NS	*	NS	NS	NS
Organic materials	NS	NS	NS	NS	**	NS	NS	NS

[1]NS not significant * significant p=0.05, ** significant $p < 0.01$, *** significant $p < 0.001$

Discussion

Results suggest that improvement from traditional livestock housing to the more intensive zero-grazing systems have beneficial effects on some aspects of manure quality. It is important to note that these beneficial effects may arise as an interaction between a number of livestock- and manure-management-factors and that the analysis of main factors only presented above may have overlooked these. However, in defence of this analytical approach, the aim of this study was to identify simple management factors that have significant influence on manure quality. Interacting factors may indeed influence quality but expressions of these interrelationships lend themselves to complex extension messages.

Similarities between Survey 1 and 2 confirm that management factors have the greatest positive influence upon P content. Both surveys point to P content increasing as the result of feeding concentrates and creating an impervious floor in the animal unit. These are important findings given that P is considered the primary limiting nutrient in Kenya highland soils. No agreement was found between the two surveys regarding best practice for N conservation. Although C:N ratio was not specifically examined in Survey 1 indications from the present study are that it is reduced by drainage and infrequent turning but increased (not surprisingly) by addition of bedding

Overall, it is suspected that the amount of moisture retained in the manure during collection has the greatest influence on the nutrient content in the manure. Conditions that give rise to optimum aerobic composting are best for conserving N while the rest of the nutrients are best conserved through conditions that minimise leaching losses. Excessive moisture from urine or precipitation creates anaerobic conditions encouraging gaseous N losses and leaching losses of other nutrients. The fact that capture of urine in manure heaps can accelerate nutrient loss is counter-intuitive to the notion that addition of urine to the manure heap increases N content.

The study endorses the familiar message that poor management of manure results in nutrient loss but goes further to specify the animal husbandry and manure management factors that can lead to large loses. Equally, it reveals that there are simple ways to raise concentrations of key nutrients. Later sections in this report examine whether these conservative practices realise improvements in crop biomass yield.

Relationship between easily discernible physical characteristics and chemical characteristics of manure-compost

In this survey a link between manure quality in terms of nutrient composition and the manure consistency or texture, colour, smell and biological activity observed visually were investigated. This study sought to investigate the extent to which simple physical parameters could be used as indicators of manure nutrient concentration or quality. If suitable indicators are identified that are reliable, reproducible and applicable with minimum training, they could provide farmers with a simple decision tool to determine the quality (or maturity) of compost and to assess the approximate fertiliser value of their manure-compost. Such an evaluation would aid decision making on application rates and choice of type and quantity of inorganic fertiliser to use as a supplement to manure. The scope for using a decision tool to determine application time would be less, as this is constrained by the crop cycle rather than by manure maturity. Three hundred farms were visited and manure samples collected from each of them for analysis. No subdivision of manures was carried out and there was, thus, a wide range of manure types and ages.

Manure consistency

The hypothesis for this parameter was that undecomposed manure containing animal faeces and possibly a range of other organic additions would have a coarse consistency. The consistency should become finer as the decomposition process progresses, resulting, at maturity in the fine loamy material, which is recognised as the mature product from all types of organic composting. Table 41 shows that only C and K differed significantly among the consistency classes, with a decline in percentage C and K within decreasing coarseness (= increasing maturity). A decline in percentage C through decomposition and a loss of the highly mobile K through leaching are expected. Although the C:N ratio differed by 13% between coarse and medium as might be expected with increasing maturity, this difference was not statistically significant.

Table 41. Relationship between consistency and manure chemical characteristics.

	C (%)[1]	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Coarse	29.0 a	1.17	26.3	2.35	0.27	2.46 ab	0.30	0.54
Fairly coarse	24.8 b	1.12	23.5	2.02	0.30	2.67 a	0.26	0.51
Medium	23.1 b	1.12	22.1	1.84	0.32	2.20 b	0.24	0.50
Fine/ very fine	24.5 b	1.10	22.9	1.93	0.34	2.21 b	0.35	0.50
p	0.001	NS[2]	NS	NS	NS	0.006	NS	NS

[1]Value followed by the same letter are not significantly different [2]NS = not significant

Manure colour

The hypothesis for this parameter was that undecomposed material consisting of a homogeneous mixture of animal faeces and other organic materials, differing in colour, would have a mottle appearance. As the decomposition process progresses, such material would be expected to become more homogeneous, appearing a uniform dark brown or black at maturity. Table 42 shows that all chemical characteristics except C:N ratio and %P differed significantly among the colour classes. All characters that differed significantly, were higher in the 'discernibly different colours' category than in the 'faded colours' category (= decline with ageing). Results for the 'one colour' category were less consistent and it is likely that this category included materials that were of a uniform colour at the start of decomposition as well as those that were initially heterogeneous but uniform later. The 'single colour' description would, therefore need further qualification to make it a useful criterion. The decrease in C and the percentage concentration of cations is as expected. However, one might expect that the %N concentration would increase and the C:N ratio decrease with age in a well-managed compost heap, and the fact that this did not occur suggests excessive losses of N through poor heap management.

Table 42. Relationship between colour and manure chemical characteristics.

	C (%)[1]	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Discernibly different colours	31.6 a	1.13 ab	28.9	3.76 a	0.31	3.26 a	0.33 a	0.56 b
Fading colours	26.1 b	1.18 a	23.2	2.10 b	0.31	2.63 b	0.29 a	0.53 b
Faded colours	22.4 c	1.06 bc	22.4	1.77 c	0.29	2.13 c	0.22 b	0.48 c
One colour	25.0 abc	0.98 c	29.8	1.88 bc	0.32	2.07 c	0.22 b	0.60 a
p	<0.001	0.011	NS[2]	<0.001	NS	<0.001	0.028	0.04

[1]Value followed by the same letter are not significantly different [2]NS = not significant

Manure smell

The hypothesis for this parameter was that fresh animal manure has a strong smell of ammonia and other organic matter also gives of strong smell of putrefaction during the early stages of decomposition. Later, ammonia is lost by volatilisation or ammonium salts converted to odourless compounds, and the organic decomposition products generally have little smell. Mature compost is expected to have only a slight 'earthy' and inoffensive smell. Table 43 shows that only percentage soluble carbon and percentage K concentration decreased significantly with decreasing smell (= increasing maturity). Although the results suggest a lower %C and C:N ratio when the compost has lost all smell (= mature), these results were not statistically significant.

Table 43. Relationship between smell and manure chemical characteristics.

	C (%)[1]	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Strong	27.3	1.24	23.4	2.95 a	0.35	2.95 a	0.32	0.55
Medium	25.0	1.14	23.3	2.48 b	0.30	2.48 b	0.26	0.52
Low	23.5	1.06	23.1	2.16 c	0.30	2.16 c	0.23	0.48
None (smells like soil)	22.2	1.08	21.5	1.99 c	0.30	1.99 c	0.24	0.46
p	NS[2]	NS	NS	0.003	NS	<0.001	NS	NS

[1]Value followed by the same letter are not significantly different [2]NS = not significant

Manure biological activity

This parameter was included in the survey speculatively with little qualification. It could thus be interpreted as the activity of macrofauna, such as earthworms and other detritivores, or as visible signs of decomposing microflora such as fungi. The fauna and flora of compost heaps changes with time, both increasing and decreasing with maturity depending on the group of organisms. For example earthworm activity might increase to a maximum and then decline towards maturity, while other soil fauna and fungi might well show peak activity at other times. It is thus not surprising that Table 44 indicates that none of the chemical characteristics differed significantly with level of biological activity. It can be concluded that this parameter is of little value in describing compost maturity without considerable further qualification.

Table 44. Relationship between compost biological activity and manure chemical characteristics.

	C (%)[1]	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
None	25.4	1.09	21.3	1.94	0.28	Nd[3]	nd	nd
Low	24.7	1.12	23.4	1.95	0.30	nd	nd	nd
Medium	23.6	1.14	22.0	2.13	0.33	nd	nd	nd
Much	21.6	1.01	20.9	1.45	0.32	nd	nd	nd
p	NS[2]	NS	NS	NS	NS			

[1]Value followed by the same letter are not significantly different [2]NS = not significant [3]nd = not determined

Discernible physical parameters affecting compost chemical characteristics

A summary of the relationship between physical and chemical characteristics is shown in Table 45. This shows that, although significant differences in C and K, no single physical character alone provided a statistically significant means of assessing the most important parameters of percentage N and P, and the C:N ratio. Nitrogen concentration did differ significantly with compost colour but the differences between colour classes were small.

Table 45. A summary of the relationship between single physical factors and chemical characteristics of manure

	C (%)[1]	N (%)	C:N ratio	Soluble C (%)	P (%)	K (%)	Ca (%)	Mg (%)
Consistency	**	NS	NS	NS	NS	**	NS	NS
Colour	***	**	NS	***	NS	***	*	*
Smell	NS	NS	NS	**	NS	***	NS	NS
Biological	NS	NS	NS	NS	NS	nd[2]	nd	nd

[1]NS not significant * significant p=0.05, ** significant p < 0.01, *** significant p < 0.001
[2]nd = not determined

Development of a decision tool for manure quality

An attempt was made to utilise the above data to develop a decision tool to allow the assessment of manure quality from simple physical parameters. The percentage nutrient concentration of the manure-compost is important in determining the total amount of nutrients applied to a crop. However, the results in Experiment 1, above, indicate clearly that quality parameters such as C:N ratio rather than total nutrient application rate are the key factors in determining the crop response to applied manure. This is shown by the close negative correlation between C:N ratio and crop yield at iso-N applications. For this reason, an attempt was made to develop a decision tool for C:N ratio. This tool took the form of a dichotomous key or 'decision tree'. Although C:N ratio did not differ significantly with any one single physical parameter, multiple regression equations could be developed that accounted for C:N ratio with significant contributions from physical parameters, especially compost consistency, colour and age.

Figures 11 and 12 show two examples of the keys produced. In Figure 11 the mean C:N ratio for 300 samples was 23.1. Separating the samples into two consistency classes (column 2) separated the mean values significantly into 22.1 and 24.5. No further division of the B2 criterion in Column 2 was possible with any other physical characteristic, but the B1 criterion was further sub-divided by age in Column 3, with the mean values being 20.4 and 25.1 for the age classes C1 and C2. Thus, it is possible to separate manures by combined characteristics of age and consistency into mature (C:N = 20.4) and immature (C:N = 24.5 or 25.1). While this is not particularly impressive, it should be noted that the difference in field trials between iso-N applications of manure with C:N = 25 and those with C:N = 19 represented maize grain yield improvements of 20 and 45% in the first and second years after application, respectively. This suggests that even this level of differentiation may be a useful guide to manure quality. Figure 12 shows a similar key when age is taken as the first parameter and consistency second.

Figure 11. Dichotomous key for determining manure C:N ratio from simple physical characteristics

<table>
<tr><td>Column 1</td><td>Column 2</td><td>Column 3</td></tr>
<tr><td>All manures</td><td>Consistency</td><td>Age</td></tr>
<tr><td rowspan="7">A. C:N = 23.1</td><td rowspan="3">B1. Medium to very fine
(C:N = 22.1)</td><td>C1. > or = 5 months
(C:N = 20.4)</td></tr>
<tr><td>C2. < or = 4 months
(C:N = 25.1)</td></tr>
<tr><td>p = 0.043</td></tr>
<tr><td rowspan="3">B2. Coarse to fairly coarse
(C:N = 24.5)</td><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td>p = 0.018</td><td></td></tr>
</table>

Figure 12. Dichotomous key for determining manure C:N ratio from simple physical characteristics

<table>
<tr><td>Column 1</td><td>Column 2</td><td>Column 3</td></tr>
<tr><td>All manures</td><td>Age</td><td>Consistency</td></tr>
<tr><td rowspan="7">A. C:N = 23.1</td><td rowspan="3">B1. > or = 5 months
(C:N = 22.1)</td><td>C1. < Medium to very fine
(C:N = 20..5)</td></tr>
<tr><td>C2. < or = 4 months
(C:N = 24.2)</td></tr>
<tr><td>p = 0.027</td></tr>
<tr><td rowspan="3">B2. < or = 4 months
(C:N = 24.7)</td><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td>p = 0.044</td><td></td></tr>
</table>

Discussion

Some simple physical parameters, which are easily discernible, do show significant relationships to some manure chemical characteristics. Manure quality, as C:N ratio, can be predicted by multiple factors but not by any single physical character assessed. There appears to be scope for the development of decision tools for manure-compost quality. However, some of the categories of the physical characteristics chosen appear not to be useful (eg general biological activity) or act to confound the analysis (eg uniform colour of materials at start and end of composting). Although the results show some significant differences in mean manure nutrient concentrations and quality, these mean values mask an enormous range of values, making significant differences in means difficult to detect. For example, the C:N ratio of the 300 samples of manure ranges from 5.3 to 81.3, representing materials with C:N ratios similar to soil at the one extreme through to a material with a C:N ratio twice that of cereal straw or 40% that of sawdust at the other extreme. Thus the significantly different mean C:N values of 20.4 and 25.1 in Column 3 of Figure *x* have ranges of 6.1-81.5 and 5.3-38.3, respectively. It seems likely that preliminary sub-division of manure-composts into types by some means before assessment of the physical parameters tried so far will be necessary .

Conclusions

Some simple physical parameters, which are easily discernible, do show significant relationships to some manure chemical characteristics. Manure quality, as C:N ratio, can be predicted by multiple factors but not by any single physical character assessed. There appears to be scope for the development of decision tools for manure-compost quality. Further work is required to refine/ qualify the physical parameter categories and to apply these to more specific sub-types of manure-compost.

Experiment 1: *Collection and Composting Strategies to Enhance Fertiliser Quantity and Quality and the impact on maize growth over two seasons*

The total amount of excreta (faeces and urine) and feed refusals collected over the 60-day period is shown in Table 46. The weight of the manure-compost at the end of the Collection Period are also shown in Table 46. Although addition of urine to the heaps contributed to the total fresh mass accumulated, those combinations mixed by hand that included urine (F+U+FR and F+U) also recorded the greatest weight. This may be due to evaporative and leaching losses.

Table 46. Fresh weights of material collected during the 60-day accumulation phase.

Manure type	Amount of waste collected (kg steer^{-1})			Total collected (kg steer^{-1})	Mass of manure at end of collection phase (kg steer^{-1})	Fresh weight loss of manure during collection (kg steer^{-1})	% loss
	Faeces	Urine	Feed refusals				
Stable	na	na	na	na	540	na	na
F+U+FR	573	272	69	913	644	269	29
F+FR	561	na	67	628	484	145	23
F+U	594	221	na	815	635	180	22
F	553	na	na	553	456	97	17

F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal
na = measurement not applicable to, or not possible for, this particular collection strategy

Tiquia *et al* (1996) reported that manure containing 70% moisture is slower in attaining the peak temperature but once attained the temperature does not go back to the ambient temperature in contrast to manure with 50-60% moisture content. Prolonged storage at the higher temperature will result in high evaporation rates.

Table 47 shows that there were no significant differences in dry matter intake by the steers during the 60-day Collection Period. Steers produced 0.76-0.81% of initial liveweight weight as faecal dry matter. Highest losses during the Collection Phase occurred with treatment F (26%). However, loss of dry matter during the Composting Phase was highest with the methods containing feed refusals probably reflecting a greater rate of aerobic composting in the larger, more loosely packed heaps with refusals. Overall loss between Collection and the end of the Composting Phase was 41-51% for all methods except F+U which was very low (18%). F+U formed a wet heap that rapidly became capped with a dry layer, probably reducing the rate of further decomposition. Highest dry matter return to the soil after composting was, therefore, with F+U (86 kg $steer^{-1}$) and this would have been even higher if the refusals were added directly to the soil without composting (F+U manure + feed refusals = 135 kg $steer^{-1}$).

Table 47. Dry matter budget during 60-day accumulation phase and 84-day composting phase for five manure collections methods.

	Dry matter					LSD
	S[1,2]	F+U+FR	F+FR	F+U	F	p = 0.05
Feed intake (kg $steer^{-1}$)	335	368	357	367	357	NS[4]
Faeces (kg $steer^{-1}$)	93	102	96	105	98	NS
Feed refusals (kg $steer^{-1}$)	41	47	46	49[3]	37[3]	NS
Total produced (kg $steer^{-1}$)	134	149	142	155	135	NS
Total added to heaps (kg $steer^{-1}$)	134	149	142	105	98	NS
Total accumulated at end of 60 days (kg $heap^{-1}$)	114	135	128	99	73	12
Total after 84 days composting (kg $heap^{-1}$)[4]	66***	75***	73***	86***	58*	7
Loss during accumulation (%)	15	9	10	6	26	-
Loss during composting (%)[6]	41a	44a	43a	13c	21b	-
Overall loss (%)	51	50	49	18	41	-

[1]F = faeces; U = urine; FR = feed refusals; S = Stable faeces, urine and feed refusals mixed on floor by animal
[2]Faeces production for this collection strategy estimated pro-rata from feed intake
[3]Recorded but not added to manure heap
[4]NS = not significant [5]Reduction during composting significant at ***p<0.001; **p<0.01; *p<0.05
[6]Values not followed by the same letter differ significantly at p = 0.05

On average, 28 and 18% of the N input as feed was recovered in faeces and urine, respectively (Table 48). Greatest losses in nitrogen during the accumulation phase were observed in heaps that had high moisture contents from the addition of urine (B, F+U+FR and F+U) which lost 37, 38 and 33 %, respectively of the N collected during the accumulation phase itself. It is suspected that ammonification of the nitrogen in urine proceeds so fast that a high proportion of ammonia is volatilised even in the presence of stover in manure. Gaseous loses are reportedly always higher than leaching losses. Dewes (1994) observed that in a 177-day experiment with cattle manure, only 2.5-3.4 % of initial nitrogen content leached with liquid, but 25-44 % of it was lost by ammonia emission. The high N content of urine-containing manure-composts may also have stimulated the rate of microbial decomposition within the heaps accelerating the reduction of organic carbon content by respiration.

The use of bedding as a means to conserve N in manure is a traditional practice in mixed farming in many climates and agricultural systems. The results show that addition of feed refusals to faeces (F+FR) leads to greater overall conservation of N than with faeces alone. However, the addition of stover in this particular case was either insufficient or ineffective at conserving N in heaps where urine was added (Stable and F+U+FR treatments) In both cases very large losses of N occurred compared with F+FR. In the Stable and F+U+FR treatments, not only was the additional N due to urine completely lost the final composts had an even lower N content (1.0 and 1.2 kg N $steer^{-1}$, respectively) that that was obtained than with the urine-free F+FR (1.4 kg N $steer^{-1}$).

Faeces alone (F) showed a relatively small N loss during the collection and composting phases. The storage of some of the manures during the accumulation phase, including faeces alone, may have resulted in compaction and anaerobic conditions that lower the pH and reduce ammonia volatilisation while diffusion is slowed down (Kemppainnen, 1989; Kirchmann and Witter, 1989).

Table 48. Nitrogen budget during 60-day accumulation phase and 84-day composting phase for five manure collections methods.

	Nitrogen					LSD
	S[1,2]	F+U+FR	F+FR	F+U	F	p = 0.05
Feed intake (kg steer^{-1})	5.0	5.5	5.3	5.5	5.3	NS[4]
Faeces (kg steer^{-1})	1.4	1.5	1.5	1.6	1.5	NS
Feed refusals (kg steer^{-1})	0.41	0.52	0.56	0.54[3]	0.40[3]	NS
Urine (kg steer^{-1})	0.9	1.2	1.0[3]	0.8	1.0[3]	
Total produced (kg steer^{-1})	2.71	3.22	3.09	2.94	2.93	
Total added to heaps (kg steer^{-1})	2.71	3.22	2.06	2.40	1.50	
Total accumulated at end of 60 days (kg heap^{-1})	1.7	2.0	2.1	1.6	1.2	0.20
Total after 84 days composting (kg heap^{-1})[4]	1.0**	1.2**	1.4**	1.3**	0.9**	0.12
Loss during accumulation (%)	37	38	0	33	20	
Loss during composting (%)[6]	38a	37a	35a	19b	22b	-
Overall loss (%)	63	63	32	46	40	

[1]F = faeces; U = urine; FR = feed refusals; S = Stable: faeces, urine and feed refusals mixed on floor by animal
[2]Faeces and urine production for this collection strategy estimated pro-rata from feed intake
[3]Recorded but not added to manure heap
[4]NS = not significant
[5]Reduction during composting significant at ***p<0.001; **p<0.01
[6]Values not followed by the same letter differ significantly at p = 0.05

As an overall strategy for the maximum conservation and return of N to the soil, composting of faeces and feed refusals (F+FR) resulted in a composted manure yielding slightly more (1.4 kg N steer^{-1}) than the next best treatment, F+U (1.3 kg N steer^{-1}). Potentially, however, from the F+FR treatment, 1 kg N steer^{-1} was also available for direct return to the soil, possibly as a liquid slurry, resulting theoretically in 2.4 kg N steer^{-1}. It is not clear to what extent this urinary N would contribute to crop production if applied since loss of N from urine applied to the soil can be both rapid and extensive (Powell *et al*, 1998). However, in the F+FR treatment any additional gain from the direct use of urine would be a net benefit compared to the consequences of the alternative strategy of adding the urine to the manure heap.

A further scenario, of composting faeces alone and adding urine and feed refusals directly to the soil would also theoretically add considerably more N to the soil, as would the direct addition of <u>all</u> materials to the soil daily. However, with these approaches, the more rapid loss of N from volatile sources, leaving high C:N residues might lead to higher levels of soil N immobilisation than with the well rotted, mature composts actually produced from this experiment.

Organic C and total N changes during composting.

Organic C: The organic C concentration (%) in all manure composts might be expected to show some decline as CO_2 is lost through respiration. In fact, a significant change in percent C was detected only with the F+U+FR manure (Figure 13).

Nitrogen: Figure 14 shows the change in N concentration during the composting period. The two treatments lacking feed refusals, F+U and F showed virtually no change in N concentration during the composting process. In contrast, the manure-composts containing feed refusals increase in percent N as the compost matures by aerobic decomposition, losing C and conserving N. The increase in percent N was particularly significant for the F+FR treatment and just significant for the F+U+FR collection method.

Figure 13. Change in percent organic C during 84-day composting period.

F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal

Stable: y = 0.213x + 33.3; R^2 = 0.193; p = 0.089
F+U+FR: y = -0.2764x + 36.9; R^2 = 0.396; p = 0.005
F+FR: y = 0.021x + 37.0; R^2 = 0.001; p = 0.909
F+U: y = -0.040x + 39.3; R^2 = 0.029; p = 0.529
F: y = -0.020x + 38.1; R^2 = 0.002; p = 0.867

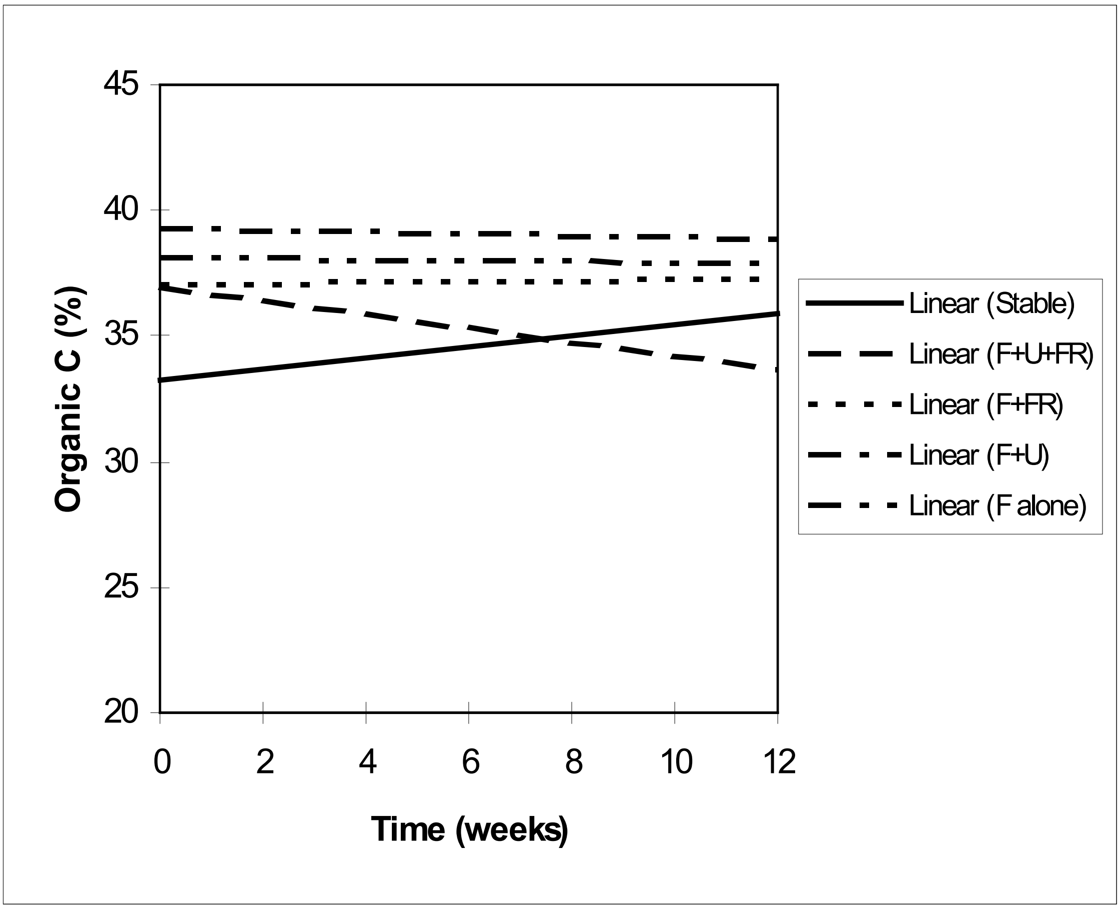
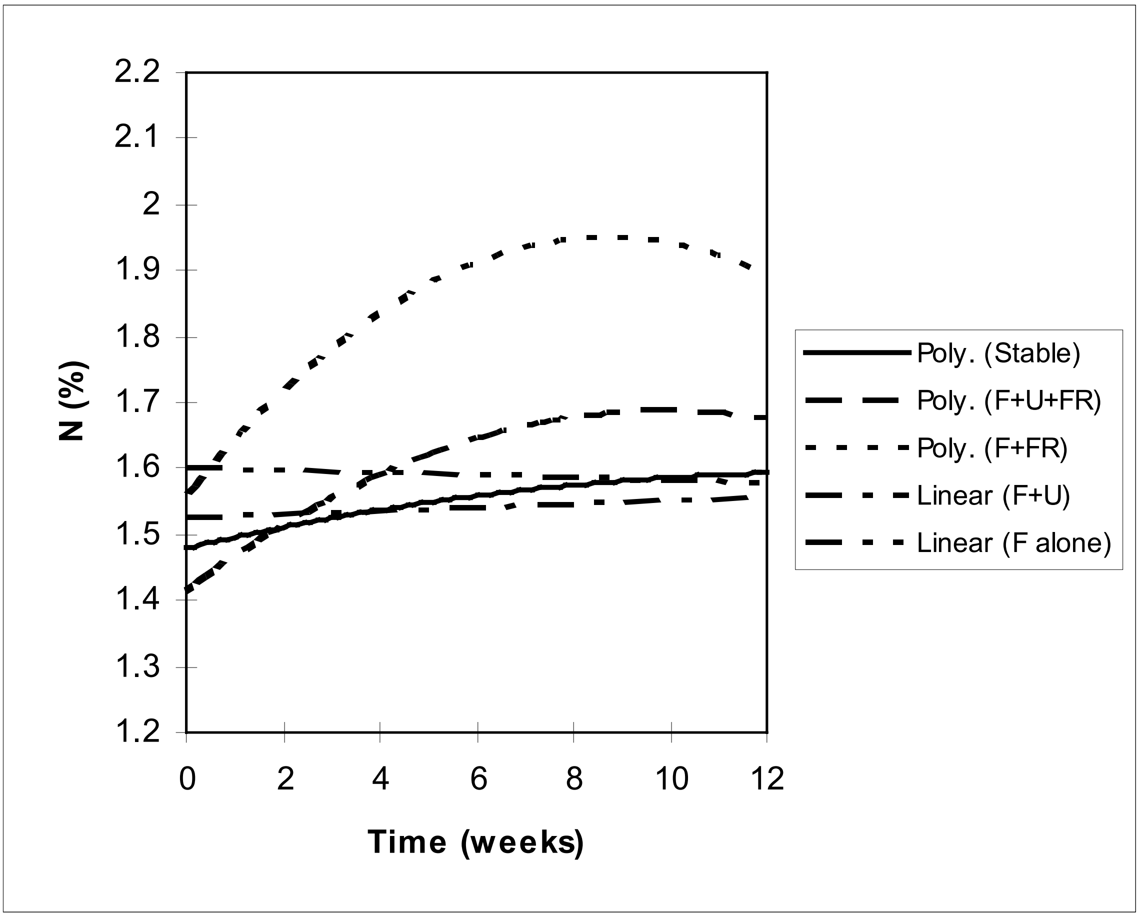

45
40
35
30
25
20
Organic C (%)
0
2
4
6
8
10
12
Time (weeks)
Linear (Stable)
Linear (F+U+FR)
Linear (F+FR)
Linear (F+U)
Linear (F alone)

Figure 14. Change in percent N during 84-day composting period.

F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal

Stable: $y = -0.001x^2 + 0.017x + 1.479$; $R^2 = 0.152$; p (linear) = 0.148
F+U+FR: $y = -0.003x^2 + 0.053x + 1.416$; $R^2 = 0.278$; p (linear) = 0.069
F+FR: $y = -0.005x^2 + 0.090x + 1.556$; $R^2 = 0.474$; p (linear) = 0.024
F+U: $y = 0.002x + 1.527$; $R^2 = 0.008$; p (linear) = 0.750
F: $y = -0.002x + 1.601$; $R^2 = 0.004$; p (linear) = 0.813


2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
N (%)
0
2
4
6
8
10
12
Time (weeks)
Poly. (Stable)
Poly. (F+U+FR)
Poly. (F+FR)
Linear (F+U)
Linear (F alone)

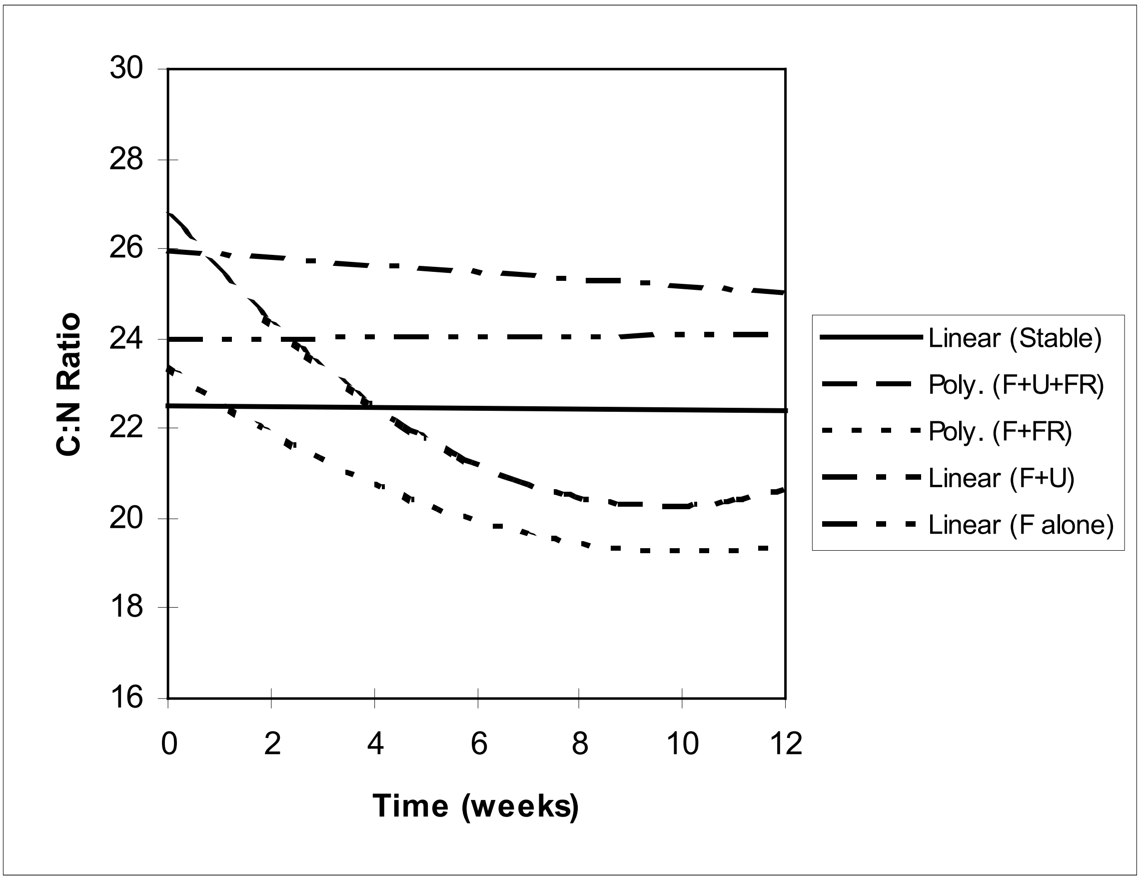
C:N ratio: The net result of the changes in C and N during composting are presented as C:N ratios in Figure 15. Again, significant changes in C:N ratio were detected only with F+FR and F+U+FR, both of which showed the decline in C:N ratio which is expected during aerobic composting, leading to a stable, mature compost. The Stable manure did not show a significant decline in C:N ratio, but this was already at a relatively low level at the start of the Composting Phase, suggesting that a considerable amount of aerobic composting had taken place during the Collection Phase when the materials were mixed by the animal and exposed as a layer spread across the floor of the cow shed.

Overall quality: The results give a good indication the differences in the quality of the manure-compost that can arise from different collection strategies. Based on the N and P concentrations and especially on the C:N ratio, the feed refusals-containing manures, F+FR, F+U+FR and Stable, appear to produce the best quality manure-composts, with the F+FR being the best quality as well as conserving the greatest amount of N.

Figure 15. Change in C:N ratio during 84-day composting period.

F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal

Stable: $y = -0.009x + 22.5$; $R^2 = 0.0004$; $p = 0.942$
F+U+FR: $y = -0.060x^2 - 1.25x + 26.7$; $R^2 = 0.450$; p (linear) = 0.021
F+FR: $y = 0.040x^2 - 0.810x + 23.4$; $R^2 = 0.332$; p (linear) =0.037
F+U: $y = -0.080x + 26.0$; $R^2 = 0.026$; $p = 0.551$
F: $y = 0.0085x + 24.0$; $R^2 = 0.000$; $p = 0.944$



C:N Ratio
30
28
26
24
22
20
18
16
0
2
4
6
8
10
12
Time (weeks)
Linear (Stable)
Poly. (F+U+FR)
Poly. (F+FR)
Linear (F+U)
Linear (F alone)

Sub-Experiment 1a: *Agronomic Experiment*

Two sites were selected for the field trials sites (Table 49). The data show that at Gatuanyaga the ferralsols are inherently low in available phosphorus, total nitrogen, soil organic matter and high in exchangeable cations, based on rankings by Okalebo *et al* (1993). The nitisols at Kariti are particularly low in nitrogen but not in the other nutrients. The rates of manure-composts (produced from the experiment above) were applied in the different treatments as shown in Table 44 together with the N %, C:N ratio and N and P application rates. Since nitrogen was considered to be the common limiting nutrient between the two sites manure-composts were applied in an iso-nitrogenous manner (at 75 kg N ha^{-1}) . The wide range of application rates providing 75 kg N ha^{-1} is a result of the range of moisture contents arising from the different manure management strategies.

Table 49. Soil characteristics at maize field trial sites.

Analysis	Gatuanyaga	Kariti
Soil pH (1:2.5 0.01M $CaCl_2$)	5.18	6.02
Total OC (%)	0.76	0.71
Total nitrogen (%)	0.07	0.10
Available phosphorus by Bray P_2 (ppm)	9.8	36.2
Exchangeable bases:		
- Potassium (mg $100g^{-1}$ soil)	41	20
- Calcium (mg $100g^{-1}$ soil)	75	120
- Magnesium (mg $100g^{-1}$ soil)	21	28

Table 50 shows the maize grain and stover yields in the field trials. It was observed that there was considerable variations between the replicates, especially for treatments where the manure-composts lacked feed refusals.

Table 50. Quality and quantity of manure applied in maize field trials at Gatuanyaga and Kariti sites.

Type of manure applied	Fresh weight applied (kg ha^{-1})	Dry matter (%)	Dry weight applied (kg ha^{-1})	N (%)	C:N ratio	N applied (kg ha^{-1})	P applied (kg ha^{-1})
Control	0	0	0	0		0	0
Farmer manure	13667	80.3	10975	1.1		121	34
Stable	21000	25.1	5271	1.6	23	75	23
F+U+FR	23708	21.3	5050	1.7	21	75	27
F+FR	14167	31.3	4434	1.9	19	75	23
F+U	28041	18.8	5272	1.5	24	75	30
F	31833	17.0	5412	1.6	25	75	29
Masai manure	13667	85.5	11685	0.8		75	30

F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal

Maize yield: Table 51 shows the maize grain and stover yields in the field trials for the first season, harvested in the first week of October 1998. There was considerable variation between replicates, especially for treatments where manure lacked feed refusals.

At Gatuanyaga, the Maasai manure and the F+FR manure resulted in significantly higher grain yield than in the unfertilised control. These two manures and the stable manure significantly increased stover yield. There was no significant difference in harvest index between the unfertilised and fertilised crops nor between the manure-compost types.

At Kariti, yields of grain and stover and harvest index for all treatments were higher than at Gatuanyaga, reflecting the better soil conditions at the former site. At Kariti, all of the manure-compsts except the farmer's own manure significantly improved grain yield compared with the unfertilised control, despite the higher N application rate with the farmer's manure. Of the experimental manures-composts, the greatest yield (F+FR, 4336 kg ha^{-1}) was significantly higher than the lowest yield (F+U, 2916 kg ha^{-1}). Of the experimental manures, all (except F+U) gave significantly higher grain yields than the farmer's own manure. Similarly, all of the manure-composts except the farmer's own significantly improved stover yield at Kariti compared with the unfertilised control. Stover yield with the best experimental manure (F+U+FR, 3805 kg ha^{-1}) was significantly higher than the lowest yield (F+U, 2648 kg ha^{-1}). There was no significant difference in harvest index at Kariti between the unfertilised and fertilised crop nor among the manure types.

The residual (second) season yield and the total yield over the two season are shown in Table 52 for the Kariti site. The Gatuanyaga site did not yield any maize in the second season due to prolonged drought. The crop just managed to germinate before drying up completely. Hence the trial was abandoned at Gatuanyaga site. At the same time the crop struggled to reach maturity at Kariti. Only Maasai manure showed significantly higher grain and stover yields than the control. The experimental manure-composts gave higher grain yields compared to the the control (971 kg ha^{-1}) by amounts ranging between 171 and 593 kg ha^{-1} and showed a similar trend in yield responses to the first season with best yields obtained from F+FR (1564 kg ha^{-1}) and F+U+FR (1542 kg ha^{-1}), and the lowest being F (1142 kg ha^{-1}).

For the Kariti site, the two-season overall grain and stover yields differed significantly between the fertilised and the unfertilised plots. Grain yield over and above the control (2342 kg ha^{-1}) ranged between 868 and 4169 kg ha^{-1}. Stover yield ranged between 833 and 3841 kg ha^{-1} above the control (2659 kg ha^{-1}). Overall, the effect of manure application on the order of maize performance in terms of grain production and total aboveground dry matter production followed the order Maasai manure > F+FR > F+U+FR > Stable > F+U > F > Farmer manure. A similar trend was observed for the two season total aboveground biomass dry matter production except that F+FR and F+U+FR swap positions.

Table 51 Yield data from maize field trials at Gatuanyaga and Kariti sites in the first season.

	Gatuanyaga			Kariti		
	Grain (kg ha^{-1})	Stover (kg ha^{-1})	HI[a]	Grain (kg ha^{-1})	Stover (kg ha^{-1})	HI
Control	636	1650	0.27	1371	1396	0.47
Farmer manure	-	-	-	2287	2155	0.52
Stable	789	2627	0.21	3718	3669	0.48
F+U+FR	982	2177	0.35	3996	3805	0.48
F+FR	1251	3112	0.30	4336	3601	0.52
F+U	829	1789	0.31	2916	2648	0.51
F	839	1791	0.32	3592	3268	0.50
Maasai manure	1419	2644	0.35	4447	4471	0.48
LSD (p = 0.05)	417	912	NS[b]	1140	1086	NS

F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal; [a]HI = harvest index; [b]NS = not significant

Manure chemical characteristics and maize performance: C:N ratio is commonly used to define the quality of organic soil amendments. This is because of its influence on the C:N ratio. The relationship between the first season maize grain and aboveground biomass dry matter production with initial manure C:N ratio of the experimentally constituted manures are shown in Figures 16 and 17 for the two sites where significant linear relationship with negative slope was observed. This observation suggests that better maize yields could be obtained with higher quality manure of lower C:N ratio.

Figure 16. Relationship between C:N ratio of experimental manures and maize grain yield.

Gat = Gatuanyaga, Thika District; Kar = Kariti, Maragua District

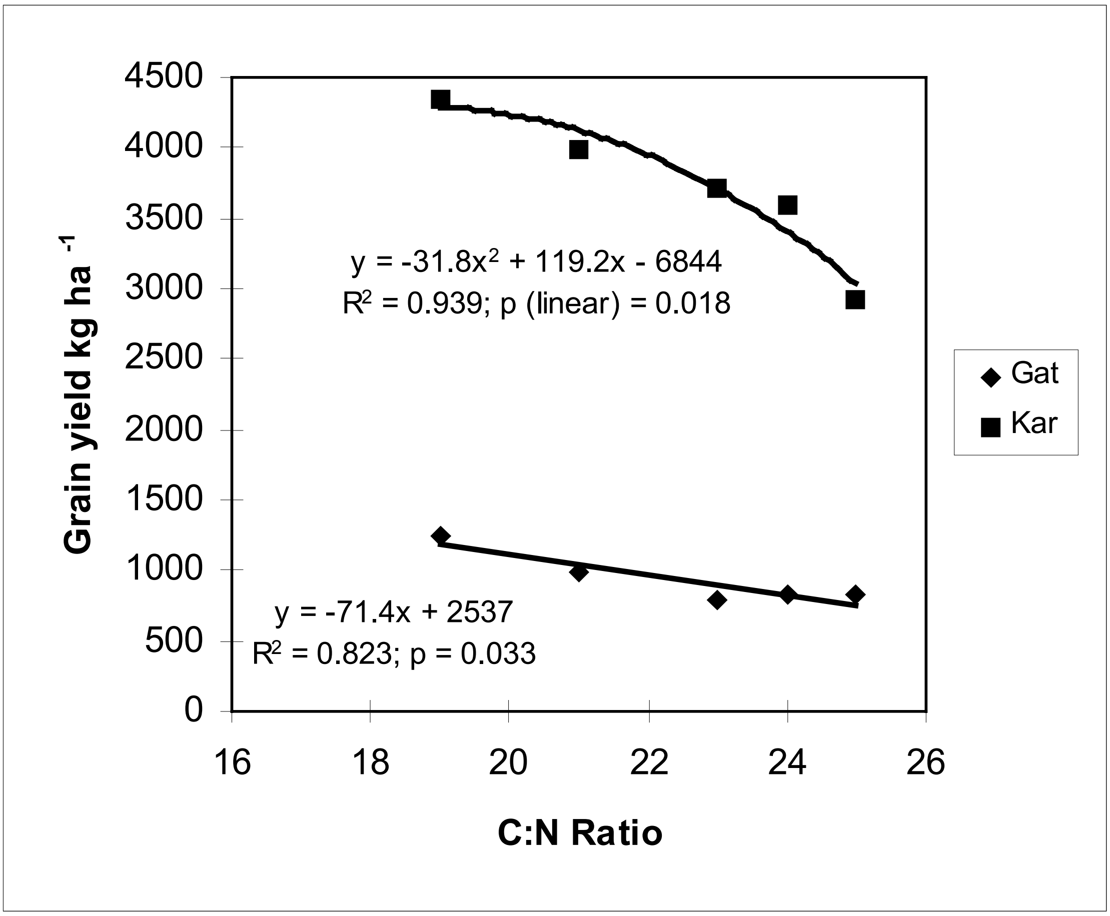


Figure 17. Relationship between C:N ratio of experimental manures and total maize biomass production.

Gat = Gatuanyaga, Thika District; Kar = Kariti, Maragua District

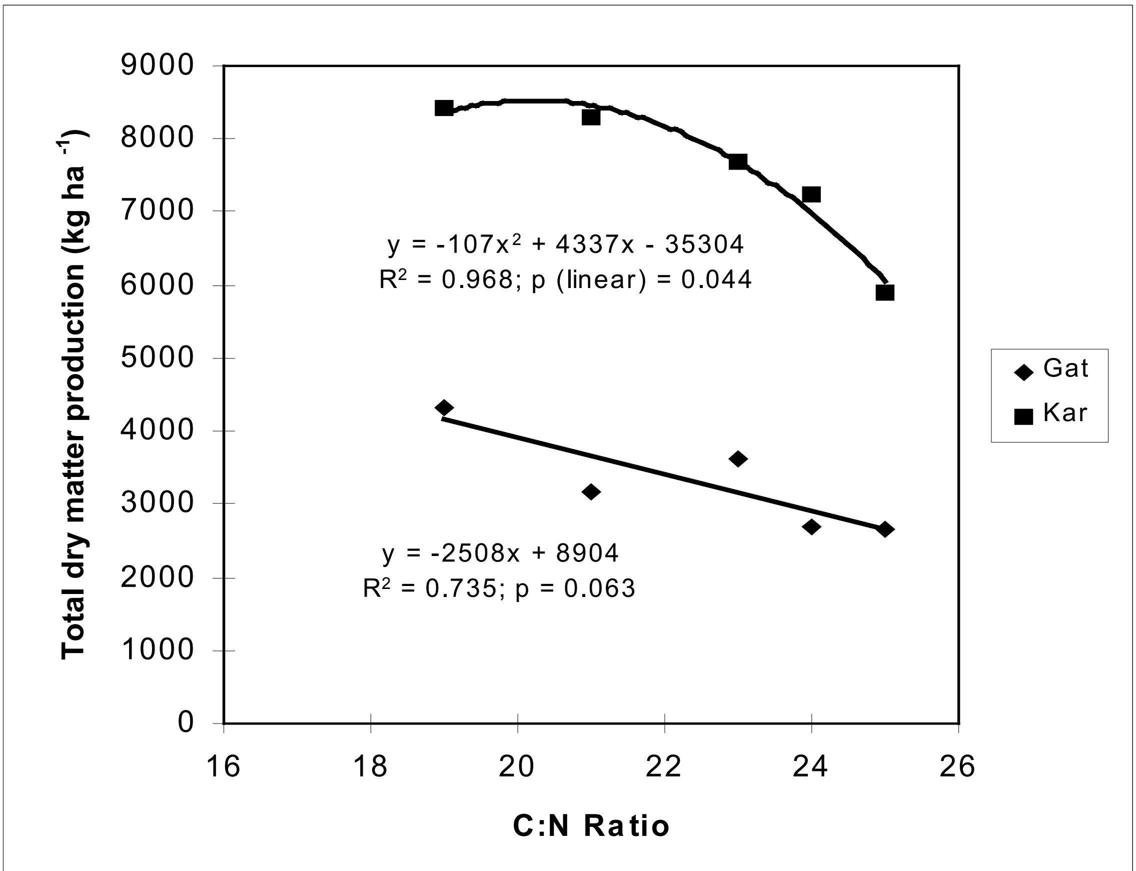

9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Total dry matter production (kg ha -1)
y = -107x2 + 4337x - 35304
R2 = 0.968; p (linear) = 0.044
y = -2508x + 8904
R2 = 0.735; p = 0.063
Gat
Kar
16
18
20
22
24
26
C:N Ratio

Table 52. Yield data from maize field trials at Kariti sites in the second season and total over the two seasons.

	Second season			Overall two seasons		
	Grain (kg ha^{-1})	Stover (kg ha^{-1})	HI[a]	Grain (kg ha^{-1})	Stover (kg ha^{-1})	HI
Control	971	2235	0.44	2342	2659	0.39
Farmer manure	922	2281	0.40	3210	3513	0.44
Stable	1334	3364	0.40	5053	5699	0.46
F+U+FR	1542	3950	0.40	5538	6212	0.50
F+FR	1564	3574	0.42	5901	5610	0.51
F+U	1402	3556	0.41	4994	5422	0.49
F	1142	2817	0.40	4059	4322	0.50
Maasai manure	2064	4093	0.50	6511	6500	0.55
LSD (p = 0.05)	812	1750	NS	2653	2964	NS

F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal; [a]HI = harvest index; [b]NS = not significant

Other parameters that can be used to describe the quality of organic materials include lignin, polyphenols and NDF-N. Table 53 shows correlation coefficients between some of these manure quality measurements and maize grain, stover and aboveground biomass dry matter production over the two seasons in the more fertile Kariti site. Lignin and NDF-N content show significant positive correlation with grain yield in the first and second season and with biomass dry matter produced in the first season.

Table 53. Correlation coefficients between some quality parameters of the five experimental manures and maize yield at Kariti site.

	Grain season 1	Stover season 1	Total season 1	Grain season 2	Stover season 2	Total season 2	Grain seasons 1 + 2	Stover season 1 + 2	Total season 1+2
Soluble C (%)	0.53	0.66	0.58	0.33	0.18	-0.51	0.48	0.51	0.50
Soluble N (%)	-0.30	-0.69	-0.45	-0.26	-0.62	0.79	-0.29	-0.69	-0.47
Soluble C:N ratio	0.20	0.56	0.32	0.03	0.21	**-0.93**	0.16	0.45	0.28
NDF-N (%)	**0.93**	0.75	**0.89**	**0.86**	0.45	0.23	**0.92**	0.67	**0.84**
C:NDF-N ratio	**-0.92**	-0.75	**-0.88**	**-0.84**	-0.43	-0.18	**-0.91**	-0.67	**-0.83**
Soluble P (5)	-0.69	-0.79	-0.72	-0.51	-0.38	0.52	-0.65	-0.67	-0.66
Lignin (%)	**0.89**	**0.96**	**0.93**	0.78	0.62	-0.32	**0.87**	**0.88**	**0.89**
Lignin:N ratio	0.77	**0.97**	**0.86**	0.70	0.75	-0.49	0.76	**0.93**	**0.86**
Ash (%)	0.67	0.29	0.56	0.77	0.36	**0.82**	0.70	0.33	0.57
Total organic C (%)	-0.74	-0.46	-0.65	-0.62	-0.08	-0.32	-0.72	-0.34	-0.57
TKN (%)	**0.86**	0.70	**0.81**	0.71	0.25	0.06	**0.83**	0.56	0.73
Tot C:TKN	**-0.91**	-0.84	**-0.86**	-0.69	-0.22	-0.12	-0.80	-0.51	-0.69
ADF (%)	0.71	0.75	0.77	**0.84**	**0.93**	0.10	0.75	**0.86**	**0.84**

Bold values are significant at p = 0.05 for a two tailed test. For a one-tailed (Q) and a two-tailed (2Q) test and 5 treatments the critical percentage points for significant levels of correlation coefficient, r, are as follows: for Q, p=0.05, and 2Q, p=0.1, r=0.805; Q, p=0.025 and 2Q, p=0.05, r=0.878; Q, p=0.01, and 2Q, p=0.02, r=0.934; Q, p=0.005, and 2Q, p=0.01, r=0.959.

N, P and K uptake by maize: In the first season, when both sites yielded maize, significantly higher N uptake in aboveground biomass was observed with the F+FR and Masaai manure fertilised crop than the unfertilised crop (Table 54) in Kariti and with Stable and Masaai manure in Gatuanyaga. The crops at Kariti showed higher N uptakes ranging between 27.2 and 65.0 kg ha^{-1} compared to the Gatuanyaga crop that ranged between 15.0 and 23.8 kg ha^{-1}. Crops fertilised with Maasai manure removed the highest quantities at both sites. Over the two seasons the uptake of applied N ranged between 10 to 48% with highest recovery observed in Stable, F+U+FR and F+FR and lowest in farmer's manure, F and F+U treatments.

Total P uptake by the maize crop is shown in Table 55 and differed significantly between treatments and ranged between 5.3 and 9.5 kg ha^{-1} in Gatuanyaga ($p = 0.0193$) and between 4.8 and 11.6 kg ha^{-1} at Kariti ($p = 0.0226$).

Total K uptake ranged between ranged between 8.3 and 13.7 kg ha-1 and 57.6 and 123.8 kg ha-1 at Gatuanyaga and Kariti sites, respectively, and differed significantly between the fertilised and the unfertilised plots at Kariti but not at Gatuanyaga (Table 56).

Table 54. Nitrogen uptake by maize at field trials at Gatuanyaga and Kariti sites in the first season.

Treatment[1]	Gatuanyaga Season 1			Kariti Season 1			Kariti Season 2		
	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N
Control	7.5	7.5	15.0	15.3	11.8	27.2	19.8	9.4	29.2
Farmer manure	5.1	7.7	12.8	25.6	15.9	41.4	15.9	12.5	25.4
Stable	7.7	9.8	17.5	41.1	22.8	63.9	19.7	11.2	30.9
F+U+FR	10.1	9.9	20.0	44.1	16.0	60.1	19.2	9.9	29.1
F+FR	12.3	9.2	21.5	41.4	17.7	59.1	18.5	11.7	30.2
F+U	8.2	8.9	17.1	39.1	14.4	53.5	15.3	8.4	23.7
F	6.8	5.3	12.2	27.4	12.4	39.9	14.6	9.5	24.1
Maasai manure	13.6	10.2	23.8	48.9	16.1	65.0	18.4	9.1	27.5
LSD (p = 0.05)	6.30	[2]NS	8.89	29.19	NS	36.65	NS	NS	NS

[1]F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal; [2]NS = not significant

Table 55. Phosphorus uptake by maize at field trials at Gatuanyaga and Kariti sites in the first season.

Treatment[1]	Gatuanyaga Season 1			Kariti Season 1			Kariti Season 2		
	Grain P (kg ha^{-1})	Stover P (kg ha^{-1})	Total P	Grain P (kg ha^{-1})	Stover P (kg ha^{-1})	Total P	Grain P (kg ha^{-1})	Stover P (kg ha^{-1})	Total P
Control	3.0	2.3	5.3	2.8	2.0	4.8	3.4	3.0	6.4
Farmer manure	1.8	4.3	6.1	5.2	0.8	6.0	2.9	1.6	4.5
Stable	3.3	4.5	7.8	8.9	1.1	10.0	3.6	2.0	5.6
F+U+FR	3.9	4.5	8.4	10.6	1.0	11.6	3.7	1.5	5.2
F+FR	4.7	4.6	9.3	9.7	0.9	10.6	2.8	0.6	3.4
F+U	3.3	4.0	7.3	9.2	1.0	10.2	2.9	1.4	4.3
F	2.7	2.8	5.6	5.1	1.1	6.2	3.5	0.5	4.0
Maasai manure	5.1	4.4	9.5	10.0	1.1	11.1	3.3	0.3	3.6
LSD (p = 0.05)	2.73	[2]NS	4.48	6.58	NS	7.32	NS	NS	NS

[1]F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal; [2]NS = not significant

Table 56. Potassium uptake by maize at field trials at Gatuanyaga and Kariti sites in the first season.

Treatment[1]	Gatuanyaga			Kariti					
	Season 1			Season 1			Season 2		
	Grain K (kg ha^{-1})	Stover K (kg ha^{-1})	Total K	Grain K (kg ha^{-1})	Stover K (kg ha^{-1})	Total K	Grain K (kg ha^{-1})	Stover K (kg ha^{-1})	Total K
Control	8.3	73.8	82.1	14.9	42.6	57.6	7.6	26.2	33.8
Farmer manure	5.2	53.2	58.4	25.9	36.2	62.1	6.5	30.7	37.2
Stable	9.4	63.0	72.4	47.1	76.6	123.8	9.0	34.2	43.2
F+U+FR	10.3	68.4	78.7	51.5	52.2	108.8	9.0	37.4	46.4
F+FR	13.0	80.8	93.8	47.6	65.1	112.7	8.9	44.2	53.1
F+U	9.0	65.5	74.4	43.4	41.9	85.3	7.1	25.7	32.8
F	8.5	39.5	48.0	32.0	42.7	74.6	6.4	24.1	30.5
Maasai manure	13.7	72.4	86.2	48.6	73.8	122.3	8.9	33.2	42.1
LSD (p = 0.05)	7.91	[2]NS	NS	30.54	NS	73.84	NS	NS	NS

[1]F = faeces; U = urine; FR = feed refusals; Stable = faeces, urine and feed refusals mixed on floor by animal; [2]NS = not significant

Discussion

Yield response to manure quality: Since the five experimental manure-composts were applied at a constant 75 kg N ha^{-1}, differences in yield must be associated with some other parameter of manure quality. C:N ratio may be this parameter since there were significant regression coefficients for the linear relationships between this ratio and first season grain yields at both sites. However, the second season crop in Kariti did not show a significant relationship between these parameters.

Overall, the data obtained for the two seasons combined showed significant relationship between lignin and aboveground biomass, and between NDF-N and grain. This observation suggests that secondary plant compound content of forage and bedding could ultimately have an effect on crop yield. Manure-composts derived from forages or bedding containing a high proportion of bound N may not have an impact upon crop yields in the first season but in subsequent seasons. This slow release of N may fit more closely to the requirements of growing plants than that from highly soluble sources (Meyers *et al*, 1994).

At both sites the Masaai manure gave the highest grain despite being the manure of lowest quality in terms of N content and C:N ratio. It is hypothesized that the physical characteristics of manure at time of application may play an important role in determining the rate of nutrient release. Maasai manure is normally purchased from semi-arid areas composed of dry particles most of which can pass through a 10 mm screen. Upon application a higher surface area comes into contact with compared with manure made up of bigger clods. This may lead to enhanced nutrient mineralisation.

Another possible reason for the good performance of Masaai manure may be attributable to a situation similar to the phenomena known as N-flush or the "Birch Effect" where a significant mineralisation of organic N occurs in soil at the onset of rains after a long dry period. Application of this relatively dry manure to moist soil may trigger a similar reaction.

Benefits of manure: Table 57 shows the production of fresh manure-compost manure per animal ("cow" of average liveweight for animals used in the experiments) on an annual basis. Together with the additional grain and stover per ton of manure applied, calculated from manure application rates and crop responses allows the calculation of the theoretical additional crop production per animal and the area of land required to achieve this.

With the best manure-compost production strategy tested in this experiment (F+FR), the manure-compost from one animal is worth an extra 296 kg of maize grain and 360 kg of stover above the no cow/no manure level on Kariti soils. There is a considerable difference between the best and worse manure collection strategies. An earlier survey of manure collection by smallholder farmers in this area indicated a variation in methods used. Many farmers are currently collecting manure using methods which appear to be very wasteful resulting in unnecessary losses of manure quantity and quality. Thus, there seems to be considerable scope for promotion of the optimum (but very simple) collection methods used in this research.

For a small farm in the highlands of 0.45 ha and 38% (or 0.17ha) of its land sown to maize each season the experiment shows how with a complement of 3.1 large cattle, 1.5 small cattle and 1.5 small ruminants (Structured Survey 1) can supply sufficient manure to maintain the high application rates already observed in the area by Kagwanja (1996). Even with the worst experimental treatment (F) a cow supplies enough faeces to fertilise 0.06 ha at 75 kg N/ha. The average herd would thus be able to fertilize at least half the farm to this level of N input each year. With better manure management methods this application could cover more area at the same N rate. One note of caution however is that whilst supplying adequate N the manure-compost may be lacking in other nutrients particularly P.

Table 57.Yield benefits from manure of various origins.

	Additional grain (kg ha^{-1})	Additional stover (kg ha^{-1})	Manure applied (t FW ha^{-1})	Composted manure cow^{-1} yr^{-1} (kg)	Area fertilised at 75 kgN ha^{-1} (ha)	Additional grain (kg cow^{-1})	Additional stover (kg cow^{-1})
Gatuanyaga							
Stable	153	1021	21	1758	0.084	17	86
F+U+FR	346	571	24	2147	0.091	31	52
F+FR	615	1506	14	1416	0.100	61	151
F+U	193	183	28	2897	0.103	13	12
F	203	185	32	2085	0.065	21	19
Kariti							
Stable	2347	3669	21	1758	0.084	197	307
F+U+FR	2625	3805	24	2147	0.091	238	345
F+FR	2965	3601	14	1416	0.100	296	360
F+U	1545	2648	28	2897	0.103	160	274
F	2221	3268	32	2085	0.065	145	214

F = faeces; U = urine; FR = feed refusals; Stable = stable: faeces, urine and feed refusals mixed on floor by animal

Sub-Experiment 1b: *Nitrogen availability of composted cattle manure by laboratory and greenhouse incubation techniques*

Soils from both Kariti and Gatuanyaga sites contain inherently low total carbon hence organic matter and nitrogen according to guidelines given by Tekalign (1991). With regards to extractable phosphorus, Kariti soil containing 36 mg of available P kg^{-1} soil, seems to contain sufficient P to maintain plant growth compared with Gatuanyaga soil which contained only 9.8 mg P kg^{-1} soil. Okalebo *et al* (1991) working on a similar type of soils observed that 15 mg P kg^{-1} of Bray No.2 extractable P is the critical level below which responses are expected to occur. Kariti soil is classified as a humic nitisol with top soil (0-20 cm) composed of 31% sand, 56% clay and 13% silt and described as having a clay soil texture. Gatuanyaga soil is classified as a nitorhodic ferralsol with a sandy clay loam soil texture composed of 57% sand, 28% clay and 15% silt. Both soils are acidic (Table 58)

Table 58. Soils from maize field trial sites used in lab and greenhouse studies

Analysis	Gatuanyaga	Kariti
Soil pH (1:2.5 0.01M $CaCl_2$)	5.18	6.02
Total OC (%)	0.76	0.71
Total nitrogen (%)	0.07	0.10
Available phosphorus by Bray P_2 (mg kg ads)	9.8	36.2
Exchangeable bases:		
- Potassium (mg $100g^{-1}$ soil)	41	20
- Calcium (mg $100g^{-1}$ soil)	75	120
- Magnesium (mg $100g^{-1}$ soil)	21	28

Aerobic laboratory incubation.

Net cumulative N release patterns: The net cumulative N mineralisation of manures aerobically incubated in Kariti and Gatuanyaga soils are shown in Figure 18 and Figure 19 respectively. Compared with the non-amended control, all the manure-composts showed diminished mineral N or net cumulative nitrate+nitrate-N (NO_3+NO_2-N), ammonium-N (NH_4-N), and total mineral N (Min-N) in the first week of incubation in both soils. (Min-N was obtained by summation of the cumulative (NO_3+NO_2-N) and NH_4-N after any specific period of incubation. The extent and pattern of net N decline and net N release differed between manures and between periods of incubation in both soils. Hence, all the manure-composts incubated in Kariti soil showed net NH_4-N release between 2 and 6 weeks of incubation, followed by a net decline up to week 16 with the exception MM, Stable and F+U which showed a net release at week 12. Net cumulative NH_4-N release was observed for all manures incubated for between 6 and 9 weeks in Gatuanyaga soil followed by a net decline to the 16th week of incubation.

Figure 18 Net N mineralisation patterns for study manures incubated in Kariti soil.

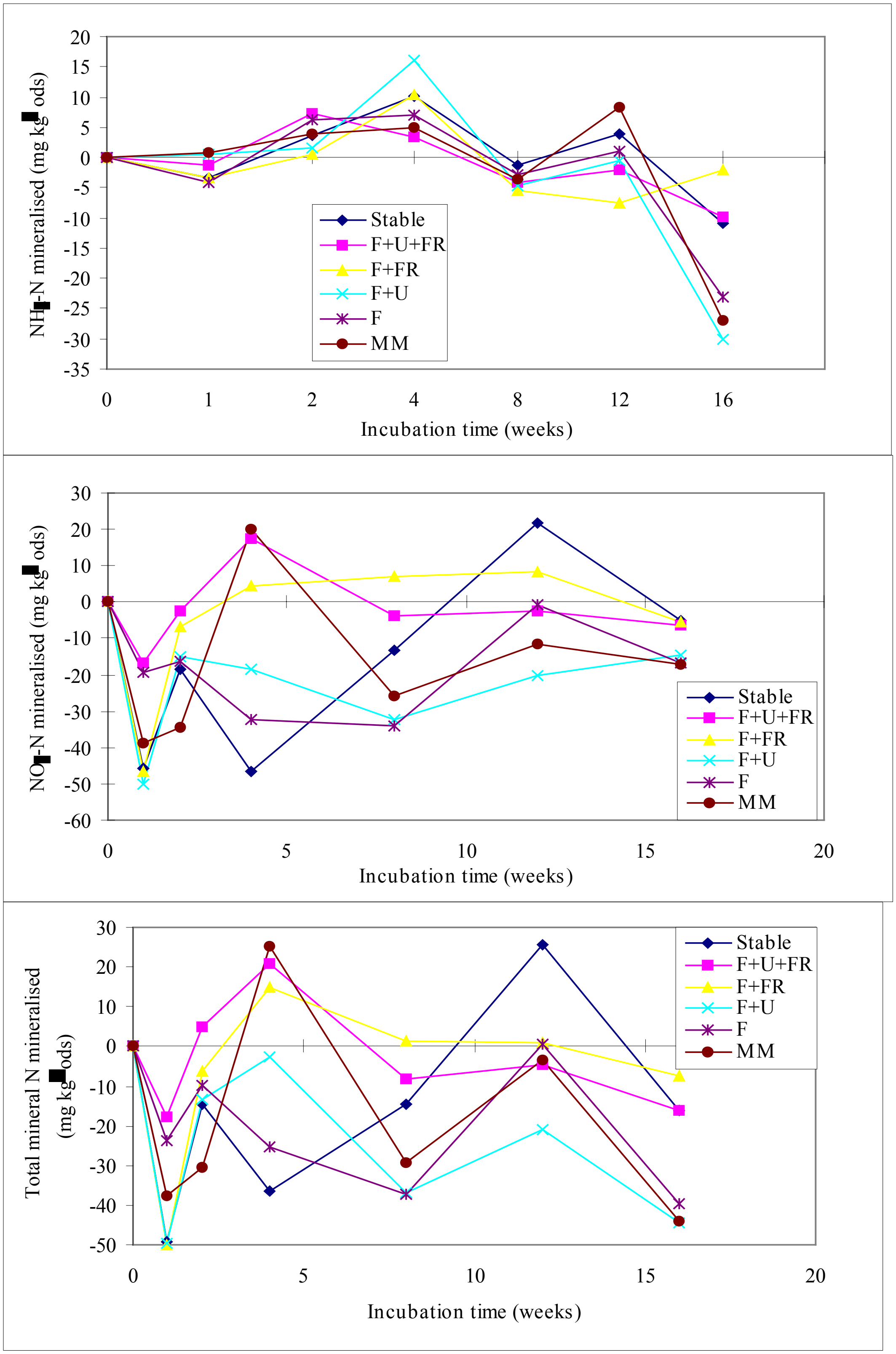
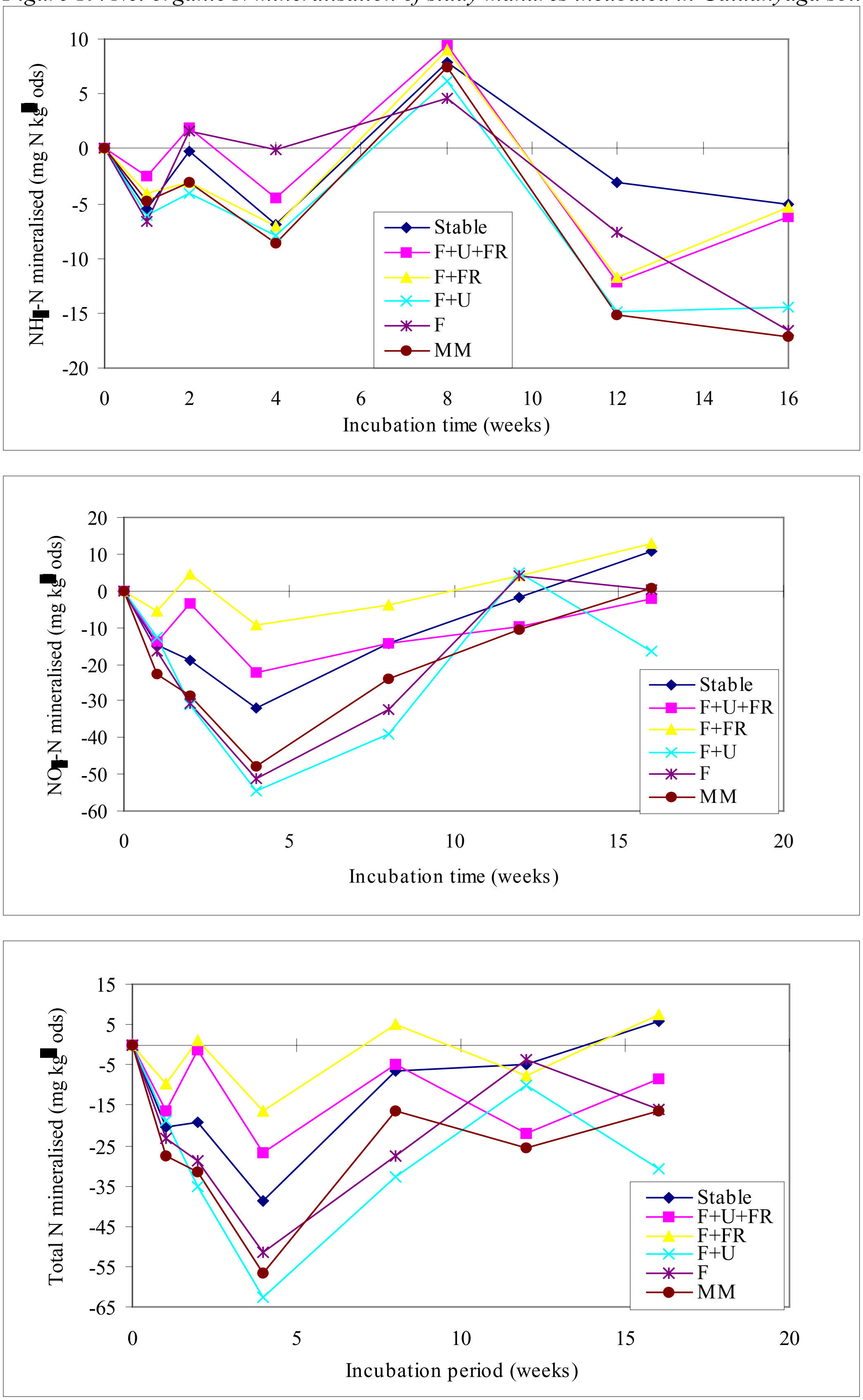


Figure 19. Net organic N mineralisation of study manures incubated in Gatuanyaga soil.



In Kariti soil, net cumulative NO_3-N decline was observed for F alone and F+U throughout the study period and Stable manure only showed a net NO_3-N release between 9-15 weeks. Net cumulative NO_3-N release was observed for Massai manure (MM)(3-5 weeks) and F+U+FR (between 2-7 weeks) and thereafter a net decline to the 16th week. M3 showed a net decline for the first 2 weeks and a net N release thereafter up to the 13th week followed by a net decline. There was no net NO_3-N release observed for Masaai manure and F+U+FR during the 16 weeks of incubation. In Gatuanyaga soil, net NO_3-N release was only observed after 2 weeks for F+FR, followed by a decline (between 3-10) and then net release that seemed would continue beyond the 16th week. Stable manure only showed net release at the 13th week and thereafter. Net NO_3-N release was also observed for F alone (between 11-13 weeks) and F+U (between 11-16 weeks).

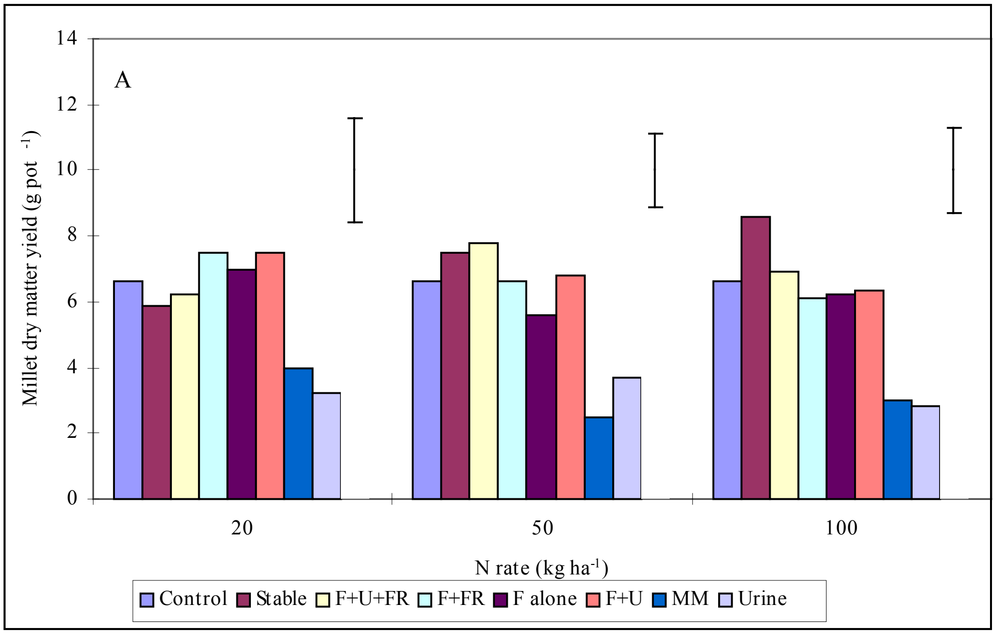
There was no net Min-N release of any of the manure in the first week of incubation in Kariti soil. Net total mineral N (Min-N) release, was maintained by F+U+FR (between 2-7 weeks) F+FR (between 3-13 weeks), MM (3-6 weeks) and Stable manure (between 9-15 weeks). In Gatuanyaga soil, all the manures maintained net negative Min-N throughout the study period except for F+FR which showed net release at week 2, between 7-9 weeks and 14-16 weeks and Stable which also showed a release at between weeks 14-16.

Greenhouse study:

DM yield and N uptake: Finger millet shoot dry matter (DM) yields obtained when Kariti and Gatuanyaga soils were amended with of the study manures and urine applied at 25, 50 and 100 kg N ha^{-1} are shown in Figure 20. For the Kariti soil, Masaai manure and Urine resulted in shoot DM yield lower than the control for the three rates of application. The rest produced yields similar to the control and did not differ significantly between application rates. For Gatuanyaga soil only F+FR resulted in a yield higher than the control at all the application rates while F+U+FR was higher at 50 and 100 kg N ha^{-1}. Overall there were no significant differences between the rates. The more fertile Kariti soil always produced approximately four-fold higher yields than Gatuanyaga soils probably due to the higher N mineralised in the former if the mineralisation trends were considered. For the Kariti soil, a significant relationship with positive slope was observed between shoot dry matter and total organic carbon (C) and Total Kjeldahl Nitrogen (TKN) while the relationship with C:N ratio was linear and negative slope.

N mineralisation and shoot N uptake: N uptake by the finger millet shoots are shown in Figure 21 where significant treatment differences were observed. On Kariti soils plants receiving F+FR, F+U and Masaai manures showed significantly lower N uptake than the control at all the three application rates. On the other hand Stable and F+U+FR manures were similar to the control. This observation suggests that nutrient immobilisation by the manure-compost could have occurred during the period of the study (60 days) or inefficiency in N utilisation due to rapid mineralisation and gaseous loss. For Gatuanyaga soil, significant treatment differences were only observed with F+FR manure at all the three application rates.

Figure 20. Finger millet shoot DM yield due to application of manure and urine to A) Kariti and B) Gatuanyaga soils (Bars indicate LSD at p=0.05)



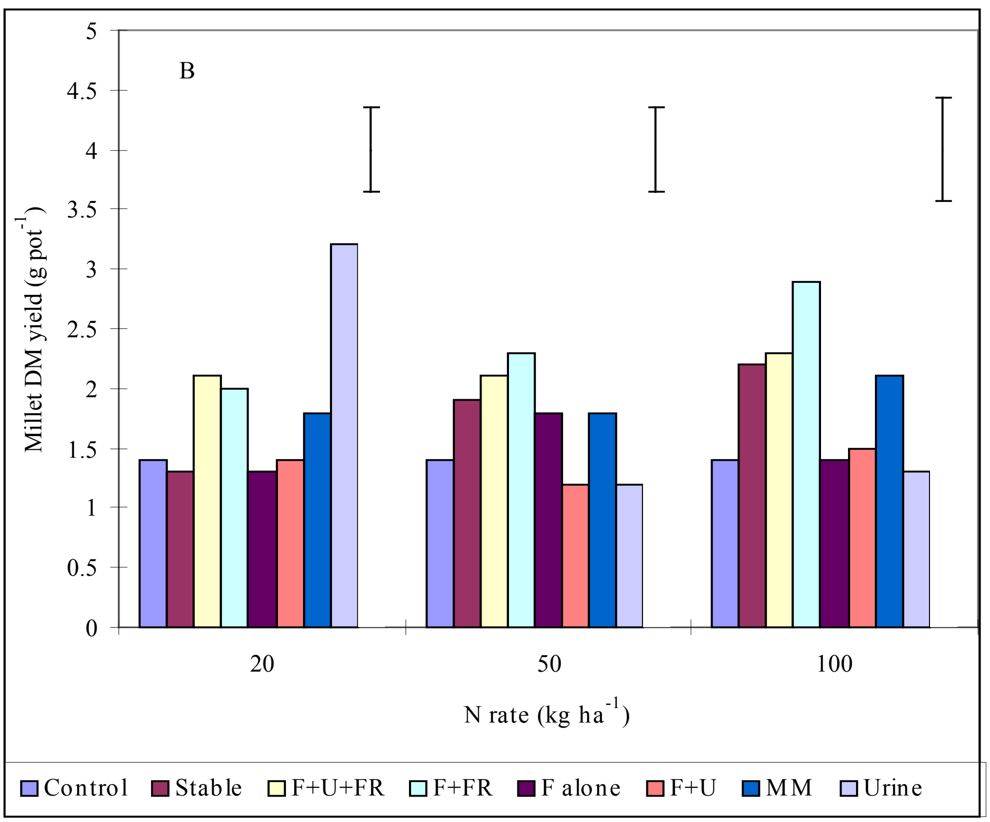
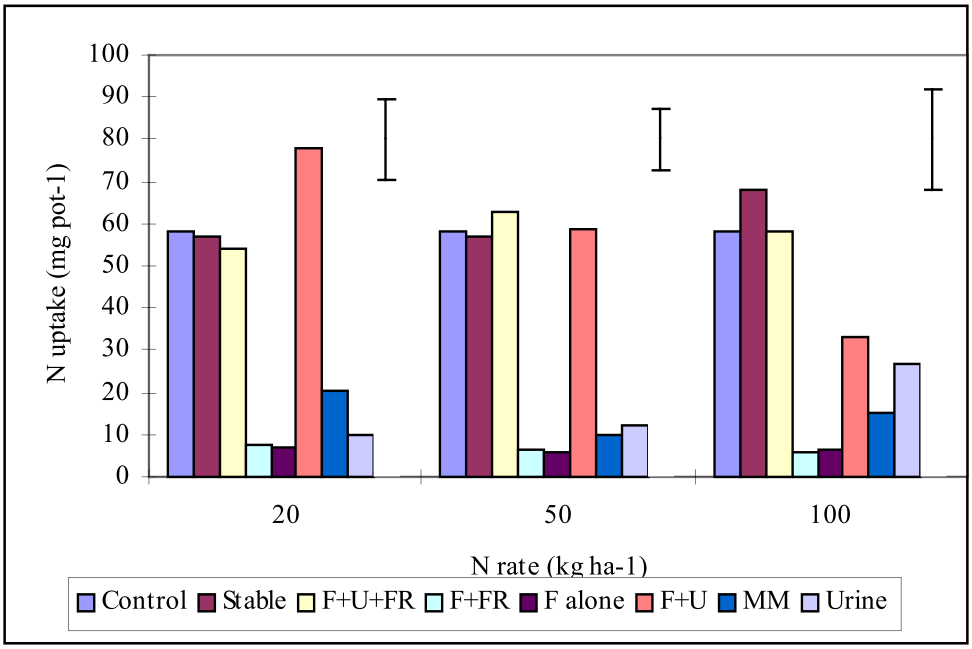
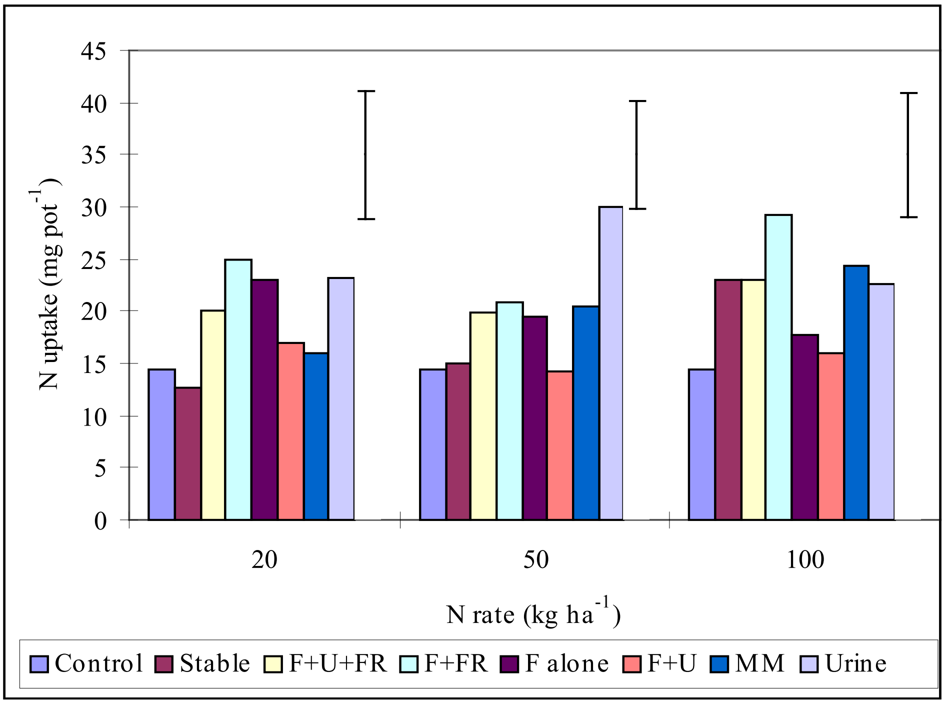


Figure 21. N uptake by finger millet shoots due to application of manure and urine to A) Kariti and B) Gatuanyaga soils (Bars indicate LSD at p=0.05)





Conclusions

Manure types and N mineralisation: It is clear from the results that animal and manure management has significant impact upon the quality of organic fertiliser produced. Incubations show that the manure-compost producing the highest maize yields in the first season in field trials at Kariti, F+FR and Masaai manure, did in fact maintain net positive N mineralisation during a phase of active growth by maize. It is interesting to note that the Stable manure (made in the manner traditionally practised by farmers in the area) did not release N until after the 9th week of incubation. Manure-composts of this kind would be undesirable since the N mineralisation would occur too late in the season to benefit maize growth. Farmers often claim beneficial effects of manures only in the second and subsequent seasons. The delayed mineralisation of N from traditionally-prepared Stable manure, could be attributed to the fact that most of the easily mineralisable fraction of manure organic N may already have been lost during composting, leaving behind more resistant N that is bound in humified stable forms of lignin. This hypothesis logically suggests that in the second season, such composts as well as the more recalcitrant experimentally-produced manure-composts (eg F+U and F) should perform better than manures which mineralise their nitrogen rapidly, because more nutrients would be "kept in reserve". In fact, the same pattern of performance was repeated in successive years of field trials, with manures that performed well in the first season also showing the greatest residual effects. This emphasises the benefits to be gained from optimum manure management and composting.

N mineralisation, DM production and N uptake by finger millet: Manure application in greenhouse pot trials resulted in contrasting responses, for instance, sometimes higher yields than the control were obtained in one soil and lower in the other. Direct urine application, the treatment which was intended to explore an alternative potential use of urine as a fertiliser if it were not being included in the manure heaps, always resulted in lower yields than the control for the more fertile Kariti soil and yields similar to the control for the Gatuanyaga soil. This observation contrasts with results obtained in the Norway and Netherlands, where application of urine resulted in significantly high grass yields similar to those obtained with inorganic N applications in pastures (Tveitnes, 1993). Reasons for a poor crop growth response to nitrogen added as urine, and a yield depression obtained in some instances are unclear from this experiment. It is possible that, depending on the application rate and type of soil, urine may increase the soil pH to a level that may cause volatilisation of the inherent soil nitrogen. Hence, N uptake at all urine application rates for Kariti soil were lower than the control while at 50 kg N ha^{-1} for Gatuanyaga soil, higher N recovery in shoots than the control were obtained. These observations, although only in a greenhouse pot experiment, have major implications for nutrient conservation strategies that propose the separation and direct utilisation of urine. Further research is required to determine the fate of urinary N and the impact of urine on soil properties so as to develop strategies to utilise urine efficiently as fertiliser since urine contains 75% of excreted N and, in addition, the extra benefit of nearly all the potassium excreted. In some cases F+U and F and MM manures resulted in lower yields than the control for both soils. This could be attributed to their high C:N ratios of 22, 23 and 32 respectively. Of great importance is the observation, in this greenhouse pot trial, that Masaai manure performed relatively poorly as predicted from its high C:N ratio, whereas in the field trials, and in the perception of farmers, Masaai manure performs as well as or better than any of the experimentally-prepared manures. An understanding of this phenomenon could have important implications for enhancing the quality of manures produced on smallholder dairy farms.

Experiment 2: The effects of composting on quality of cattle manure-compost derived from a napier grass/concentrate/poultry litter diets

Dry matter intake: Table 59 shows that there were no significant differences in Napier grass dry matter intake ($p = 0.6004$) but there were significant differences ($p = 0.0001$) in total dry matter ingested between the treatments. This difference was obviously due to differences in concentrate intake but shows that that steers on the low concentrate diets (LC) were not compensating for restricted concentrate intake by consuming more Napier grass.

Faecal and urine production: The volume of urine produced were similar for both the HC and the LC treatments (this is a somewhat artificial comparison since urine production by steers in the Stable could not be measured and were estimated based on liveweight extrapolatiion from other treatments). There was a significant difference ($p = 0.0189$) in the amount of total faecal dry matter production. Faecal output was higher on the HC diet than in the LC diet.

Dry Matter changes during Collection and Composting Phases: There was no significant (p = 0.0.3984) difference in the total amount of manure DM added to the heaps over the 61-day Collection Phase. Losses in DM during both Collection and Composting Phases ranged between 17.1 and 39.7% and 44.2 and 59.1%, respectively (Table 59). Although not significantly different, manure that had urine added to it appeared to lose less DM during the Collection Period. This reduction in loss may have been due to the anaerobic conditions limiting microbial respiration. On the other hand, manure derived from HC diets showed significantly lower dry matter loss than those derived from LC diets during the Composting Phase and hence significantly lower overall dry matter loss.

N intake / N excretion: N intake ranged between 0.30 and 0.46 g kg^{-1} LW_{mean} day^{-1} while N excreted ranged between 0.07 and 0.21 g kg^{-1} LW_{mean} day^{-1} and between 0.03 and 0.05 g kg^{-1} LW_{mean} day^{-1} in faeces and urine, respectively. The cumulative figures for the 61-day Collection Period are given in Table X.

Of the total N excreted (which ranged between 36 and 58% of the total N intake) between 21 and 31% was contained in urine while the rest occurred in the faeces. Since a readily fermentable source of non-protein N (poultry waste) was fed it was not surprising that the urine of animals on the HC diet contained significantly more N than those on the LC diet.

Table 59. Concentrate effects on dry matter and urine budget during 61-day accumulation phase and 90-day composting phase.

	Dry matter (kg kg^{-1} LW_{mean})						LSD p = 0.05 (all pair comparison)
	[1]HC+U	HC-U	LC+U	LC-U	Stable HC[a]	Stable LC[a]	
Napier DM intake (kg kg^{-1} LW_{mean})	1.28	1.16	1.26	1.19	1.14	1.20	NS[b]
Concentrate DM intake (kg kg^{-1} LW_{mean})	0.58	0.59	0.29	0.30	0.59	0.30	0.027
Total DM intake (kg kg^{-1} LW_{mean})	1.85	1.76	1.55	1.50	1.74	1.50	0.270
Faeces DM production (kg kg^{-1} LW_{mean})	0.94	0.86	0.75	0.70	0.82	0.71	0.178
Urine production (kg kg^{-1} LW_{mean})[2]	1.51	NR[c]	1.61	NR	1.86	1.63	NS
Feed refusals DM production (kg kg^{-1} LW_{mean})	0.30	0.40	0.36	0.51	0.41	0.51	NS
Straw DM added (kg kg^{-1} LW_{mean})	0.29	0.30	0.29	0.30	0.29	0.30	NS
Total DM added to the heaps (kg kg^{-1} LW_{mean})	1.23	1.16	1.04	1.00	1.11	1.01	NS
Total DM accumulated for 61 days (kg kg^{-1} LW_{mean})	1.02	0.70	0.86	0.61	0.77	0.88	0.116
Total after 90 days composting	0.58	0.34	0.39	0.29	0.43	0.36	0.25
Loss during accumulation (%)	17.1	39.7	17.3	39.0	30.6	12.9	NS
Loss during composting (%)	43.1	51.4	54.5	52.5	44.2	59.1	9.74
Overall loss (%)	52.8	70.1	62.5	71.0	61.0	64.4	NS

[1]HC+U = high concentrate with urine; HC-U = high concentrate without urine; LC+U = low concentrate with urine; LC-U = low concentrate without urine; Stable = faeces, urine and straw mixed on the concrete floor by animal
[2]Indicates amount of urine added to the heaps
[a]Faeces and urine production for this collection strategy estimated pro-rata from feed intake
[b]NS = not significant
[c]NR = not recorded
[d]Recorded but not added to manure heap

N changes during the Collection and Composting Phases: Manure-composts LC+U and Stable LC increased slightly in N content (Table 60). This observation cannot be explained. For the rest, for the rest there was no trend in N losses which could be explained by diet or urine conservation. At the end of the Composting Phase there was significantly higher N in the urine-treated manure-composts ($p < 0.001$) and particularly in the manure-composts derived from the HC diet ($p = 0.001$). However, interaction between the effect of quality of diet and presence of urine in the manure-compost was not significant ($p = 0.073$). Nitrogen losses during composting ranged between 2.0 and 30.1% with significantly higher losses occurring in manure-composts derived from low concentrate diets compared with those obtained from high concentrate diets. The overall N losses ranged between 14.8 and 43.4%. Although not significantly different higher losses occurred in manure-compsts that did not have urine added.

P changes during the Collection and Composting Phases: Although P excretion may not necessarily be related to diet (Lomba *et al*, 1969), in the present study, faecal P production was significantly greater on the HC diets. Urine contains only a trace of P so makes no contribution to the P budget of the manure heap and therefore does not explain why there should be an increase in P between that collected and that present at the beginning of composting. No physiological explanation can be given for the fact that at the beginning of the Composting Phase manure-composts with urine added contained higher amounts of P than those without (Table 61). The effect of concentrate on the P-content of manure-composts at the beginning of composting was not significant neither were the diet x urine interactions. At the end of composting however, significant interactions between concentrate level and presence of urine occur – the manure-compost with the significantly higher amount of P was derived from HC+U treatment. This observation suggests that urine may positively contribute to the conservation of P in manure during composting. P losses due to composting ranged between 32.3 and 53.0% and were significantly higher in manures that were derived from low concentrate diets than from manures from high concentrates. This losses are very high compared to those reported in similar studies which ranged between 2.0-21.9% (Ulen, 1993, Eghball et al, 1997, Sauer et al, 1999).

Table 60. Nitrogen budget during 61-day accumulation phase and 90-day composting phase.

	Nitrogen (N) (g kg $^{-1}$ LW_{mean})						LSD p = 0.05 (all pair comparisons)
	HC+U	HC-U	LC+U	LC-U	Stable HC	Stable LC	
Napier N intake (g kg $^{-1}$ LW_{mean})	14.7	13.4	14.5	13.7	13.2	13.8	NS
Concentrate N intake (g kg $^{-1}$ LW_{mean})	11.9	12.2	5.1	5.3	12.2	5.3	0.55
Total N intake (g kg $^{-1}$ LW_{mean})	26.6	25.6	19.1	19.1	25.4	19.3	3.11
Faeces N production (g kg $^{-1}$ LW_{mean})	9.9	9.6	8.7	9.2	8.7[a]	6.6[a]	NS
Urine N (g kg $^{-1}$ LW_{mean})	2.9	2.9[a]	2.4	2.3[a]	2.9[a]	2.3[a]	0.66
Feed refusals N production (g kg $^{-1}$ LW_{mean}) [b]	3.5	4.6	4.1	5.8	4.7	6.0	NS
Straw N added (g kg $^{-1}$ LW_{mean})	2.1	2.1	2.1	2.1	2.1	2.1	NS
Total N added to heaps (g kg $^{-1}$ LW_{mean}) (Faeces+(Urine)+Straw)	14.9	11.7	13.2	11.3	13.7	10.9	4.52
Total N accumulated for 61 days (g kg $^{-1}$ LW_{mean})	14.6	10.0	13.4	8.2	10.7	11.3	3.54
Total after 90 days composting (g kg $^{-1}$ LW_{mean})	12.7	7.4	9.1	6.4	9.5	7.9	2.23
Loss during accumulation (%)	14.6	14.5	(1.5)	27.4	21.9	(3.6)	
Loss during composting (%)	2.0	26.0	29.9	22.0	11.2	30.1	17.1
Overall loss (%)	14.8	36.8	30.9	43.4	30.7	27.5	

HC+U = high concentrate with urine; HC-U = high concentrate without urine; LC+U = low concentrate with urine; LC-U = low concentrate without urine; Boam = faeces, urine and straw mixed on floor by animal

[a]Faeces or urine N production for this collection strategy estimated pro-rata from feed intake

[b]Recorded but not added to manure heap

[c]NS = not significant

Table 61. Amount of P collected in faeces and the changes in content of P during collection and composting.

	[1]HC+U	HC-U	LC+U	LC-U	Stable HC	Stable LC	$LSD_{(0.05)}$
[2]Collected in faeces							
P (g/kg LW_{mean})	7.1	5.2	4.7	4.1	-	-	1.16
Beginning of composting							
P (g/kg LW_{mean})	8.0	4.2	4.8	2.8	3.1	4.9	2.98
[3]End of composting							
P (g/kg LW_{mean})	5.0 (37.5)	2.4 (42.9)	2.4 (50.0)	1.5 (40.4)	2.1 (32.3)	2.3 (53.1)	1.90 (17.09)

[1]HC+U = high concentrate with urine; HC-U = high concentrate without urine; LC+U = low concentrate with urine; LC-U = low concentrate without urine; Stable = faeces, urine and straw mixed on floor by animal.
[2]Estimates for the stable not done and LSD calculation done by using student t.
[3]Values in parenthesis indicate percent losses during the composting phase.

Discussion

At the outset of this experiment a future scenario was posed in which the diet quality of backyard livestock improve (more concentrates) either due to necessity (lack of forage) or opportunity (better milk markets). In order to gain the maximum benefit from expensive purchased feeds trapping the maximum quantity of excreted nutrient is essential. This is less problematic as long as nutrients are excreted in the faeces. This is more likely to be achieved when diets are balanced in terms of nitrogen and energy. However, due to the opportunism associated with smallholder feeding practices this is often not the case for dairy animals. Thus the experiment was designed to feed a typical mixture of local feeds in which nitrogen and energy are unbalanced and a greater excretion on nitrogen occurs in urine. The challenge then is to trap the nutrients (particularly N) contained in the urine. It is also well established that as N intake levels results so exponential increases occur in urinary N (Kirchgessner and Kreuzer (1986); Kebreab *et al* (1999)). It is unlikely that the high levels of N intake (300 – 600 g N/head/day) reported in these studies in the UK would be attainable by smallholders in East Africa.

Overall percentage loses of N in this experiment were generally lower that those in Experiment 1. A major factor at play could the nature of the bedding used. Barley straw is more absorbant than maize stover and being less coarse compacts down to a denser heap allowing less passage of air hence slower aerobic composting. An interesting deviation from Experiment 1 is that these factors urine makes a positive contribution to the nitrogen mass balance. Thus it might be tentatively concluded that when higher quality diets are fed the N excreted is best captured with a fibrous materials with fine texture such as barley straw. However there are two points of note here. Firstly, use of barley straw for bedding in a Stable system (even with a roof) leads to loses of around one third of the N in the excreta (Stable HC). Secondly, barley straw is rarely used as a bedding unlike maize stover (it was used because of necessity here) so is likely the losses will be even higher when maize stover is used.

The following are estimates of the N output from one steer of 400 kg live-weight used to make manure for one year:

- high concentrate diet would result in 61.0 kg of N if urine were to be included and hand-mixed (HC+U)
- high concentrate diet would result in 45.6 kg of N if steers were to be kept in the stable and manures animal-mixed (Stable HC)
- high concentrate diet would result in 36.0 kg of N if urine were to be excluded and manure hand-mixed ((HC-U)
- low concentrate diet would result in 43.2 kg of N if urine were to be included and hand mixed (LC+U)
- low concentrate diet with animals in the stable would result in 38.4 kg of N (Stable LC) and finally
- low concentrate diet would result in 31.2 kg of N if urine were to be excluded and manures hand mixed (LC-U).

The main point here is that if diets improve the maximum benefits to be gained from the better quality excreta will only be obtained when collected faeces and urine can be combined with fine and absorbent materials such as barley straw. This can increase the N conserved by 34% (HC+U versus stable HC). Even on the LC diet hand-mixing appears the best option but is only marginally better than stable mixing. Although urine makes no contribution to P it appears to conserve it during storage.

Experiment 3: *The Effects of Barley Straw Addition and Covering on the Quality of Composted Cattle Manures*

Urine was not included in this experiment as it was anticipated that farmers would be slow to adopt labour-intensive urine collection compared to simple covering of heaps. An important rider to this experiment is that it was conducted during an unusually dry period of the year. Results may have been different had the heaps been wetted by rain. Results should be tentatively interpreted.

DM changes: Dry matter losses during Collection Phase were and 9.3 and 7.0% for plus straw and minus straw manure-composts, respectively, and were not significantly different (Table 62). After composting dry matter losses were found to be significantly higher in the covered manures than in the uncovered ones and ranged between. 55.2 and 65.2 %. A two-way analysis of variance to determine the effect of covering and straw addition on dry matter loss due to composting indicated that ±straw ($p = 0.015$) and ±cover ($p = 0.003$) were significant. However the interaction was also significant ($p = 0.002$) suggesting that neither of the two parameters would be said to be the sole determinant of dry matter loss.

Nitrogen changes: Table 63 shows the cumulative nitrogen budget. N intake from Napier grass was 64.8 and 65.3% of total N intake the rest coming from dairy meal concentrate. Nitrogen losses during the Collection Phase were 35.1 and 23.1% for the heap which straw was to be added and no straw addition respectively. This was intriguing since at this stage the heaps were both strawless and were stored in the same way. No explanation can be offered. This highlights why the heaps were subsequently mixed, the straw then added resulting in almost isonitrogenous experimental heaps.

At the beginning of the composting, the N content of the manures were similar and ranged between 7.0 and 8.6 g kg^{-1} LW_{mean} . At the end of 120 days composting, in a two-way analysis of variance, significant differences in manure N content were observed which occurred as a result of both addition of straw ($p = 0.039$) and covering ($p = 0.028$). The interaction was also significant ($p = 0.007$). In this study, N losses ranged between 27.2 and 55.6% during composting. Covering of manure during composting resulted in significantly higher losses when straw was not present. Not adding straw and not covering resulted in the least N loss (27.2%) whereas covering strawless manure resulted in the greatest N losses (55.6%).

Table 62. Dry matter budget during manure production cycle. Masses expressed in terms of steers initial (accumulation) and mean (composting) liveweight.

Accumulation phase	Plus straw		Minus straw		LSD p = 0.05
Napier DM intake (kg kg^{-1} LW_i)[a]	1.51		1.50		NS[b]
Total DM intake (kg kg^{-1} LW_i)	2.04		2.03		NS
Faeces DM production (kg kg^{-1} LW_i)	0.75		0.71		NS
Feed refusals DM (kg kg^{-1} LW_i)[c]	0.43		0.41		NS
Straw DM added to heap at 1% fresh faecal production (kg kg^{-1} LW_i)	0.03		NA[d]		
Faeces DM accumulated for 60 days (kg kg^{-1} LW_i)	0.68		0.66		NS
Loss during accumulation (%)	9.3		7.0		
Composting phase	Covered	Uncovered	Covered	Uncovered	
DM at the beginning of composting (g kg^{-1} LW_{mean})	0.54	0.48	0.50	0.54	NS
Total DM after 120 days composting (g kg^{-1} LW_{mean})	0.18	0.17	0.17	0.24	0.065
Loss during composting (%)	66.3	63.6	65.2	55.2	7.09

[a]DM = dry matter [b]NS = not significant [c]Recorded but not added to manure heap
[d]NA= not applicable

Table 63. Nitrogen budget during manure production cycle. Masses expressed in terms of steers initial liveweight (LW_i) during accumulation phase and mean initial liveweight LW_{mean} during composting phase.

Accumulation phase	Plus straw		Minus straw		LSD p = 0.05
Napier N intake (g kg^{-1} LW_i)	17.3		17.3		NS[a]
Total N intake (g kg^{-1} LW_i)	26.7		26.5		NS
Faeces N (g kg^{-1} LW_i)	13.2		12.1		NS
Feed refusals N (g kg^{-1} LW_i)[b]	5.0		4.7		NS
Straw added to heaps (g kg^{-1} LW_i)	0.20		NA[c]		
Total N added to heaps (g kg^{-1} LW_i)	13.4		12.1		NS
N accumulated for 60 days (g kg^{-1} LW_i)	8.7		9.3		NS
Loss during accumulation (%)	35.1		23.1		
Composting phase	Covered	Uncovered	Covered	Uncovered	
Nitrogen at the beginning of composting (g kg^{-1} LW_{mean})	8.1	7.0	8.6	7.6	NS
Nitrogen after 120 days composting (g kg^{-1} LW_{mean})	4.0	3.8	3.8	5.5	1.40
Loss during composting (%)	50.1	43.7	55.6	27.2	17.3

[a]NS = not significant [b]Recorded but not added to manure heap
[c]NA=not applicable

Effects of adding straw and covering on P content: Changes in the amount of P in manure-composts as affected by straw addition and covering during composting are shown in Table 64. At the beginning of composting, the amount of P in the manure heaps ranged between 1.9 and 2.5 g kg^{-1} LW_{mean} the higher figures relate to those heaps containing the straw. At the end of 120-day Composting Phase the manure-compost heaps contain similar amounts of P. This is because significantly higher ($p = 0.0009$) P losses (ranging between 17.2-48.2%) were attributed to the presence of straw irrespective of covering effect.

Table 64. Changes in amounts of P due to composting.

	With straw addition		No straw addition		$LSD_{(0.05)}$
	Covered	Uncovered	Covered	Uncovered	
Beginning of composting					
P (g kg^{-1} LW_{mean})[a]	2.5	2.3	2.0	1.9	0.42
End of composting					
P (g kg^{-1} LW_{mean})	1.3 (48.2)[b]	1.2 (47.5)	1.2 (36.5)	1.6 (17.2)	NS

[a] LW_{mean} = mean liveweight of the seven steers used to produce manure
[b] Values in parenthesis are the percent losses due to composting after 120 days

Discussion

Effects of composting on dry matter and nutrient content of manures

Straw addition in the uncovered heaps resulted in high N losses during accumulation and even whilst heaps underwent composting. This observation is in agreement with what has been reported by Dewes (1995), where it was noted that increasing straw addition from 2 to 6 kg straw large animal $unit^{-1}$ day^{-1} increased gaseous N losses from 9.2 to 24.8. Kirchmann and Witter (1989) have reported beneficial effects of straw in reducing N volatilisation from 44 to 9% during composting where they observed that straw immobilised nitrogen under aerobic conditions. However, anaerobically composted manures ended with higher C:N ratios of between 33.1 and 87.5 than aerobically composted manures with C:N ratios of between 9.5 and 18.0.

The results from this experiment and from elsewhere in the literature are ambiguous with respect to the impact of straw addition to manure heaps. In Kenyan smallholder farming systems it is more likely that that additions of highly carbonaceous plant material to a manure heap would more likely have the effect of increasing the C:N ratio. The effect of this is then is the greater risk of immobilisation of nitrogen when applied to the soil and poorer crop yields (see above).

Although no leaching measurements were conducted, studies have shown that substantial amount of nutrients can be lost through this pathway. Leaching is the main pathway by which these nutrients are lost except for N which is also lost in gaseous forms. It is, therefore, not suprising that where significant losses of these nutrients occured during composting under conditions without precipitation, covered manures that retained high moisture levels also experienced high losses. For example, C+S treatment had the highest P amount at the beginning of composting but ended with nearly the lowest amount. This emphasizes the important role that high moisture levels could play in determining nutrient losses other than

N. The process of composting produces water that could leach out of the heaps with dissolved nutrients.

Under the experimental condition in this study it appeared that covering of manure heaps with plastic sheet during storage was of no significant benefit in terms of both dry matter and nutrient conservation for as long as no precipitation fell on the heaps. Similar observation have been reported by Dewes (1995) where covering with a plastic sheet did not result in beneficial effects in terms of N conservation during storage and composting of cattle manures for 177 days. However, if the heaps were not protected from rainfall then there could be a likelihood that the leakage of water draining from the heaps could result in high nutrient losses especially those that are normally found in cationic forms. In such circumstances, large amounts of straw could be used to reduce these losses.

Conclusion

In the unusual circumstances encountered, with no precipitation during the composting phase, neither covering the heap with a plastic sheet, nor adding straw to the compost heap, aided in the conservation of dry matter, nitrogen or phosphorus. In this experiment straw was added after accumulation of faeces, at the start of the composting phase. Without precipitation, the addition of small amounts of straw or feed refusals to faeces (Experiment 1), or the addition of larger amounts of straw to faeces and urine (Experiment 2), during the collection phase, would appear to be a better strategy to conserve nutrients. Most smallholders have only the former option of using low organic matter additions to faeces. An evaluation of improved composting techniques and organic additions during composting is required under conditions of normal precipitation.

Contribution of Outputs

NRSP Goal: Livelihoods of poor people sustained by maintaining the productive potential of the NR base

The research has established that:

- In intensifying agricultural production systems livestock, particularly cattle, are regarded by rural communities as fundamental factor underpinning the viability of agricultural based-livelihoods in densely populated areas.

- The high ratio of livestock numbers : arable land on the <u>smallest</u> farms provide poor farmers with the greatest potential for the maintenance and improvement of soil fertility through the use of excreta.

- Although research elsewhere has shown that the smallest farms also have the highest ratio of on-farm feed resources : livestock numbers (Tanner *et al*, 1993) future prospects for retaining livestock on the smallest and poorest farms is likely to rely upon sustained access to common property fodder resources and credit to purchase feed.

- Manure-compost quality has a profound influence upon crop yields not just in the season of application but up to one year later. The quality of manure-compost can be influenced by simple no- or low-cost changes animal and excreta management.

- Animal management, feeds and feeding practices have significant impact on the quality of excreta (particularly P). However improvements attained through feeding can be lost during manure storage particularly where nutrient are excreted in urine and inadequate urine storage mechanisms are in place.

- Urine may not be most effectively used as an addition to the manure heap but perhaps, instead, applied directly to actively growing crops.

The DFID Country Strategy Paper (CSP) for Kenya (DFID, 1998) acknowledges that the largest numbers of Kenya's poor live in high potential areas operating farming enterprises on very small land areas. The CSP suggests that "increased agricultural productivity is still achievable…….., but a rapid increase in off-farm employment opportunities is essential for pro-poor growth". Project outputs show that application of high quality manure-compost from one cow to 0.25 acre of maize can produc 3.3 extra bags of staple food grain per season (~300 kg) as well as producing between 4-7 liters of milk daily. This higher crop productivity was demonstrated to persist across seasons.

Projects outputs impact significantly upon subsistence food production and have application in a large number of poor households across the Region. In line with the CSP (DFID, 1998) the project has successfully demonstrated that the integration of crops and livestock can deliver greater and sustained land productivity whilst, at the same time, protecting the natural resource base.

The project has also made an important contribution to re-orienting research amongst the soil science community of East Africa. The project has shown a direct link between livestock management, manure quality and agronomic response. These results have encouraged soil scientists operating under the aegis of the African Highlands Ecoregional Programme to adopt a much broader systems perspective to their work.

Dissemination

The Project has disseminated outputs to the international research and development community through publications and activities listed below. However, in recognition that DFID "will support a range of activities to tackle the constraints faced by the rural poor……(including)…….improve access of poor rural women and men to knowledge, information and technology services" (DFID, 1998) the Project focussed effort on the production of extension literature. In collaboration with LPP Project R7452 (Development, validation and promotion of appropriate extension messages and dissemination pathways) the Project produced a highly illustrative extension pamphlet aimed at 7-11 year olds in rural primary schools. Six thousand copies of "Better Manure, Better Crops – Wambui Finds Out" (See Appendix 3) have been distributed to households in a pilot area (Kyeni Division, Embu District) through the schools, churches, civil society groups, MoA Extension Dept. The project aims to find the most effective routes and media reaching the rural poor and to demonstrate some impact upon knowledge concerning technical issues such as manure management. At the time of writing this report the knowledge impact assessment is underway and so results cannot be reported here.

Further Action

Promotion of the findings: Due to the heterogenous nature of highland agroecosystems it would be inappropriate to suggest that the precise and detailed findings of this project be promoted widely. However, some important principles have emerged relating to the need for the poor to retain crop/livestock enterprises on smallholdings to ensure their viability. It is tempting to regard this as a rather prosaic suggestion given that mixed farming systems are in the majority in the East African highlands. However, observers of recent events in Burundi and Rwanda suggest causes for the social disaster have roots in the loss of access to productive land. Prior to the upheaval a process of "involution" was occurring in these countries where livestock numbers had been declining as farm sizes reduced (de Haan, Steinfeld, & Blackburn, 1997). It is clear from the sentiments of farmers in Embu presented in this study that livestock are crucial to the "health" of small farms. Without them productivity declines, jeopardising livelihoods (and perhaps lives). This Project advocates broad promotion of the values of mixed farming across a wide ranging audience: from those concerned for development policy in recipient and donor governments to new generations of smallholder farmers through schools.

Further research might be conducted into:

- Implications of (reported) trend to reduced livestock numbers or changing livestock species (cattle to goats) for nutrient cycling in intensive highland production systems
- Scope for more effective use of locally-available nutrient sources by improving farmers' knowledge of organic fertiliser quality.
- Crop yield benefits to be derived from alternative manure forms (eg particle size), placement strategies, organic matter additions to compost and utilisation of urine as fertiliser.
- Scope for public/private sector (seed/fertiliser companies) link-up for sustainable promotion of manure management and use in combination with inorganic fertilisers.
- Validation of best-bet technologies for appropriate combination and utilisation of cattle excreta (eg separate utilisation of urine, combination of faeces and feed refusals) among smallholder farmers.

Who might carry out and/or fund this action

- The World Bank/FAO Livestock, Environment and Development Initiative (LEAD) have expressed an interest in investigating the implications of reducing herd numbers upon farm nutrient status in the East and Central African Highlands.
- The African Highlands Initiative (AHI) plan co-ordinated research activities in East Africa focusing on the production and use of manure as an organic fertiliser. AHI have formed a Manure Working Group to steer regional-level research activities.
- The MoA/KARI/ILRI Smallholder Dairy (R&D) Project (DFID bilateral funding) has expressed an interest in promoting the technologies generated by this project with target-group farmers in Central Kenya. Workplans for these activities are being produced by KARI staff.
- ILRI will continue to champion the integration of crop and livestock production - "because of increasing land pressure, research to enhance complementarities between crop and livestock production has high priority" (ILRI, 2000)

Project Publications:

Fitzhugh, H.A. 1997. *Livestock and Nutrient Cycling.* ILRI Director General's Presentation to International Centre's Week. Washington, November 1997. (Reported findings from this project) (See ILRI WWW Page)

Lekasi, J.K. 2000. Manure management in the Kenya Highlands: collection strategies to enhance fertiliser quality and quantity. University of Coventry, PhD Thesis (in preparation)

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Internal reports

All quarterly and annual reports provided as contracted. Copies can be obtained from: RNRKS, Rural Livelihoods Department, DFID, 94 Victoria Street, London SW1E 5JL

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Appendix 1: ILRI Backgrounder (Dec 1997)

Livestock and soil fertility: exploiting the natural balance

(overview of ILRI's livestock and nutrient cycling programme)

Appendix 2: Executive Summary: Implications of Livestock Feeding Management for Long-term Soil Fertility in Smallholder Mixed Farming Systems (LPP Project R6283)

Minimising nutrient losses through promoting effective recycling of nitrogen (and other nutrients) is a key issue in maintaining the sustainability of many smallholder, mixed farming systems. However, it is only recently that the dynamic role that may be played by livestock in mediating N transfers has come to be recognised. This includes the potentially high sensitivity of the N dynamics of the farming system as a whole to changes in livestock feeding management. The varying quality (e.g. N, lignin and polyphenol content) of livestock diets influences feed digestibility, partitioning of nutrients amongst different ruminant tissues and partitioning of excreted nutrients between faeces and urine. The consequences of variation in these partitions for the value of excreta in providing nutrients to the soil and hence supporting crop production, have been poorly understood and under-researched.

This LPP project (R6283: ' Implications of Livestock Feeding Management for Long-term Soil Fertility in Smallholder Mixed Farming Systems') has used both experimental and simulation modelling techniques to examine the implications of changes in N dynamics in animals for the subsequent behaviour of N in soils to which their excreta has been added and for plant growth on those soils. A significant, novel feature of the approach taken in R6283 has been to integrate animal metabolism experiments with soil and plant growth studies conducted under controlled conditions by using characterised manure from the animal experiments. An on-farm study was then established to verify the implications of the results of the experimental studies under field conditions. Despite a number of difficulties during the establishment phase, delivery of project outputs has now been completed to schedule.

Animal metabolism studies indicated the high degree of variation that may be induced in manure quality by dietary manipulation. Changes in both level and form of N supplementation radically altered the total amounts of N excreted and its partitioning between faeces and urine. The results of the studies indicated that the presence of dietary polyphenols might also affect the extent to which faecal N was bound to neutral detergent fibre with considerable implications for the dynamics of N release on the incorporation of manure into the soil.

The dynamics of N mineralisation (measured in leaching tubes) was affected considerably by the provenance of the manure (i.e. the diet that had produced it). Manures produced from diets supplemented with *Calliandra calothyrsus* and *Macrotyloma axillare* had similar N mineralisation patterns, with net cumulative N release occurring at around week 16 following incorporation. However, N mineralisation from these manures was much faster than mineralisation from manure derived from diets supplemented with poultry manure. Nonetheless, there was evidence that N was immobilised for at least 12 weeks following applications of all manure types suggesting that application at planting (a common local practice) may not always be most effective in promoting crop growth.

The potential significance of these observations was confirmed by seedling growth studies conducted in pots in which the highest dry matter assimilation was observed after 12 weeks in treatments where no manure had been added. Reductions in DM yields associated with the addition of manure produced from the different treatment diets ranged from 6% to 27% in comparison with the un-manured control - a finding that was consistent with the pattern of immobilisation of soil N observed in the leaching tube experiment. Such a lag period between application of manure to the soil and a net release of N has considerable significance for planning organic matter applications in practice. Furthermore, these results would suggest that dietary factors might need to be taken into account in doing this. Early manure applications before planting could provide better synchrony of crop N demand with N release from added manure. Alternatively, the beneficial effects of manure application may only be realised in the growth of a later season's crop.

An on-farm study conducted in the Tea, Coffee and Semi-arid agro-ecological zones to the east of Nairobi, and again using characterised manure, examined whether these experimental findings are borne out in the farmer's field. Initial findings (from one season's crop) were somewhat ambiguous. Lower rates of crop dry matter assimilation in manured and littered plots were consistent with the observations of N immobilisation under controlled conditions. However, the differences amongst litter and manure types observed in the mineralisation and pot growth experiments were not repeated under field conditions. These observations might longer-term studies for confirmation as data were not available on mineralisation beyond 24 weeks (i.e. beyond the first crop). However, it is also likely that appropriate manure and litter handling techniques for conservation of N may be a priority area for research if the potential benefits for soil fertility of the interactions of organic resources with animals are to be realised.

Modelling activities carried out by the project in parallel with the experimental studies described above led to the development of the ANORAC (Allocation of Nitrogen in Organic Resources for Animals and Crops) model. Among other things, ANORAC allows the consequences of different strategies of organic matter use (e.g as litters / green manures or as feeds) to be evaluated. A copy of the model and its documentation is included with this report.

Recommendations

On the basis of the project's main findings, the following are suggested as key areas for future research:

- Collaborative on-farm studies aimed at the development of integrated management strategies. For example, where poor growth during establishment has been identified as a problem on-farm, an examination of the consequences of interventions in livestock management, manure management and composting and agronomic practices *and their interactions* might be used to identify an appropriate range of solutions;
- evaluation of strategies for optimising the balance between diet quality and manure management strategies for maximum transfer of nutrients in manure at application;
- the inclusion of a manure - compost module in the ANORAC model that would allow it to be used more effectively as a decision support tool. This might be undertaken concurrently with the activities outlined above.

Appendix 3: Tanner, J.C. & Bain, R.K. Bain (1999) "*Better Manure, Better Crops – Wambui finds out……….*" The Mediae Trust (Kenya & UK)

(Extension leaflet. 6000 copies have been distributed (November 1999) to farmers in Kyeni Division, Embu District. Impact assessment currently being conducted under LPP Project 7452)

Appendix 4:

(Article for Target (1998) The Newsletter of the Soil Fertility Research Network for Maize-based cropping systems in Malawi and Zimbabwe)

Maize 'n' Milk - Perfect Partners?

Joseph Methu, John Lekasi (KARI) & Jon Tanner (ILRI)

In the Central Highlands of Kenya dairy cattle are stall-fed on farms of less than 1 ha. on average, where maize is also intensively cultivated. Cattle diets are forage-based and farmers rely upon napier grass and maize stover as the main sources of feed. Forage is generally in short supply throughout the year and the shortage will increase in the face of human population pressure resulting in farm sub-division. KARI/ILRI research in collaboration with the Universities of Reading and Coventry, U.K., is looking for strategies for tighter integration of dairy with maize production in order to increase fodder supply from limited land areas whilst maintaining soil fertility.

Farmers in Central Kenya traditionally plant 2 maize seeds per planting hole. These plants are taken through to maturity with the dry or partially-green stover being harvested for cattle feed. Joseph Methu planted 3 or 4 seeds per planting hole instead, thinning immature plants for fodder over the growing period and harvesting the remaining two plants at maturity for grain and stover. He found that this strategy yielded large quantities of high quality green forage and did not affect final grain or stover yields when compared with the more traditional practice of planting 2 seeds per hole.

Seeds per hole (plants/ha)	**2(88,000)**	**3(133,000)**	**4 (177,000)**
Green forage, early thinning (kg DM/ha)	**-**	**-**	**325**
Green forage, late thinning (kg DM/ha)	**-**	1663	1627
Dry stover (kg DM/ha)	4042	3706	4483
Grain (kg DM/ha)	2126	2054	2338
N extraction rate (kg/ha)	66	90	104

High density planting/thinning regimes significantly increased N extraction rates from soils and so could accelerate nutrient depletion. Cattle manure is widely used for soil fertility maintenance on smallholdings. In a survey of 60 farms in Central Kenya, John Lekasi estimated the potential for replenishing N loss through the use of manure (in this case, faeces only). He based estimates on his findings that ruminants produce 0.8% of their liveweight as faecal dry matter daily and the average N content of faeces sampled from farms (1.4%N). He disaggregated the farms in the survey by size (small 0.1 - 0.6 ha; medium 0.7 - 2.9 ha; large > 2.0 ha).

Farm size	Ruminant livestock number			Production of faeces per unit area (t DM/ha.yr)	Maximum N application rates possible from faeces (kg/ha.yr)
	Adult cattle	Immature cattle	Sheep/ Goats		
Small (n=17)	3.1	1.5	1.5	8.2	115
Medium (n=22)	3.5	2.3	2.3	3.6	50
Large (n=21)	5.4	1.2	4.6	2.2	31

His results largely agreed with farmer-estimates of their manure yields and show that, due to the size of the livestock population on the smallest (poorest) farms, N collected in one year's faeces from stall-feeding systems could theoretically (if excreta collection/storage systems were improved) compensate for the soil N extraction rates resulting from one season's high density maize planting. This is not the case on larger farms which may have alternative sources of fodder anyway and so not rely so heavily on maize fodder.

The KARI/ILRI team continues to assess through participatory research with farmers the potential for modifying maize cultivation practices for fodder production (eg varietal differences, leaf stripping etc). The team is also working on strategies for improved collection/storage of animal excreta, particularly urine, in stall-feeding systems. The research programme demonstrates the biological and economic compatibility of dairy/maize production and the positive contribution that livestock make to nutrient turnover and availability in highly intensive smallholder farming.

Appendix 5: Inventory for Project R6731

Item	Make and Model	Serial No.	Date received	Purchase price	Location
Kjeltec Auto 1030 Analyser	Kjeltec	3694	12/96	£15516	Kenya KARI
Digestor	Tecator 2020	17288	12/96	£4207	Kenya KARI
Scrubber	Tecator	36139	12/96	£2183	Kenya KARI
Desktop PC	Gateway P5-200	448289	01/97	£1399	Kenya ILRI
Laptop	Toshiba 100ct	07616703	01/97	£2670	Kenya ILRI
Vehicle 4x4	Toyota		96/97	£9000	Kenya ILRI
Desktop PC	Gateway 2000		96/97	£2520	Kenya ILRI
Laptop	Toshiba Pentium		96/97	£2500	UK (broken – reported to NRI)
Printer	HP Inkjet		96/97	£350	UK
40 Place block-digestor	DS40		96/97	£7035	Kenya KARI
UPS			96/97	£230	Kenya ILRI
40 Digestion tubes				£1883	Kenya KARI
Lab-glass			96/97	£3766	Kenya KARI