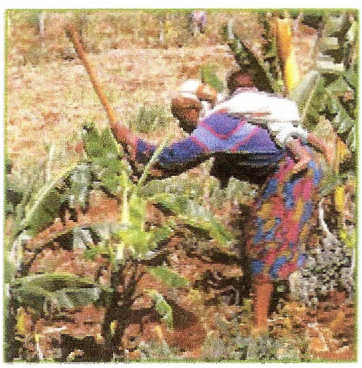
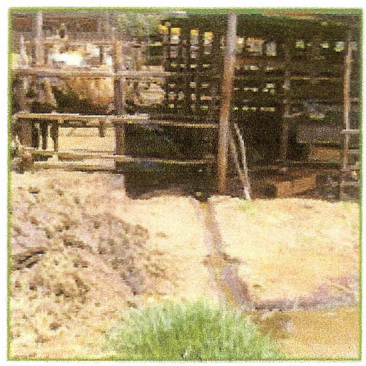
DFID Natural Resources Systems Programme

Managing Manure to Sustain Smallholder Livelihoods in the East African Highlands



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SUMMARY

One consequence of decreasing size of land holdings in the Central Kenya Highlands is a shift from extensive to more intensive mixed crop/livestock farming systems including acquisition of external inputs to feed livestock and replenish soil nutrients. Inorganic fertilisers are too expensive for most smallholders. The scope of this study was to evaluate manure management options that could best conserve nutrients and improve manure quality.

A survey documented current and potential manure management options, and evaluated manure physical characteristics and nutrient concentrations that could be associated with manure quality. Results suggest that modification of traditional livestock housing (boma) to the zero-grazing system may have beneficial effects on some aspects of manure quality.

When steers were fed with a basal diet of napier grass and dairy meal concentrate, high concentrate levels resulted in both faeces and urine of significantly higher N than the low concentrate levels. It was possible to conserve urinary N when wheat straw was applied at the relatively high amount of 1.8 kg liveweight/yr, about 720 kg/400 kg cow liveweight/yr.

The effects of simple strategies for combining cattle faeces, urine and rejected maize stover forage on the conservation of nutrients during storage/composting and on maize productivity over two seasons after field application of manure were investigated. The strategies were; S - faeces (F) + urine (U) + feed refusals (FR) mixed in a deep-litter system by steers; F+U+FR; F+FR; F+U and F, with all except S collected and mixed manually.

On average, 28 and 18% of the N input as feed was recovered in faeces and urine, respectively. Of the total N excreted, faecal N contributed between 47 and 76% (mean 61%) while urinary N ranged between 24 and 53% (mean 39%). Greatest loss of N during the accumulation phase was observed in heaps with high moisture contents from the addition of urine. During the composting phase, manures with maize stover refusals manually added had the greatest N losses. Overall, N losses ranged between 34 and 63% with F+FR resulting in the lowest loss. S and F+U+FR showed the highest overall N losses.

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. However, in this experiment, the addition of feed refusals was either insufficient or ineffective in conserving N added to the manure heap as urine. The combination of F+FR very effectively conserved the N in the faeces and feed refusals. In S and F+U+FR treatments, the additional N from urine was completely lost, and even lower total N in the final compost (5.5 and 5.6 g N kg^{-1} LW_i, respectively) was obtained than with the urine-free F+FR (6.5 g N kg^{-1}).

In the F+FR treatment, 4.7 g N kg^{-1} LW_i from urine was also available for direct return to the soil, possibly as a liquid slurry feed to perennial fodder crops, resulting in a 11.2 g N kg^{-1} LW_i return to the soil. It is not clear to what extent this

urine N would contribute to crop production if applied as a liquid, since loss of N from urine applied to the soil can be both rapid and extensive. However, in the F+FR manure scenario, any additional gain from the direct use of urine, however small, would be a net benefit above the alternative of adding the urine to the manure heap.

Calculations based on waste derived from livestock at densities found in the Central Kenya Highlands, suggest that small farms (mean 0.45 ha) potentially produce composted manure equivalent to 112 kg N/ha of the whole farm area, if optimum collection and composting strategies are followed. Given the first season uptake efficiency of 43.9% of applied N from F+FR manure, a smallholder farmer potentially produces enough composted manure for a first season maize crop uptake of 47.6 kg N/ha over the whole farm area, an amount quite close to the recommended rate of 50 kg N/ha

Experimental manures were tested in maize (*Zea mays*) production field trials. Maasai manure (*kraal* or *boma* manure) obtained from the pastoralists of Kajiado in the Rift Valley, and a farmer's own manure were also tested. All of the experimental manures, applied at a rate to give 75 kg N ha^{-1}, significantly improved grain yield in the first season compared with an unfertilised control. The greatest yield (F+FR, 4336 kg ha^{-1}) was significantly higher than the lowest yield (F+U, 2916 kg ha^{-1}). First season maize stover yield, which represents nutrients that can recycled through the livestock, was similarly affected by manure quality.

With the best manure collection strategy, F+FR, the manure from one steer (mean liveweight 212 kg) would be worth an extra 356 kg of maize grain and 295 kg of stover above the control level from 0.1 ha of land over two seasons.

Laboratory N-mineralisation and manure lignin, polyphenols, NDF-N and the C:N ratio were examined to correlate quality parameters with crop response. Manures that attained low C:N ratios and maintained high N concentrations at the end of composting promoted higher maize yields. The importance of the C:N ratio as an indicator of manure quality is suggested even in the second season where a significant negative correlation of total C:N ratio with grain yield was observed. However, Maasai manure gave the highest grain and stover yield, despite having the lowest N concentration and highest C:N ratio.

With Maasai manure included, significant positive correlations were found between lignin concentration and grain, stover and total yield in the first season, and grain and total yield in the second season. Significant correlations were also found between lignin + polyphenols and lignin:N ratio for some yield parameters, while negative correlations were found between polyphenol concentration and the second season grain and total yield.

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. In this survey, links between manure nutrient concentration and C:N ratio, and the manure texture, colour, smell and biological activity observed visually were investigated. There appears to be scope for the development of decision tools for manure-compost quality.

In conclusion, the diet fed to the animals and the type of organic materials added to the manure had an effect on the manure quality as assessed by nutrient content and crop response. Livestock make an important contribution to the sustainability of intensive smallholder farming through their contribution to soil fertility. This research has shown that increases in crop yields on smallholder farms in the Central Kenya Highlands, gained from simple techniques for better care of manure during collection and storage, can be substantial and enduring. It may well be that the contribution this research makes to enhancing the competitiveness of the smallholder sector in Central Kenya is increased where improved manure management can be linked to cultivation of higher value horticultural crops.

1.0 INTRODUCTION

1.1 Increasing population density

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 *et al*, 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 (20%) will be achieved through expansion of the arable area 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 *et al*, 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 viable land units providing a year-round food supply is very real. This has led to a popular paradigm that rising rural populations place increasing pressure on land through increased cropping intensity and that this threatens the fundamental bio-physical factor underpinning food security _ soil fertility (Donovan & Casey, 1998).

The effect of increasing population on landholdings can be seen in high agricultural potential areas of Embu District in Kenya's Eastern Province. Here, soils are dominated by the humic nitisol soil type and rainfall is 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 mountainsides. 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 *et al*, unpublished data). Although this intensive mixed farming currently maintains populations of up to 800 persons/km^2 (Imbernon, 1997), there is concern that this is reaching an upper limit and there is now a steady flow of poor people out of the high potential areas to the low potential, semi-arid areas in search of land to sustain livelihoods.

In Embu District, land was demarcated in 1963. Families were allocated land holdings of between 5 and 15 acres (2-6 ha). In a recent survey, farmer groups were asked to describe and map changes on a typical farm in the immediate area. Box 1 describes the changes on a typical farm.

Box 1 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 3 acres of land. 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 sustained 60 people. The kiosk no longer functioned.

- In 2008 the family anticipated that each of the 2 acre holdings would be split again as the third generation inherited land. 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.

The intensive farming systems of Central Province, Kenya, where most of the research described in this publication was carried out, are similar and have been described in detail by Lekasi *et al* (1998). For example, farm sizes in Murang'a District ranged from 0.4 to 12.5 ha with a mean of 1.8 ha. Thirty-three percent of farms occupied less than 1 ha. In Kiambu District, farm size averaged 1.4 ha (range: 0.1-4.3 ha). Fifty two percent of farms were less than 1 ha. Mean household size for the sample was seven individuals. All farms grew a mixture of food crops. Higher altitude farms in the sample grew coffee as a cash crop. Vegetables such as potatoes (*Solanum* and *Ipomea*), kales, french beans, tomatoes, citrus fruit and bananas were grown partly for home consumption and partly for sale. Maize and beans (*Phaseolus*) were grown ostensibly for home consumption.

Dairy cows were owned by all households in the survey by Lekasi *et al* (1998) since this was one of the criteria for inclusion in the sample. All dairy cows on farms in the sample were kept in permanent confinement and fed by cut-and-carry. Livestock, particularly dairy cattle are, however, clearly an important enterprise in the Central Kenya Highlands generally. 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.

1.2 Declining soil fertility?

As stated above, there is a popular conception that the high population densities now present in the East African Highlands (Swift *et al*, 1994) pose a serious threat to the maintenance of soil fertility. In Kenya, 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 in soil fertility is thought to be mainly due to increased cropping intensity and to the limited use of inorganic fertiliser. Smaling *et al* (1992) estimated that N and P fertiliser use in Kenya was only 6 and 3 kg/ha/yr in 1981.

As little or no land is available to be left fallow to sustain soil fertility in the smallholder farming systems of Central Kenya Highlands, farmyard manure (FYM) and crop residues have been the main organic resources available as soil amendments for soil fertility replenishment in these systems (Woomer & Muchena, 1996).

Although the evidence that soil fertility is in decline in sub-Saharan Africa is purportedly incontrovertible (Smaling *et al*, 1997), alternative views have been advanced. Scoones & Toulmin (1999), for example, point the scientific world to reasons why the evidence for decline 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.

However, 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 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 *et al* (1994), Reij *et al*, (1996) and Mortimore (1998).

1.3 Intensification and livestock

In order to adapt to increasing population and decreasing farm size, while attempting to maintain or increase productivity, farmers in Embu District of Kenya adopt a range of strategies (Box 2). It is clear that in the absence of widespread opportunities for off-farm employment the way to sustain the increasing population in the future was thought to be through greater farm diversity and productivity. Subsistence agriculture, i.e. 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.

Box 2 Strategies adopted by farmers in Embu District to adapt to increased population and decreased farm size

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

In the high potential farming systems of East Africa, the conservation and efficient use of nutrients is paramount to ensuring their productivity. There is tentative evidence to suggest that livestock are the major conduit for nutrient flow onto farms through feed collected and brought onto the farm (Shepherd & Soule, 1998). A major feature of the strategy for successful intensification proposed by the Embu farmers was the inclusion of an intensive dairy enterprise. This is considered to offer more than medium-term financial viability to small farms. Mixed farming appears to have had particular appeal to poor farmers in locations where external fertility inputs are not available (Winrock, 1992). The presence of cattle underpins strategies for the sustainable intensification of smallholdings. One important advantage of integrated farming is the opportunity to convert by-products and waste from one activity into inputs for another. The livestock provides inputs such as manure for crop production with crop products such as residues and fodder being used in livestock production.

Livestock production systems are currently being scrutinised with regard to their negative environmental impact (Steinfeld *et al*, 1997) but are also globally recognised for their major contribution to the income and welfare of the poorest people (Livestock In Development, 1999). One purpose of the research undertaken in this project was to contribute to evidence that livestock enterprises on intensively managed mixed-farms actually make a positive contribution to livelihoods of the poor and also help sustain the farming system.

In discussions, farmers in Embu District ranked manure as the most important output from cattle despite the proximity to a local milk market. Statements made by older members of the group concerning the use of manure included "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. Other surveys (Lekasi *et al*, 1998) in Kiambu and Murang'a Districts, Central Province Kenya ranked manure a close second behind milk in importance as a cattle product. However, a key question is whether, in these intensive small mixed farms, there is sufficient quantity and quality of soil fertility inputs from stall-fed livestock to sustain intensive cropping and facilitate the rate of turnover of nutrients.

1.4 Importance of livestock manure

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 crop residues, animal manures and green manures (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 (e.g. Pereira & Jones, 1954).

From the 1960s, when the use of organic fertilisers, particularly livestock manure, might be considered to be 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). Utilisation of cattle manure as a soil amendment is an integral part of the smallholder crop-livestock farming systems of the Kenya Highlands and of East Africa in general. Manure produced in these systems is usually applied prior to planting of field crops such as maize, beans and potatoes as well as vegetables such as kale, cabbages and tomatoes, and cash crops such as coffee.

The beneficial role of manure in crop production has long been recognised. The capacity of manures to provide nutrients, especially N, P and K is one such benefit. Other benefits that have been demonstrated include an increase in cation exchange capacity (CEC), pH, water holding capacity, hydrolylic conductivity and infiltration rate, and decreased bulk density.

Studies on utilisation of composts and FYM for crop production in East Africa have been reported since the 1930s (Beckley, 1934; Beckley, 1937; Mehlich, 1965). Many crop response trials have looked at rates and methods of application, effects on soil chemical and physical properties and effects on soil moisture dynamics (Dagg *et al*, 1965) and more recently biological properties and soil organic matter dynamics have attracted some interests (Kapkiyai *et al*, 1999). What these trials have lacked is that they have not considered the different factors that affect the quality of the manures. The chemical composition of cattle manure is influenced by the diet of the animal and by the way the manure is collected, stored and handled before utilisation (Kirchmann, 1985; Kemppainnen, 1989; Mugwira & Murwira, 1997).

In order to optimise and maintain manure quality, proper knowledge is required for manure collection, storage and utilisation that would minimise nutrient loss and yet allow the nutrients to be readily available to the plants. For instance, by analysing manures that have been derived from different diets with different organic materials added and with storage in pits or heaps, covered or not covered.

2.0 MANURE MANAGEMENT PRACTICES AND MANURE QUALITY

2.1 Survey

In 1997 a preliminary survey of manure management practices and manure quality was carried out in Kiambu and Murang'a Districts, Central Kenya. The results of this survey have been published by Lekasi *et al* (1998). In order to obtain further information on manure management and quality from a larger sample of farms, a further survey was conducted between the first week of February and the second week of March 1999. This second survey was conducted in Kariti Location, Kandara Division, Maragua District, Central Kenya to within approximately 5 km radius from a small town. Three hundred farmers were interviewed. The survey sought information on practices likely to influence manure quality, namely (1) cattle management - including all aspects of animal housing such as type of animal enclosure, roofing, floor type, drainage, bedding and use of concentrate feeding; and (2) manure management - including the way the manure was handled and stored prior to utilisation including the role of urine and organic materials additions.

2.2 Manure nutrient concentration

From each farm approximately 1 kg of manure was obtained at about 45 cm from the surface of the heap and stored in a plastic bag in a cool hut. The manure was collected weekly and taken to the Muguga laboratories of the Kenya Agricultural Research Institute where it was air dried, ground to pass through a 2 mm sieve and analysed for nutrient content according to methods described by Anderson & Ingram (1996). Only a sub-sample of approximately 50% of the samples was analysed for nitrate-N and ammonium-N.

Only 17 out of 299 farmers did not add both urine and at least some organic matter to the manure during composting. Including urine in the manure did not significantly affect nutrient concentration as measured in heaps reported by the farmer to be ready for application to the field. This observation provided an early indication that addition of urine to composting manure may not necessarily increase nutrient concentration in the finished product.

Some farmers reported adding organic materials directly to the manure heap rather than using it as bedding first. One major source of these materials added directly to the manure heap is rejected fodder. 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 other materials (16%) that included avocado leaves, coffee leaves, *Lantana* prunings, mango leaves and sweet potato vines, reeds, sawdust and weeds. Although these materials were also being used for bedding it is interesting that farmers distinguish between the same material used as feed or as bedding. It might be assumed that bedding consisted of all rejected feed. This is evidently not always the case, and organic materials appear to be selected for particular usage. An example of this is maize leaves being used as fodder whilst maize stems are used as bedding _ both are classified as `maize stover'. Including organic matter directly in the heap affected only the P concentration of the manure, reducing it from 0.32% to 0.30% ($p = 0.032$).

Considerable differences were observed in the nutrient concentrations of the manures, excluding those where urine and/or organic matter had not been added to the heaps (Table 1).

2.3 Management practices and their effect on manure

Housing and roof type: The three categories of housing structure found in the study were traditional boma (kraal), improved boma and zero-grazing (a model design developed by the National Dairy Development Project incorporating roof, separate lying and feeding areas, water trough, feeding trough and impervious flooring), which represented 6, 84 and 9% respectively, of the total number of farms surveyed. Of the total housing types surveyed 16% had no roof, 69% had partial roof and 15% had a full roof.

Floor type: Ninety-six percent of farms had soil floors and 4% had concrete or stone floors in the boma/zero grazing unit.

Drainage: Farms had 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 on 58% of farms surveyed.

Use of bedding: Sixty-nine percent of all farms surveyed used some form of bedding material. The main type of materials used (expressed as proportions of farms that used at least some bedding) were: maize stover (92%), banana residues (51%), grass (45%), napier grass (34%), *Grevillea* prunings (13%). Other organic materials include reeds (15%), weeds (6%), avocado leaves (4%), mango leaves (4%), bean trash (3%), sawdust (3%), coffee leaves (2%), jacaranda (1%), and *Lantana* (1%). Most of the farms used more than one type of organic material for bedding.

Concentrate feeding: Seventy percent of farms fed their animals some sort of purchased concentrate.

Table 1. Summary chemical analysis of manure/compost

	P (%)	K (%)	Ca (%)	Mg (%)	N (%)	Soluble C (%)	Organic C (%)	C:N ratio	Total mineral N (mg/kg)
Mean	0.30	2.38	0.26	0.51	1.12	1.96	24.4	23.1	494
n	279	279	279	279	281	280	281	281	141
Min	0.06	0.43	0.00	0.05	0.33	0.12	6.5	5.3	24
Max	0.75	7.00	1.34	1.19	1.91	7.98	49.2	81.0	1685
s.d.	0.11	1.06	0.21	0.19	0.33	1.30	8.8	9.7	330

n = number of samples analysed; s.d. = standard deviation

Manure management practices: Most farmers preferred to store their manure in a heap or pit (67%) rather than by deep littering (33%), and 90% did not cover the manure. Forty-six percent of farmers kept the manure under some sort of shade.

Farmers who did not turn, infrequently turned and frequently turned the manure during storage represented 45, 51 and 4%, respectively. The reported age of the manure heaps at sampling time ranged from 1 to 8 months, with 5 months being the most common age (5 months (42%), 4 months (13%), 6 months (13%), 3 months (12%), 2 months (10%), 1 month (5%), 8 months (4%) and 7 months (1%).

Multi-factor Analysis of Variance was carried out using General Linear Model on Minitab to determine the effect of a range of livestock and manure management practices on manure/compost quality, excluding manures where urine and/or organic matter had not been added to the heaps (Table 2). All values were log transformed prior to analysis to normalise the data. Only single factor effects and two-factor interactions were analysed, and rank deficiency and/or colinearity restricted the number of interactions that could be examined with the statistical model used. Very few two-factor interactions were significant and these did not appear to have much biological relevance.

Relatively few of the management practices could, as single factors, be shown to significantly affect the nutrient content of the manure. Percentage P was higher in zero grazing units (0.42%) than in improved bomas (0.30%) or traditional bomas (0.24%); higher with a full roof (0.34%) than with a partial roof (0.31%) or no roof (0.25%); higher when concentrates were fed (0.31%) than when not (0.28%); and higher when manure was stored in a pit or heap (0.31%) than when stored as deep litter (0.28%).

The inclusion of bedding significantly decreased the mineral-N concentration (420 mg/kg compared with 804 mg/kg without bedding) and significantly increased the C:N ratio (23.9 compared with 21.1 without bedding). Turning the heaps significantly increased the mineral-N concentration (667 mg/kg compared with 362 mg/kg without turning) and decreased the C:N ratio (21.5 compared with 24.9 without turning).

Results suggest that modification of traditional livestock housing (boma) to the zero-grazing system may 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 the current and earlier surveys 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. This is an important finding given that P is considered the primary limiting nutrient in Kenya highland soils. No clear agreement was found between the two surveys regarding best practice for producing manures with high N concentration. The present results suggest that inclusion of bedding and turning affect the C:N ratio and N-mineralisation of the manures and this could have an impact on compost maturity and synchronisation of nutrient release with crop growth.

Although nutrient concentrations are valuable indicators of manure quality, these measurements do not reflect the total amount of nutrients that could be potentially available in the farms. It is quite possible that manures with low nutrient concentration could also have high heap mass, resulting in potentially higher nutrient cycling capability. The full impact of livestock and manure management practices on nutrient cycling can only be determined if mass balances are recorded. Section 3 reports on-station trials to assess the impact of management practices on total nutrient content.

Table 2. Effect of animal and manure management practices on manure/compost quality and nutrient content

	Total N	Total P	Total Min N	C:N
Housing type	NS	< 0.001	NS	NS
Roof	NS	< 0.001	NS	NS
Floor type	NS	NS	NS	NS
Drainage	NS	NS	NS	NS
Bedding use	NS	NS	< 0.001	0.027
Concentrates	NS	0.044	NS	NS
Storage method	NS	0.005	NS	NS
Cover	NS	NS	NS	NS
Shade	NS	NS	NS	NS
Turning	NS	NS	0.002	0.027
Housing x shade	NS	NS	0.025	NS
Floor x shade	NS	NS	0.041	NS

Values are the probability, p; NS - not significant at $p = 0.05$

3.0 EXPERIMENTAL MANAGEMENT OF MANURE NUTRIENT QUANTITY

There are many pathways that lead to nutrient loss, especially nitrogen, from composting manure heaps. These include gaseous and leaching losses (Dewes, 1994). There is a need to apply collection and storage management strategies that minimise these losses so that efficient nutrient cycling can be achieved.

In the Central Kenya Highlands, surveys have shown that due to population pressure, per capita land size is diminishing and farming is tending towards more intensive systems where livestock and crop production are integrated (Woomer & Muchena, 1996). One of the main advantages of integrated farming is the opportunity to convert by-products and wastes from one activity into inputs for another (McIntire *et al*, 1992). Intensive livestock production leads to an increase in use of off-farm fodder and high value feeds, such as animal concentrates, requiring additional financial resources. Manures derived from such diets could be expected to be of high quality if nutrient losses are minimised through better collection and storage strategies. Such strategies are essential if smallholders are to reap the full benefit from the extra resources invested in a manner that is cost effective.

To investigate the effects of livestock and manure management on the quantities of nutrients available for application to soils after composting, a series of experiments was carried out at the Animal Production Farm of the Kenya Agricultural Research Institute (KARI), National Agricultural Research Centre (NARC) Muguga, Kenya. This station in located 25 km west of Nairobi at 1°13' 53.0" S and 36° 38' 1.1" East and an altitude of 2096 m asl. Muguga experiences a bimodal rainfall at peaks between March-May and October-December with annual averages of 986 mm (average of 20 years from 1980). Mean annual maximum temperature ranges between 19.8 and 22.0 °C and minimum ranges between 4.7 and 11.5 °C over the same period.

3.1 Level of concentrates and addition of urine

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, a value confirmed by a survey in this study. Regular purchase of feed thus represents a major route for the importation of nutrients onto the farm. Overall, the net effect on feedings strategies in these systems will lean towards replacement of the less rumen degradable crude protein contained in fodder with less recalcitrant N in concentrate protein supplements. As intensification becomes more dominant, new feeding practices are simultaneously evolving. The unstable and ever increasing cost of conventional concentrate supplements, which are sometimes unavailable when required, has necessitated the acceptance and use of poultry litter as a cheaper alternative. This is usually mixed with conventional concentrates or used solely to cut down on cost. Since poultry litter contains substantial amounts of urea (a non-protein N), which is absorbed in the rumen, and most of which ends up in the urine, it is important that the urinary N is trapped and efficiently recycled for crop/fodder production. Otherwise it would be most vulnerable to leaching and volatilisation losses. Use of organic materials as bedding in the animal sheds or as intentional additions during composting of cattle manure are methods by which urinary N could theoretically be conserved (Dewes, 1995).

3.1.1 Experimental details

An experiment to examine the effect of feeding diets more rich in nutrients, and conserving urine on manure nutrient content was conducted between the third week of August 1998 and the fourth week of February 1999 allowing two weeks for diet acclimatisation before starting data collection. The study was conducted in two phases; (1) a 61 day collection and accumulation of manure and (2) a composting period lasting 90 days where no additional `new' manure was added. Friesian steers were used for the production of animal excreta (faeces and urine). The experiment comprised four treatments in a 2 x 2 factorial design with concentrate offered at two levels and manures derived from these diets handled in two ways with three replicate steers per treatment.

Manures containing urine were obtained from steers housed so that excreta could be collected separately and measured. Steers for manure collection without urine were housed in a roofed, concrete floored barn where the urine flowed to a drain leaving behind the dung, which was collected and weighed every morning. After weighing and subsampling of faeces and urine, the manures were stored in a roofed, concrete floored barn. Each treatment was replicated three times thereby comprising three steers. The faeces and urine samples were kept under refrigeration at between 2 and 4 °C before the weekly faeces collections was bulked, dried at 65 °C for 72 h and ground to pass through a 2 mm sieve. Total nitrogen was analysed by the modified Kjeldhal oxidation method where salicylic acid is added during digestion so as to include nitrate-N and nitrite-N.

The steers in each treatment were balanced for liveweight. This was intended to remove the variability in waste production from the different sized animals as the measurements were expressed as a function of the liveweight. The steers were weighed fortnightly and the fodder and concentrate offers adjusted accordingly. Mean liveweight (LW_{mean}), calculated by averaging steer weights at 0, 15, 30 and 45 days, was used in calculations when expressing parameters in respect to units of liveweight.

Quality parameters of the locally available feeds used in this study, namely: napier grass, commercial concentrate and poultry litter are given in Table 3. Concentrate was purchased from an animal-feed retail store at the cost of Kshs. 850 per 70 kg bag (Kshs. 100 = UK£1). The poultry litter was obtained from a neighbouring smallholder farm. The price of poultry litter in this case was Kshs. 400 per 90 kg bag after sieving through 5 mm mesh openings. Napier grass was obtained daily from the KARI's NARC Muguga estate farms. Wheat straw, added to the excreta at approximately 5g/kg LW_{mean}/day to simulate the addition of bedding, was purchased from a retail store at Kshs. 125 per bale.

The steers were fed on a basal diet of napier grass equivalent to 2% liveweight (LW) in dry matter. Steers receiving high concentrate diets were supplemented with a mixture of 0.5% of LW as dry matter of conventional commercially available dairy meal + 0.5% of LW as dry matter of poultry litter sieved to pass a 5 mm screen. Steers for the low concentrate treatments were provided with 0.5% LW dry matter of dairy meal only. The steers were provided with mineral supplements and water *ad libitum*. ANOVA was carried out using statistical programme MS Excel version 5.0. All the LSDs were calculated at 5% significance level.

3.1.2 Faeces and urine production

High concentrate diets produced significantly more urine than the low concentrate diets. Daily faecal dry matter (DM) production ranged between 40.5 and 57.0% of total dry matter intake representing between 1.0 and 1.8% LW_{mean}. There was a significant effect of concentrate on the amount of total faecal dry matter production per kilogram liveweight, being higher in the high concentrate diet than in the low concentrate diets. Dependence of faeces and urine on dry matter intake has been reported in a study conducted by Kirchgessner & Kreuzer (1986) who observed that slurry production and dry matter content increased with dry matter or concentrate intake as well as with increasing milk yields.

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

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

	DM[1] (g/kg fresh weight ± s.d.[2])	Chemical composition (g/kg dry matter ± s.d.)		
		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
Wheat straw	910 ± 41.1	7.2 ± 0.12	0.36 ± 0.031	24.8 ± 1.93

[1] DM = *dry matter*, [2] s.d. = *standard deviation, values are means of four samples*

3.1.3 Dry matter production

There was no significant difference between the urine collection methods nor between high and low concentrate in the amount of total DM added to the heaps over the 61 days accumulation phase. However, manures derived from high concentrate diets showed significantly lower dry matter loss than those derived from low concentrate diets during the composting phase. Total dry matter after 90 days composting was significantly higher with high concentrate than low concentrate diets. Where urine was included, total dry matter after composting was higher than when urine was excluded. One possible explanation for this observation is that addition of urine may have created more anaerobic condition in the heaps than when urine was excluded leading to retardation in the composting process. Similar observations have been reported by Dewes (1996) and Eghball *et al* (1997).

3.1.4 N intake and excretion

The N intake ranged from 0.300 to 0.458 g/kg LW_{mean}/day while N excreted ranged from 0.075 to 0.209 g/kg LW_{mean}/day and from 0.033 to 0.055 g/kg LW_{mean}/day in faeces and urine, respectively. Total N excreted (urinary + faecal N) ranged between 36 and 58% of the total N intake. Between 21 and 31% of total N excreted was contained in urine while the rest was excreted in the faeces.

Significant linear relationships were observed between the daily N intake (N_{intake}) and the daily N excreted in faeces and urine, with the urine better correlated to N intake than the faecal N. The N excreted in the faeces and in the urine could be described by the first order linear equations:

$N_{faeces} = 0.368N_{intake} - 0.0112$ $R^2 = 0.534$

$N_{urine} = 0.098N_{intake} + 0.0068$ $R^2 = 0.745$

The overall N excreted in faeces plus urine was described by the equation:

$N_{total\ excreted} = 0.446N_{intake} - 0.0045$ $R^2 = 0.667$

Similar relationships have been reported by E. Kebreab (Centre for Dairy Research, Reading University, UK, pers. comm., 1999) and Kirchgessner & Kreuzer (1986) who observed that a linear relationship existed between N intake and faecal N excretion. As the crude protein increased in the diets so did the faecal N excreted. However, these two reports suggest that urine N was better described by a first order exponential fit. Their observation was based on experiments where dietary crude protein levels ranged between 11.5 and 17.0% and N intake ranged between 300 and 600 g/day (Kirchgessner & Kreuzer, 1986; Kebreab, pers. comm., 1999).

The difference in urinary N output between that reported by previous authors conducting work in a northern country-context and that observed in this experiment could be explained by the fact that, in this study, the N intake, ranging between 60 and 180 g/day, was far below what previous authors had offered the dairy animals in their investigations. This means that the diet offered might have been just sufficient to provide energy and protein such that the steers were able to utilise most of the consumed N for rumen microbial biomass production and body maintenance with modest amounts excreted in urine. In fact, Mason (1969) observed that high fibre diets such as clover-rye grass or hay and oat straw resulted in significantly higher undigested dietary N in faeces than concentrate supplemented diets in sheep. High fibre diets encourage enhanced rumen microbial activities culminating in rich faecal N excretion of bacterial origin.

3.1.5 N budget during manure production cycle

Changes in the amounts of N during the manure production cycle are shown in Table 4. The high concentrate diet did not result in significantly higher faecal N excretion but did lead to a significantly higher urinary N excretion. Significantly more N was present in the urine treated manures than in the urine-free manures at the end of the accumulation phase of the experiment.

At the end of composting phase there was significantly higher N in the urine treated manures and in the manures derived from the higher concentrate diets. The interaction between the effect of quantity and quality of diet and presence of urine in the manures was not significant. N losses during the composting phase ranged between 2.0 and 30.1% with significantly higher losses occurring from manures derived from low concentrate diets than from those obtained from high concentrate diets. However, the overall N loss during collection and composting ranged between 14.8 and 43.4% and was not significantly different among the different treatments.

The fact that a high concentrate diet resulted in both higher faecal N excretion (as shown by the regression data in Section 3.1.4, though not by the ANOVA data from Table 4) and higher N concentration in urine is a vital observation in view of the farming practice in the smallholder farming systems of the central Kenya Highlands. The N contained in urine is most prone to losses by volatilisation and leaching. It is crucial to note that studies have shown that 75% of urinary N is in the form of urea. Urea and uric acid from urine are rapidly hydrolysed to ammonia and carbon dioxide gases by enzymes from faecal bacteria (Tveitnes, 1993).

This study suggests that one way of conserving urinary N when making manure composts could be by mixing the urine with faeces and organic materials such as wheat straw to absorb the urine. If, for instance, a steer of 400 kg liveweight was used to make manure for one year, and assuming that it was fed on the types of diets under consideration in this study, then the following scenario of N conservation would be envisaged after composting of the manures:

* high concentrate diet would result in 61.0 kg of N if urine were included (HC+U)

* high concentrate diet would result in 36.0 kg of N if urine were excluded (HC-U)

* low concentrate diet would result in 43.2 kg of N if urine were included (LC+U)

* low concentrate diet would result in 31.2 kg of N if urine were excluded (LC-U)

In the Kenya Highlands, however, wheat or barley straw is an expensive organic material entering the nutrient cycling chain primarily as livestock feed and rarely used as bedding. The benefits of conservation of N observed in this experiment may be outweighed by the cost of obtaining effective amounts of bedding. The rate of straw used in this study, for instance, was high at 1.8 kg/kg LW/yr, which amounts to 720 kg of straw per 400 kg animal per year. If this amount is required to effectively conserve the urinary N then this approach may not be practicable for the smallholder farmer in these farming systems. However, with no treatment lacking straw in this experiment, it is not possible to determine the contribution made to N conservation made by addition of straw.

3.2 Combinations of cattle excreta and organic materials

An experiment was carried out which sheds further light on the effect of manure management practices on nutrient cycling, in which cattle were fed on a low concentrate diet in which maize stover was the fodder rather than napier grass, and in which only the limited available feed refusals, rather than purchased straw, were available as bedding or additions to the compost heaps. Napier grass contained between 14 and 47% (mean 32%) dry matter, whereas maize stover was relatively drier and contained between 59 and 73% (mean 75%) dry matter. The two types of fodder contained different concentrations of nitrogen, ranging between 0.7 and 0.9% (mean 0.8%) in maize stover and 1.0 and 1.2% mean (1.0%) in napier grass suggesting that napier grass was a better diet for crude protein than maize stover.

The objectives of this part of the work were to study the effect of combining cattle excreta (faeces and urine) and organic materials originating from the bedding and feed refusals by different strategies in order to conserve nutrients upon composting.

3.2.1 Experimental details

Twenty steers were used for faeces, urine and feed refusal production in the collection phase of the experiment with each treatment comprising four animals (replicates). The steers were approximately balanced for weight for each of the treatments so that the total weight of the animals at the beginning of the study were similar. The five methods of manure collection were:

* faeces + urine + feed refusals mixed on the floor of the cow shed by the animal (S)

* faeces + urine + feed refusals mixed manually (F+U+FR)

* faeces + feed refusals mixed manually but without urine (F+FR)

* faeces and urine only, mixed manually (F+U)

* faeces only, without urine or feed refusals (F)

The steers were fed on maize stover obtained from the KARI-Muguga estate farm, at 2.5% initial liveweight (that is, the animal weights at the beginning of the study, LW_i) dry matter, and 2 kg dairy meal concentrate, purchased locally, split into two 1 kg rations fed in the morning and afternoon, and provided with minerals and with water *ad libitum*. Steers used for treatments F+U+FR and F+U were enclosed in metabolism units where faeces and urine could be collected separately. Steers for treatment S were enclosed in cubical sheds with feed refusal (maize stover) bedding on a concrete floor while for treatments F+FR and F steers were kept as in treatment S but not provided with bedding, and raw manure was collected daily and recombined appropriately. Treatment F resulted in a high moisture content product as a result of inevitable contamination with urine on the floor of the cow shed.

The amount of feed given to the animals and what they rejected was recorded daily. A composite sample of the feed was obtained daily and at the end of each week this was bulked and ground for laboratory nutrient analysis as described in Section 3.1. No other measurements were taken for treatment S until the end of the accumulation phase. For the other treatments, additional measurements included mass of faeces and the mass of urine produced by the animal daily, and the amount of feed refusal that went into the composting heap. These three components, that is, faeces, urine and feed refusal, were daily recombined appropriately according to treatments for 60 days. In order to estimate the amount of faeces and urine produced for the treatments whose animals were not kept in the metabolism units, pro-rata measurements based on food intake were calculated. At the beginning of the composting phase, the amount of manure going into the replicate compost heaps was weighed. After 84 days composting, and before taking the manures to the field the heaps were weighed. Nutrient mass balances were calculated for N to ascertain losses occurring during accumulation and composting. Analyses of materials was carried out as described in Section 3.1.

Accumulation and composting of the manures were carried out on the concrete floor of a roofed cow shed. The manure heaps were stored in 1 m^3 chicken wire cages with 10 mm openings mounted on steel frames. On the inside, a finer plastic netting of 2 mm openings was used that would retain collected waste, prevent the manures coming into contact with the metal frames, and yet still allow free air circulation. The concrete floor below the cages was lined with non-porous plastic sheet, extending to about 20 cm high up the sides of the cages, to minimise leaching from the heaps.

Table 4. Nitrogen budget during 61-day accumulation phase and 90-day composting phase

	Nitrogen (N) (g/kg LW_{mean})				Significance of effect of concentrates (C) and urine (U)
	HC+U[1]	HC-U	LC+U	LC-U	
Napier N intake	14.7	13.4	14.5	13.7	NS[4]
Concentrate N intake	11.9	12.2	5.1	5.3	C: $p < 0.001$; U: NS
Total N intake	26.6	25.6	19.1	19.1	C: $p < 0.001$; U: NS
Faeces N	9.9	9.6	8.7	9.2	NS
Urine N	2.9	2.9[2]	2.4	2.3[2]	C: $p = 0.002$; U: NS
Feed refusals N[3]	3.5	4.6	4.1	5.8	NS
Straw N	2.1	2.1	2.1	2.1	NS
Total N accumulated after 61 days	14.6	10.0	13.4	8.2	C: NS; U: $p < 0.001$
Total N after 90 days composting	12.7	7.4	9.1	6.4	C: $p < 0.001$; U: $p < 0.001$

[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;*
[2] *Urine N production for this collection strategy estimated pro-rata from feed intake*
[3] *Recorded but not added to manure heap*
[4] *NS = not significant; unless stated, interaction between main factors was not significant*

3.2.2. Dry matter budget

There was no significant treatment dry matter differences in the amount of feed intake, faecal production or in the total amount of waste produced during the 60 days accumulation period. This is as expected as the animals were approximately balanced for weight by treatments and the data is expressed as per kg LW. It was observed that of the 2.4-3.3% (mean, 2.8%) of initial body weight of dry matter consumed as maize stover and concentrates, the steers produced 0.73-1.1% (mean, 0.8%) of initial body weight dry matter as faeces.

Loss of dry matter during composting was highest with the methods containing feed refusals and significantly lower in F and F+U, probably reflecting a greater rate of aerobic composting in the larger, more loosely packed heaps with refusals. Overall dry matter loss between collection and the end of composting was 29-51% for all methods except F+U which was very low (15%). 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 with S (0.46 kg/kg LW_I). However, this would have been even higher with F+U if the refusals were added directly to the soil without composting (F+U manure (0.4 kg) + feed refusals (0.23 kg) = 0.63 kg/kg LW_I) as well as with F alone (F manure (0.29 kg) + feed refusals (0.31 kg) = 0.60 kg/kg LW_I). Lowest return of dry matter to the soil was with F+U+FR and F+FR, both giving 0.35 kg/kg LW_I.

Table 5. Nitrogen budget during 60 days accumulation and 84 days composting for five manure collections methods

	Nitrogen (g/kg LW_I)					$LSD_{0.05}$
	S[1,2]	F+U+FR	F+FR	F+U	F	
Feed intake	27.0	25.4	25.9	25.5	27.1	NS[3]
Faeces	7.6	6.9	7.1	7.5	7.6	NS
Feed refusals	2.4	2.4	2.8	2.4	2.1	NS
Urine	4.9	5.1	4.7[4]	4.0	5.1[4]	NS
Total produced	14.9	14.4	14.6	13.9	13.9	NS
Total added to heaps	14.9	14.4	9.9	11.5	7.6	2.54
Total accumulated at end of 60 days	9.0	9.1	9.8	7.3	5.8	1.32
Total after 84 days composting	5.5	5.6	6.5	6.2	4.5	0.90

[1] *F = faeces; U = urine; FR = feed refusals; S = 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] *NS = not significant.*
[4] *Recorded but not added to manure heap.*

3.2.3. N Budget

On average, 28 and 18% of the N input as feed was recovered in faeces and urine, respectively (Table 5). Of the total N excreted, faecal N contributed between 47 and 76% (mean, 61%) while urinary N ranged between 24 and 53% (mean, 39%). Greatest loss in nitrogen during the accumulation phase was observed in heaps that had high moisture contents from the addition of urine (S, F+U+FR and F+U). These lost 39, 37 and 37 %, respectively, of the N collected during the accumulation phase, whereas the urine-free F and F+FR lost only 24 and 1% N, respectively during the accumulation phase.

During the composting phase, N losses were 39, 37, 33%, respectively, for S, F+U+FR and F+FR, but only 22 and 14%, respectively for F and F+U, suggesting that manures with maize stover refusals manually added had the greatest N losses. Overall, N losses ranged between 34 and 63% with F+FR resulting in the lowest loss. S and F+U+FR showed the highest overall N losses of 63 and 61%, respectively.

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. However, in this experiment, the addition of feed refusals was either insufficient or ineffective in conserving N added to the manure heap as urine in the S and F+U+FR treatments, since in both of these cases very large losses of N occurred compared with F+FR despite the presence of the feed refusals. In fact, the combination of F+FR very effectively conserved the N in the faeces and feed refusals. In the S and F+U+FR treatments, not only was the additional N due to urine completely lost but, with these treatments, even lower total N in the final compost (5.5 and 5.6 g N/kg LW_i, respectively) was obtained than with the urine-free F+FR (6.5 g N/kg). In the F+FR treatment, 4.7 g N/kg LW_i from urine was also available for direct return to the soil, possibly as a liquid slurry feed to perennial fodder crops, resulting in a 11.2 g N/kg LW_i return to the soil.

It is not clear to what extent this urine N would contribute to crop production if applied as a liquid, since loss of N from urine applied to the soil can be both rapid and extensive (Powell *et al*, 1998). Reports have indicated between 10-80% N loss from fresh manure application depending on the weather conditions, state of manure (slurry or solid) and the method of application (Klausner & Guest, 1981; Kemppainnen, 1989; Smith & Chambers, 1993). To arrest these nitrogen losses, proper strategies for handling and applying manure to the fields need to be employed such as stabilising the N with organic materials so that it can mineralise and be available when the crop needs it (Beauchamp, 1986; Myers *et al*, 1994).

However, in the F+FR manure scenario, any additional gain from the direct use of urine would be a net benefit above the alternative of adding the urine to the manure heap. A further scenario, of composting the faeces alone and adding urine and feed refusals to the soil would also theoretically add considerable N to the soil (7.2 g/kg LW_i), as would the direct addition of all 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.

Similarly, although F+U gave a greater N accumulation after composting than F, F+U did not conserve significantly more or less N after composting than F+FR did, because of the high loss of nitrogen with this treatment, with the latter treatment offering the possibility of using the urine directly, as discussed above.

The treatments F+U+FR and F+FR can broadly be compared with low concentrate diets with or without urine added to the manure heap (LC+U and LC-U) in Section 3.1. In this experiment F+FR retained most N at the end of the composting period while in the study in Section 3.1 LC+U retained more N than LC-U. This difference may indicate that the wheat straw used in Section 3.1 is better at conserving urinary N than the maize stover obtained as feed refusals in this experiment. Not only was the wheat straw added at a 50% higher rate on a dry matter basis, but the finer wheat straw appeared to absorb urinary N more effectively than the more coarse maize stover stems. It can tentatively be suggested that urinary N can be partially conserved if composting with adequate and absorbent organic material (e.g. LC+U) or by the somewhat anaerobic F+U combination, However, under aerobic conditions with only maize stover feed refusals available as an organic addition, it is difficult to conserve urinary N. These tentative conclusions needs verifying since the two experiments were conducted with different conditions and feed sources.

4.0 EXPERIMENTAL MANAGEMENT OF MANURE QUALITY

In an earlier survey (Lekasi *et al*, 1998) farmers were able to suggest many ways in which management of livestock and of manures might improve manure quality as opposed to quantity. Suggestions covered aspects such as better feed, capturing urine, mixing manures from different species, composting, storing in a covered pit, adding ash and inorganic fertiliser, adding green biomass, and roofing the cattle pen. In both the earlier survey and the survey described above it was difficult to ascribe manure quality differences to individual management practices. Furthermore, in both surveys, the associated manure analysis included only nutrient concentration. No data was collected on crop response to the different manures and no analyses of chemical parameters that might influence manure quality, other than C:N ratio were undertaken. There was thus a need to investigate the effect of manure management on manure quality under more controlled conditions and with the inclusion of crop response in field experiments designed specifically to compare manure qualities.

4.1 Maize response trial details

A maize response field trial was conducted at Kariti in Maragua District. Kariti soil is classified as a humic nitisol (FAO, 1997) with top soil (0-20 cm) composed of 31% sand, 56% clay and 13% silt, and described as having a clay soil texture. Soil pH (1:2.5 0.01M $CaCl_2$) 6.02; total OC 0.71 %; total nitrogen 0.1%; available phosphorus by Bray P_2 36.3 mg/kg ads; exchangeable bases, potassium 20 mg/100g soil, calcium 120 mg/ 100g soil, magnesium 28 mg/100g soil.

The soil contains inherently low total carbon hence organic matter and nitrogen according to guidelines given by Tekalign *et al* (1991). With 36 mg of available P/kg, the soil seems to contain sufficient P to maintain plant growth. Okalebo (1987) and Okalebo *et al* (1991), working on a similar type of soils, observed that 15 mg P/kg of Bray No.2 extractable P is the critical level below which responses are expected to occur. The site receives mean annual rainfall of 1300-1600 mm with mean annual temperature of 19.7-28.0 °C.

The experiment had eight treatments including the five experimentally-constituted manures described in Section 3.2. Two additional manures were also used for comparison purposes, Maasai manure, obtained from a Maasai boma (kraal) in Kajiado District and manure obtained from the farmer on whose farm the experiment was conducted. Maasai manure is of economic importance because it is widely used in central Kenya and yet is purchased at high prices (approximately Kshs 2000/t, 1UK£=100 Kshs) from as far as 150 km away in the Rift Valley Districts. Extensive use of Maasai manure demonstrates the extent of nutrient transfer from the drier lowland regions of the country most suited for ranching, to the arable land of the Central Highlands.

Farmer manure (FM) was provided by the owner of the farm from an 8-month old manure compost heap made from cattle manure that he had prepared to use in his crops that season. The cattle enclosure was partially roofed and poorly drained. The manure looked dark and well composted but with visible soil contamination, which may have occurred at the heaping stage during storage as it was being scraped from a deep litter soil floor. The storage heap was not covered and neither was it shaded.

The experimental design was a randomised complete block design with four replicates. With the exception of the farmer's manure, all manures were applied at a rate equivalent to 75 kg N/ha, evenly broadcast in the plots and then incorporated into the soil. Incorporation was done by digging the manure into the soil using a forked hoe and burying it as much as was possible. The farmer's manure was applied at the same rate as the Maasai manure, 13.7 t (fresh weight)/ha, but analysed after application, when N application rate was calculated to have been 121 kg N/ha. Maize (*Zea mays*) variety Pioneer 3452 was used as the test crop. Unfertilised plots were included as controls. The plot size was 4 x 6 m and maize was planted at a spacing of 30 cm (intra-row spacing) x 75 cm (inter-row spacing) giving a population of 43,000 plants/ha. Maize was planted in the first week of April 1998 and harvested in the third week of September 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 extension staff.

At maturity, an area of 9 m^2 in each plot comprising four middle rows was harvested and cobs and stover weighed. Sub-samples of ten randomly selected cobs and six plants were taken for moisture by oven drying at 65 °C for 72 h. Nutrient analyses were carried out using methods described by Anderson & Ingram (1996).

A second season trial was planted in the second week of November 1998 in order to study the residual effect of the manures with all agronomic practices being the same as in the first season except that no fresh manure was applied.

The rates of manure applied in the different treatments are shown in Table 6 together with the N and P application rates. The wide range of application rates required to provide 75 kg N/ha is a result mainly of the different moisture contents arising from the different manure management strategies.

Table 6. Quality and quantity of manures applied in the maize field trial at Kariti

Type of manure[1]	Fresh weight applied (t/ha)	N applied (kg/ha)	P applied (kg/ha)
Farmer manure	13.7	121	34
S	21.0	75	23
F+U+FR	23.7	75	27
F+FR	14.2	75	23
F+U	28.0	75	30
F	31.8	75	29
Maasai manure	13.7	75	30

[1] *F = faeces; U = urine; FR = feed refusals; S = faeces, urine and feed refusals mixed on floor by animal. See Section 3.2 for further details of manure production.*

4.2 Maize response results

Table 7 shows the maize grain and stover yields in the field trial. All of the manures except the farmer manure significantly improved grain yield in the first season compared with the unfertilised control, despite the higher N application rate with the farmer manure. Of the experimental manures, the greatest yield (F+FR, 4336 kg/ha) was significantly higher than the lowest yield (F+U, 2916 kg/ha). Of the experimental manures, all except F+U gave significantly higher grain yields than the farmer manure. Similarly, all of the manures except the farmer's own significantly improved stover yield compared with the unfertilised control. Stover yield with the best experimental manure (F+U+FR, 3805 kg/ha) was significantly higher than the lowest yield (F+U, 2648 kg/ha).

In the second season, due to prolonged drought, the crop struggled to reach maturity. Only Maasai manure, F+U+FR and F+FR showed significantly higher grain yields than the control, while Maasai manure, F+U+FR and F significantly increased stover yield. In the second season, there was no significant difference in grain or stover yields among the five experimental manures. The two-season overall grain yields were significantly higher than the control for all manures except the farmer's own, while the two-season overall stover yield was higher than the control for all manures except the farmer's own and F+U. With the two-season data F+U gave the lowest yield of grain and stover among the experimental manures. Yields were significantly higher with F+FR and F+U+FR respectively. There was no significant difference in harvest index between the unfertilised and fertilised crop nor among the manure types in either season. Harvest index ranged from 0.47 to 0.52 in the first season and 0.40 to 0.50 in the second season.

The five manures composted on-station had a known history of source and chemical composition of the constituents from which the manures were derived, but considerable variation in chemical properties of the finished product was observed, which could be attributed to the different manure management strategies during composting. Differences in manure quality, derived from the different collection practices, influenced crop response over two seasons, even when the manure was applied at the same rate of total N. A variety of parameters may have influenced the efficacy of the different manures, other than total N applied, which was controlled, and total P applied which was measured but did not correlate with yield performance. These factors could include, among others, the relative supply of other, unmeasured, macro- or micro-nutrients, effects on the soil physical chemical or biological properties, and chemical properties of the manures that influence nutrient mineralisation. In order to investigate possible factors, the mineralisation of N from the experimental manures was investigated and correlations were tested between some chemical characteristics of the manures and crop yield response.

Table 7. Yield data from the maize response field trial

Manure type[1]	First season		Second season		Combined seasons	
	Grain (kg/ha)	Stover (kg/ha)	Grain (kg/ha)	Stover (kg/ha)	Grain (kg/ha)	Stover (kg/ha)
Control	1371	1396	971	1263	2342	2659
Farmer manure	2287	2155	922	1358	3210	3513
S	3718	3669	1334	2030	5053	5699
F+U+FR	3906	3805	1542	2407	5538	6212
F+FR	4336	3601	1564	2009	5901	5610
F+U	2916	2648	1142	1674	4059	4322
P	3592	3268	1402	2154	4994	5422
Maasai manure	4447	4471	2064	2029	6511	6500
$LSD_{0.05}$	1140	1086	505	832	1626	1818

[1] F = *faeces*; U = *urine*; FR = *feed refusals*; S = *faeces, urine and feed refusals mixed on floor by animal*

4.3 Mineralisation

Net nitrogen mineralisation, has been considered as a measure of nitrogen availability of organically bound N in soils. The amount of N mineralised or immobilised from manure and compost depends on soil mineralogy (Beckwith & Parsons, 1980), organic material chemical and physical characteristics (Castellanos & Pratt, 1981; Janssen, 1996) and environmental conditions (Adriano *et al*, 1974; Virgil & Kissel, 1995). A good manure should synchronise mineral N (Min-N) release and plant demand such that the peak Min-N release coincides with peak plant biomass development and hence peak N requirements (Myers *et al*, 1994).

The five experimental manures and Maasai manure were studied to determine the rate of net N mineralisation. Topsoil (0-20 cm) was obtained from the farm used for the maize field trial, described in Section 4.1, from a site with no prior history of fertiliser usage. The soils were air dried in a greenhouse and ground to pass through a sieve of 2 mm mesh openings. Fifty grams of soil were weighed into 200 ml plastic bottles with four replicates. Manure was applied at the rate of 10 mg N/50 g soil. Replicate samples were included with no manures added as controls. Water holding capacity of the soil had been predetermined by the method described by Anderson & Ingram (1996).

The bottles with soil and manure were stoppered and shaken on an end-to-end shaker for 15 minutes to ensure a homogenous mixture. They were removed and allowed to stand for one hour for the dust to settle before gently applying distilled water to 60% water holding capacity. The bottles were closed loosely so as to allow gaseous exchanged and yet maintain the same level of moisture. The bottles were incubated at 25 °C and 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 colorimetric methods described by Anderson & Ingram (1996).

Min-N was obtained by summation of the cumulative (NO_3+NO_2-N) and NH_4-N. All the manures showed net NH_4-N release at 2 and 4 weeks after incubation, followed by a net decline up to week 16, with the exception of Maasai manure, S and F+U which showed a further net release at week 12.

Net cumulative NO_3-N decline was observed for F alone and F+U throughout the study period and S manure only showed a net NO_3-N release at week 12. Net cumulative NO_3-N release was observed for Maasai manure and F+U+FR (week 4) and thereafter a net decline at weeks 8-16. F+FR showed a net decline for the first 2 weeks and a net N release at weeks 4, 8 and 12 followed by a net decline at week 16.

There was no net total mineral N (Min-N) release from any of the manures in the first week of incubation. Net Min-N release, was maintained by F+U+FR (weeks 2 and 4) F+FR (at weeks 4, 8 and 12), Maasai manure (week 4) and S (week 12). F and F+U showed no net Min-N release at all during the 16 weeks of the experiment. During storage these two types of manure formed a crust due to desiccation, covering the whole area exposed to the atmosphere. This crusting may have created anaerobic conditions in the manure heaps that reduced the composting process. Similar results have been reported by Castellanos & Pratt (1981), who observed immobilisation of N in soils treated with anaerobically composted dairy cattle and beef feedlot manures.

During sampling of manures F+U and F at the end of composting period, it was also observed that their physical characteristics were similar to freshly voided faeces. Compared with manures S, F+U+FR and F+FR, these two manure types also finished with the lowest and similar N concentrations of 1.59 and 1.6% after composting. This observation suggests that mixing of urine with faeces does not necessarily result in forms of organic N that are easily mineralised to available mineral N.

Thus, broadly speaking, the two manures, F and F+U, that performed badly in the field trials also showed no net Min-N release in aerobic laboratory incubation trials, while the other manures mineralised N at different rates and over different periods, but did all show net N mineralisation at some stage during the experiment. However, only a limited amount of information can be deduced from laboratory aerobic incubation studies and these alone were not enough to account for the influence of manure quality on crop yield when Maasai manure as well as the experimental manures was considered.

4.4 Correlations

The manures were analysed to examine whether the manure management strategies affected a number of chemical characteristics that might influence the fertiliser quality of the final product, and whether these parameters were correlated with crop response. One chemical characteristic that is commonly used to define the quality of organic soil amendments is the C:N ratio because of its influence on organic N mineralisation. Other parameters that could be used to describe the quality of organic materials include lignin, polyphenols and NDF-N (Mellilo *et al*, 1982; Tian *et al*, 1992; Lekasi *et al*, 1999) as these compounds normally impose an effect on the rate of nutrient mineralisation, especially that of N.

Neutral detergent fibre nitrogen (NDF-N) was determined by the ANKOM method. Using neutral detergent solution comprising a mixture of sodium lauryl sulphate, ethylenediaminetetraacetic disodium salt, sodium teteraborate decahydrate, sodium phosphate dibasic and triethylene glycol, the neutral fibre was extracted, then dried in the oven at 65 °C and analysed for N using the Kjeldhal method. This N is referred to as the NDF-N. The NDF-N is always lower than the total N since during the extraction of the fibre part of the total N is lost.

Table 8. Some chemical characteristics of manure at the end of composting phase

	Experimental manures						
Chemical characteristic	S	F+U+FR	F+FR	F+U	F	$LSD_{0.05}$[6]	Maasai
Soluble C (%)[1]	7.16	6.20	6.34	4.71	3.57	0.522	-
Soluble N (%)[2]	0.05	0.08	0.11	0.13	0.08	0.041	-
Soluble C:N	178.0	86.8	59.0	41.3	47.0	80.51	-
NDFN (%)[3]	1.48	1.64	1.82	1.28	1.34	0.170	-
Lignin (%)	27.5	26.2	27.1	17.2	21.6	6.90	43.6
Polyphenols (%)	1.40	1.08	0.88	1.35	0.84	0.27	0.54
Ash (%)	11.0	13.0	14.0	11.7	12.7	NS	-
Organic C (%)	35.4	32.7	34.8	35.9	36.8	NS	26.4
N (%)[4]	1.76	1.75	1.91	1.60	1.59	0.152	0.82
C:N ratio	20.2	19.9	17.2	22.4	23.1	2.60	32.2
ADF (%)[5]	55.3	58.2	56.4	52.1	58.0	3.24	-
Lignin:NDF-N ratio	18.7	15.9	14.9	13.5	16.1	NS	-
C:NDF-N ratio	24.3	21.2	18.0	28.2	27.4	4.50	-
Lignin:N ratio	15.5	14.8	14.2	10.8	13.7	NS	-

[1] C = carbon.
[2] N = nitrogen.
[3] NDF-N = *neutral detergent fibre nitrogen.*
[4] N = *total Kjeldhal nitrogen.*
[5] ADF = *acid detergent fibre.*
[6] LSD *does not apply to Maasai manure of which there were only two replicates analysed*

The polyphenolics were analysed by the Folin-Denis method and included hydrolysable tannins and condensed tannins as well as non-tannin polyphenolics. This method is an adaptation from King & Heath (1967) and Allen *et al* (1974) and is fully described in Anderson & Ingram (1996). Lignin was analysed via the acid detergent fibre by boiling the manures with sulphuric acid solution of cetyltrimethyl ammonium bromide (CTAB) under controlled condition (Van Soest, 1963). The CTAB dissolves nearly all the nitrogenous constituents and the acid hydrolyses the starch to leave a residue containing lignin, cellulose and ash. Cellulose is destroyed by 72% sulphuric acid; lignin is then determined by weight-loss upon washing.

The major quality characteristics that were found to be significantly different (Table 8) were soluble C and N, total kjeldhal nitrogen (N%), C:N ratio, NDF-N, polyphenols and lignin. These observations suggest that the nature of the materials added to the compost heap does affect the quality of the cattle manure compost. For instance, F and F+U, which did not have organic materials added produced composted manures with lower N, NDFN and soluble C content compared with manures that had organic materials added to them, that is S, F+U+FR and F+FR. A similar trend can also be observed where the C:N ratio is considered as a measure of manure quality. F and F+U resulted in lower quality manures with higher C:N ratio compared with the lower C:N ratio observed with manures that had feed refusals added to them.

The importance of these parameters as indicators of manure quality has been shown further in the field trial described in Section 4.1. Hence it was observed that the manures with high N and NDF-N, for example, have lower C:N ratio and also resulted in higher maize yield.

Correlation coefficients were calculated for all parameters and field yield data for the five experimental manures. Table 9 shows only significant correlation coefficients between manure quality measurements and maize grain, stover and aboveground biomass dry matter production over the two seasons. The importance of the C:N ratio as an indicator of manure quality is suggested even in the second season where a significant negative correlation of total C:N ratio with grain yield was observed as in the first season.

Significant positive correlation was observed between NDF-N (grain) or lignin (grain, stover, total) and yield in the first season and some of these correlations remained significant when combined data for seasons 1 and 2 were considered. As with C:N ratio, C:NDF-N ratio can also be used to describe the quality of an organic material. Table 9 shows a significant negative correlation indicating that maize grain yield increased with decrease in initial manure C:NDF-N ratio.

Table 9. Significant ($p < 0.05$) correlation coefficients between some quality parameters of the five experimental manures and maize yield. Non-significant correlation coefficients are not shown

	Season 1			Season 2			Season 1+2		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
NDF-N (%)	0.93						0.92		
C:NDF-N ratio	−0.92						−0.91		
L (%)	0.89	0.96	0.95					0.88	0.91
L:N ratio		0.97						0.93	
L + PP (%)		0.95	0.93						0.88
C:N ratio	−0.94			-0.89			−0.93		
ADF (%)					0.93	0.95			

Table 10. Significant ($p < 0.05$) Correlation coefficients between some quality parameters of the five experimental manures plus Maasai manure and maize yield. Non-significant correlation coefficients are not shown

	Season 1			Season 2			Season 1+2		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
L (%)	0.89	0.96	0.95					0.88	0.91
L:N ratio		0.97						0.93	
L + PP (%)			0.95	0.93					0.88

However, when the Maasai manure was included in the correlation tests somewhat different results were obtained which contradict the idea that C:N ratio is a key predictor for crop yield. The Maasai manure gave the highest grain and stover yield, despite appearing to be the manure of lowest quality in terms of N content and C:N ratio. With the low fresh weight application rates required because of the high dry matter content of this material, and the excellent crop response, it is no wonder that Maasai manure is a valued and sought after commodity for the small intensive farms. With Maasai manure included (Table 10), significant positive correlations were found between lignin concentration and grain, stover and total yield in the first season, and grain and total yield in the second season. Significant correlations were also found between lignin + polyphenols and lignin:N ratio for some yield parameters, while negative correlations were found between polyphenol concentration and the second season grain and total yield. C:N ratio was not correlated with yield.

The parameters lignin, polyphenol and lignin:N ratio were subject to multiple regression to examine their ability to predict crop yield in the field trial when both experimental and Maasai manures were included. The best multiple regression equations were:

1. First season grain yield (kg/ha) =

$$120\ L - 866\ PP - 54.2\ L{:}N + 2550$$

nitrogen and other nutrients in such a manner that the synchrony with maize crop demand was achieved to the end of the cropping season.

Overall, the results suggest that manure lignin or NDF-N could be manipulated by varying the concentration in manure before application so as to synchronise N release with plant nutrient demands. Manures derived from forages containing high N bound in the form of lignin and NDF-N, that are able to maintain these high levels after composting are more likely to result in greater crop yields, not only in the immediate application season, but also for subsequent crops by controlled gradual release of nutrients, especially nitrogen. It is increasingly evident that N released in a slow manner may fit more closely to the requirements of growing plants than that from highly available sources (Brinton, 1985, Myers *et al*, 1994). The field results suggests that high lignin content of organic soil amendments, such as manure, should not always be viewed negatively as undesirable because it is associated with reduced nitrogen mineralisation in incubation studies (Palm & Sanchez, 1990; Myers *et al*, 1994).

It is vital to understand what lignin levels of manures should be termed as undesirable and which organic material additions would lead to these undesirable levels and therefore should be avoided when making manure composts. This means that, considering only one parameter, for instance C:N ratio, as the sole manure quality predictor is not advisable, especially when working at the farm level.
Consideration of several parameters singly or in combination would be a better option. However, the combinations and the critical levels of these parameters to predict manure quality can only be achieved by realistic field experimentation in order to develop user-friendly models for the desired crop types.

Of course the occurrence of significant correlation does establish a cause and effect relationship between lignin content and crop performance. Maasai manure is also physically very different from the experimental manures and may possess other, unmeasured chemical and physical attributes that influence its value. For example, Maasai manure is normally obtained dry and composed of particles most of which can pass through 10 mm screen openings. This ensures that a high surface area comes into contact with the soil for microbial activity compared with manures of bigger clods. This then leads to enhanced nutrient mineralisation.

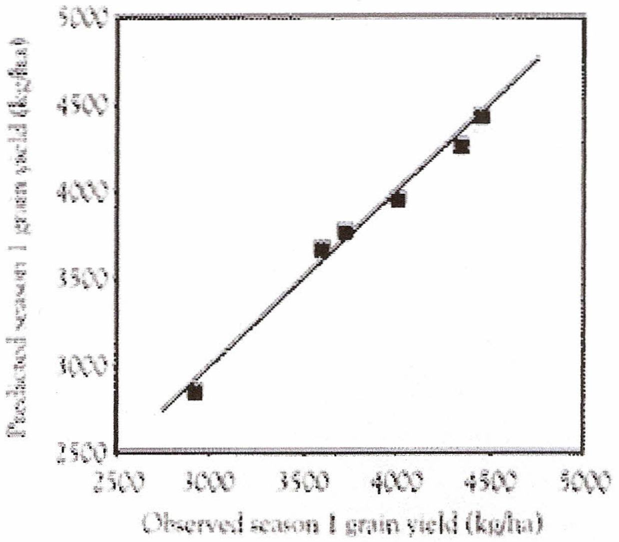

Figure 1. Relationship between observed grain yield and grain yield predicted by the equation: First season grain yield (kg/ha) = 120 L - 866 PP - 54.2 L:N + 2550

5. 0 HOW WELL ARE FARMERS ABLE TO ASSESS QUALITY?

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. The complexity of assessing compost biomaturity in smallholder farming systems is attributed to the fact that the different farmers conceive this aspect differently. For instance, some farmers believe that a completely composted manure heap with a characteristic fungal smell is the best manure. Others may not judge the quality until the results are seen in the final crop yield obtained after application of such manures. It has been reported by Motavalli *et al* (1994), from a survey conducted in the semi-arid tropics of India, that farmers conceptualise farmyard manure quality in diverse ways. They judge the manure from the physical composition, which determines its workability and its effect on crop development, and edaphic and biotic factors. Mugwira & Murwira (1997), in a review of the use of cattle manure to improve soil fertility in Zimbabwe, report on the quality in terms of the nitrogen content, an aspect that farmers may not comprehend by mere visual observation of the physical appearance of the manure heaps.

In an earlier survey (Lekasi *et al*, 1998), farmers were asked how they knew what a good manure looked like. Thirty percent, 20% and 50% of farmers in the large, medium and small farm categories, respectively, said a good manure is one that is "fully decomposed". The remainder (i.e. the majority of farmers) said that the quality of the manure could only be known by applying it to a crop. It was 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. In this survey, links between manure quality in terms of nutrient composition and C:N ratio, and the manure 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. The following parameters were assessed:

Manure texture. The hypothesis for this parameter was that undecomposed manure containing animal faeces and possibly a range of other organic additions would have a coarse texture. The texture 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.

Manure colour. The hypothesis for this parameter was that undecomposed material consisting of a heterogeneous mixture of animal faeces and other organic materials, differing in colour, would have a mottled appearance. As the decomposition process progresses, such material would be expected to become more homogeneous, appearing a uniform dark brown or black at maturity.

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 and ammonium salts are 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.

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 none of the chemical characteristics differed significantly with level of biological activity (Table 11). It can be concluded that this parameter is of little value in describing compost maturity without considerable further qualification.

Multi-factor analysis of variance was carried out using General Linear Model in Minitab to examine the relationship between the above simple manure characteristics and some of the nutrient characteristics reported in Section 2. Only total N, P and Min-N, and C:N ratio were tested. Tables 11 and 12 show the significance of these relationships. In addition, the relationships between the continuous variable, age, and the nutrient characteristics were examined by regression. Only the regression between age and C:N ratio was significant ($p = 0.021$ negative correlation, $R^2 = 0.02$; Y ($\log_{10}$C:N ratio) = 6.037 - 1.23x (age in months)), confirming a decline in C:N ratio with manure age.

Table 11. Significance (p values) of relationship between physical properties of manure and nutrient content

	Total N	Total P	Total Min N	C:N
Texture	NS	0.027	0.042	0.018
Colour	0.021	NS	NS	NS
Age (ANOVA)	NS	NS	0.017	NS
Age (Regression)	NS	NS	NS	0.021
Smell	NS	NS	NS	NS
Biological activity	NS	NS	NS	NS

NS - *not significant*

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 Section 4 indicate clearly that quality parameters rather than total nutrient application rate may be the key factors in determining the crop response to applied manure. This is shown by the strong negative correlation between C:N ratio and crop yield at iso-N applications for the experimental manures (Section 4). For this reason, an attempt was made to develop a decision tool for only C:N ratio, a measure of manure quality and maturity, and Min-N, to some extent a measure of compost maturity and immediate fertiliser value. Unfortunately the chemical analysis of the large sample of farmers' manures did not include the factors such as lignin and polyphenol concentration, which proved significant in predicting the field performance of manures when Maasai manure was included (Section 4).

Table 12. Details of relationship between physical properties of manure/compost quality and nutrient content

	Mean*	n	Min	Max	s.d.
Texture - P (%)					
1 (coarse)	0.26 a	34	0.06	0.43	0.089
2	0.30 b	99	0.1	0.75	0.103
3	0.32 b	133	0.12	0.72	0.122
4+5 (fine)	0.27 a	13	0.14	0.49	0.11
Texture - Min N (mg/kg)					
1 (coarse)	394 b	20	38	1499	402
2	359 c	55	30	1587	461
3	652 a	56	24	1609	575
4+5 (fine)	546 b	10	36	1685	655
Texture - C:N					
1 (coarse)	26.4 a	34	12.8	47.9	8.2
2	23.7 b	99	8.7	81.3	9.61
3	21.9 c	134	5.3	62.1	9.56
4+5 (fine)	22.4 c	14	6.1	52.5	11.73
Colour - N (%)					
1 (different)	1.13 ab	7	0.45	1.51	0.436
2 (fading)	1.18 a	125	0.43	1.87	0.317
3 (faded)	1.07 b	141	0.33	1.91	0.331
4 (uniform)	0.98 b	8	0.44	1.38	0.35
Age - Min N (mg/kg)					
< or = 4 months	406 a	61	30	1685	487
> or = 5 months	560 b	80	24	1609	554

* *Means for each parameter not followed by the same letter differ significantly at $p < 0.05$.*

This decision tool took the form of a dichotomous key or `decision tree'. C:N ratio and Min-N differed significantly with texture and age as single factors and these factors were used in the decision tool.

Figures 2 and 3 show examples of the keys produced. In Figure 2, the mean C:N ratio for 288 samples was 23.1. Separating the samples into two texture classes separated the mean values significantly into 21.9 and 24.4. No further division of the coarse to fairly coarse category was possible with any other physical characteristic, but the medium to very fine category was further sub-divided by age, with the mean values being 20.2 and 25.2 for the age classes ³ 5 months and £ 4 months. Figure 3 shows a similar key for predicting the Min-N (mg/kg) concentration of manures.

Figure 2. Dichotomous key for determining manure C:N ratio from simple physical characteristics

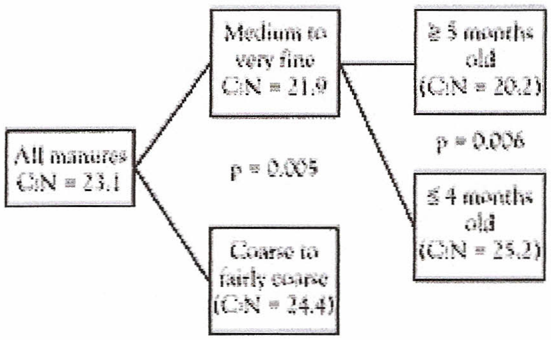

Figure 2. Dichotomous key for determining manure C:N ratio from simple physical characteristics

Figure 3. Dichotomous key for determining manure total mineral N (Min-N mg/kg) from simple physical characteristics

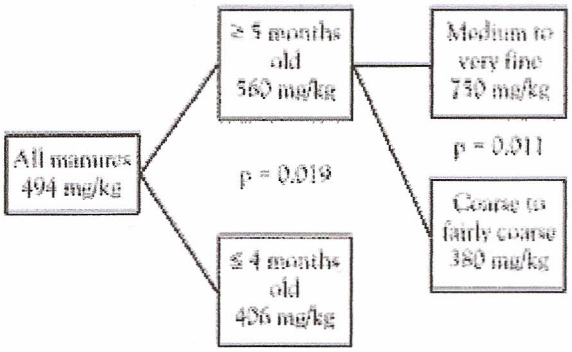

Figure 3. Dichotomous key for determining manure total mineral N (Min-N mg/kg) from simple physical characteristics

Thus (Figure 2), it is possible to separate manures by combined characteristics of age and consistency into mature (mean C:N = 20.2) and immature (mean C:N = 24.4 or 25.2). 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 113 and 216%, respectively, above the plots without manure in the first season after application, and 18 and 61%, respectively, in the second season after application.

Similarly, the prediction of mean Min-N of 750 mg/kg for the old, fine manure is 84 and 97% higher than for the old coarse and young manures, respectively, and could have a significant impact on crop response and/or on the decisions of application rate of manure and of possible mineral fertiliser supplementation (Figure 3). This suggests that even this level of differentiation may be a useful guide to manure quality.

Thus, some simple physical parameters, which are easily discernible, do show significant relationships to some manure chemical characteristics. 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 (e.g. general biological activity) or act to confound the analysis (e.g. 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 288 samples of manure ranged 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 20.2 and 25.2 in of Figure 2 have ranges of 6.1-62.1 and 5.3-52.5, 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 to refine the decision tool. Correlation of physical characteristics with other important chemical characteristics reported in Section 4 might also be productive.

6. 0 THE BENEFITS OF LIVESTOCK AND MANURE

6.1 Manure

Table 13 shows the production of fresh composted manure per animal on an annual basis, calculated from the fresh weights of manure produced after 60 days collection and 84 days composting in the experiment in Section 3.2. This, together with the additional grain and stover per ton of manure applied, calculated from manure application rates and crop responses in Section 4.2, allows the calculation of the theoretical additional crop production per animal (mean liveweight 212 kg) from the use of its composted manure, and the area of land required to achieve this. With the best manure collection strategy tested in this experiment, F+FR, the manure from one animal is worth an extra 356 kg of maize grain and 295 kg of stover above the no animal/no manure level from 0.1 ha of land over the two seasons. There is also a considerable difference, between the best and worst experimental manure collection strategies, with the best strategies giving up to twice as much additional grain as the worst strategies, if only the composted manure is considered and not the direct application to the soil of waste materials not added to the compost heap.

The economic value of an organic resource, such as manure, to the farmer is the value of the increase in crop yield and/or quality that is derived from its use (Parr *et al*, 1986). Farmers can be expected to utilise organic materials to the point where the revenue from increment is equal to its price, assuming production and application costs are included, basically following the law of diminishing returns. However, the trend of this hypothesis is not always straightforward. In the kind of system in which this study was conducted, the need to produce sufficient crop yields for both subsistence and income generation normally dictates the proportion of available organic resources, that is allocated to the different crop enterprises without necessarily taking into account the individual crop needs. If this aspect is taken care of, then optimum benefit could be attained by judiciously allocating a particular crop enough manure to provide the more expensive of the most limiting nutrients.

Table 13. First plus second season grain and stover yield benefits above unfertilised crops from experimental manures produced annually by steers (mean liveweight, 212 kg)

Manure type[1]	Composted manure produced (kg FW/cow/yr)	Manure applied (t FW/ha)	Potential area fertilised at 75 kg N/ha (ha)	Additional grain (kg/animal)	Additional stover (kg/animal)
S	17.6	21.0	0.084	227	255
F+U+FR	21.5	23.7	0.091	289	322
F+FR	14.2	14.2	0.100	356	295
F+U	29.0	28.0	0.103	177	172
F	20.1	31.8	0.065	174	181

[1] *F = faeces; U = urine; FR = feed refusals; S = faeces, urine and feed refusals mixed on floor by animal*

6.2 Nutrient production on small farms

A previous survey by Lekasi *et al* (1998) showed that the stocking densities of cattle and also of total ruminants was higher on small farms. Average numbers are shown in Table 14. This suggested that livestock numbers, especially cattle holdings, are not apparently constrained by farm size and indicated greater manuring potential for the smaller farms. Farmers were asked to estimate yearly production of manure from their ruminant stock using local units of measure and there was good agreement with 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).

The average ruminant herd in each farm category was 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.). This allowed the estimation of manure production per year. It was assumed that manure N content was 14 g N/kg. It was also estimated that steers produce 25 g urine/kg liveweight/day, a figure which agreed with that given for ruminants by Sundstøl & Owen (1993). Urine was assumed to contain 10 g N /l (Sundstøl & Owen, 1993). When it was assumed that all faeces and urine were captured and that no N was lost in the course of a year, then if all excreta were conserved, relatively large application rates of nutrients to farmland could be maintained. These earlier estimates for N are shown in Table 15. The results for the experimental manures described in Section 3.2 now provide data on actual production and losses during collection and composting, allowing the earlier estimates to be revised.

Clearly, previous estimates of urinary N production were much too high. Nevertheless, the small farms with livestock densities found in an earlier survey (Lekasi *et al*, 1998) potentially produce composted manure equivalent to 112 kg N/ha of the whole farm area. Data in Section 4 indicate that the quality of the manure produced as well as the N content may be important in determining crop response.

Table 14. Ruminant holdings on farms of varying size and estimated annual production of faeces per hectare (from Lekasi *et al*, 1998)

Mean farm size* (and range) (ha)	Mean (and range of) ruminant livestock numbers		
	Large cattle	Small cattle	Small ruminants
Small 0.44 (0.1-0.6)	3.1 (1-9)	1.5 (0-9)	1.5 (0-9)
Medium 1.08 (0.7-1.8)	3.5 (1-11)	2.3 (0-8)	2.3 (0-8)
Large 2.82 (2.0-5.2)	5.4 (0-20)	1.2 (0-5)	4.6 (0-21)

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

Net N uptake from the manures, that is the N uptake above that achieved by an unfertilised crop, in the first season field trial of this experiment was determined and is shown in Table 16. These can be used to calculate apparent N recovery from the manure by the maize crop, giving an indication of the quality of the manure or its value as a fertiliser. All the manure types that had some organic materials added during storage also resulted in relatively higher N recovery compared with those without, except for the Maasai manure, based on the application used in the trial (75 kg N/ha).

Potential maize crop N uptake in the first season after application of manure, calculated from the available application rates in Table 15 and the uptake efficiency in Table 16 is, therefore, F+FR 47.6, S 47.4, F+U+FR 42.1, F 27.0 and F+U 18.2 kg N/ha based on the whole farm area of the small farm. Thus, a smallholder farmer using the F+FR strategy for manure collection, potentially produces enough composted manure for a maize crop uptake of 47.6 kg N/ha, an amount quite close to the recommended rate of 50 kg N/ha (FURP, 1994). At the same time, there is still 81 kg N/ha/yr from urine, which could be applied directly to the soil to make up for the shortfall. In contrast, similar calculations for when F+U are collected and composted without inclusion of feed refusals, suggest a mere 18.2 kg N/ha uptake leaving a shortfall which is unlikely to be obtained from the 41 kg N/ha/yr available in feed refusals if these are applied directly to the soil. The manner in which waste products are combined and composted clearly has a major impact on the efficiency of nutrient recycling into subsequent crops.

Table 15. Potential nitrogen application rates to farmland from ruminant excreta produced on small (mean area 0.45 ha) farms with the livestock as shown in Table 14

Manure/ compost type[1]	Mean N application rates (kg/ha/yr)				
	Fresh faeces	Composted	Feed refusals	Urine	Total
Estimated from Lekasi *et al* (1998) without losses	114			289	403
S		95			95
F+U+FR		96			96
F+FR		112		81	193
F+U		107	41		148
F		77	36	88	201

[1] F = *faeces*; U = *urine*; FR = *feed refusals*; S = *faeces, urine and feed refusals mixed on floor by animal*

6.3 Value of livestock

Technical interventions aimed at improving soil fertility may not always be directly targeted at the soil. For example, using green manure-legumes is a well-proven technique for improving soil fertility in the semi-arid tropics. However, green manure-legumes that serve the single purpose of improving soil fertility have not often been adopted by poor farmers because they must be grown at the expense of food crops on limited land holdings. Dual-, or better still, triple-purpose legumes (yielding food, feed and fertility) may better serve the more complex livelihood objectives of households farming small land areas. The presence of productive livestock enterprises on farms is one strategy that can offer a more profitable route for nutrient return to the soil. 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.

Table 16. First season Net N uptake by maize and use efficiency of manures applied at 75 kg N/ha

Manure type	Net N uptake (kg/ha)	% of applied N
Farmer manure	14.2	11.7
S	36.7	49.9
F+U+FR	32.9	43.9
F+FR	31.9	42.5
F+U	12.7	17.1
F	26.3	35.1
Maasai manure	37.8	50.4

Similarly, crop residues are utilised for various purposes depending on the type available and the farming system. When left in the field after crop harvest they conserve soil moisture and recycle nutrients. However, in an intensive crop-livestock farming system, crop residues are frequently used as livestock feed while the manure and urine produced are used to produce crops and fodder (Tanner *et al*, 1995; Powell & Unger, 1997). This was confirmed in the surveys for this study. No households used organic materials, e.g. plant foliage, other than manure, directly as a fertiliser. Plant material was more likely to be fed to livestock or used as animal bedding than to be applied directly to soil. Some farmers 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) whenever possible. Thus, livestock represent an integral step in the nutrient cycle within farms. Additionally, livestock (mainly dairy cattle) are the main reason for importation of exogenous nutrients onto highland farms (Shepherd & Soule, 1998) and farmers buy concentrates and forage on a regular basis to complement forage grown on farm (Lekasi *et al*, 1998).

7.0 CONCLUSIONS

Contrary to the popular paradigm it is not always the smaller, poorer farmer who is threatened by lack of nutrients. This study confirms earlier conclusions (Lekasi *et al*, 1998) that the small, mixed farm featuring a dairy enterprise has a significant nutrient supply available to use to improve soil fertility. As such, in intensifying agricultural production systems, the presence of livestock, in this case cattle, are regarded by rural communities in densely populated areas as a fundamental factor determining the viability of agricultural-based livelihoods.

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 in animal and excreta management.

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

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

In line with the DFID Development Strategy for Kenya (DFID, 1998) the project described in this book has successfully demonstrated that mixed farming can actually deliver greater and sustained land productivity whilst, at the same time, protecting the natural resource base. The fact that `best practice' for sustainable agriculture involves close integration of livestock with crops, and probably has done for centuries, is essential to bear in mind at a time when livestock are currently considered a global scourge on the environment. It is true that environmental threats exist where intensive rearing methods have become de-linked from crop production as in the case of industrial animal production systems and that these rearing methods, often operating on subsidised inputs, also serve to undermine the viability of smallholder livestock production. However, the research described above demonstrates that it is possible for small-scale farmers to sustainably intensify production in the face of both environmental and economic challenges. The techniques demonstrated for better manure management conserve a greater proportion of nutrients for subsequent uptake by crops and do so at minimal extra cost to the producer. It may well be that the contribution this research makes to enhancing the competitiveness of the smallholder sector in Central Kenya is increased where improved manure management can be linked to cultivation of higher value horticultural crops.

8. 0 RESEARCHABLE ISSUES

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 of Kenya. The estimates in this report support observations of Kagwanja (1996) for Embu District that the smaller farms do actually apply considerable quantities of manure on a regular basis. There is a still a need, highlighted by Lekasi *et al* (1998), to measure manure accumulation and application rates on the smallest (poorest) farms in high potential farming areas of Kenya.

The survey described in Section 2 documented the wide range of organic materials that are available at the farm level and it was observed that they are generally used in combination in different proportions either as bedding or deliberate additions in the heaps. Some of these materials are mixed with animal excreta when they are still fresh (green), as is the case with napier grass feed refusals and hedge and tree prunings. Others are mixed when dry as is the case with most crop residues such as bean trash, maize stover and fallen leaves from avocado and mango trees. Quantification of the nutrient cycling capability of these different forms of organic materials would assist in formulating the kind of composting strategy that could be applied in order to optimise nutrient retention when combined with animal excreta. This quantification would also clarify, whether any pre-treatment would be necessary before mixing, as is the case with maize stover where it may be necessary to break open the stalks to allow absorption of urine.

The composting strategy experiments reported here have shown that including urine when manure is composted with limited amounts of organic material does not necessarily contribute significantly to the conservation of N, and including urine with faeces only may conserve N but leads to a poor quality manure. This suggests that direct application of urine to the field may be a possible way of utilising urinary nutrients. However, further investigation may be necessary in order to ascertain the long term effects the urine would have on soil chemical, physical and biological characteristics associated with crop production. For instance, urine has been shown to increase the soil pH, available P and ammonium levels in the top 10-15 cm of soil in semi-arid West Africa and increased millet yield production (Powell *et al*, 1998).

A substantial amount of research has been conducted on crop residues with respect to nutrient mineralisation and crop production (Woomer & Swift, 1994). Information from such trials may be useful and can be extrapolated to give an indication of the potential of feed refusals in recycling nutrients if directly returned to the soil without prior composting. In comparison, information on the capability of urine to recycle nutrients without passing through the manure heap in intensive farming systems of the Kenya Highlands is scarce.

A more radical alternative to conserve urinary N during collection and composting would be to use inorganic chemicals, such as calcium and potassium salts of sulphuric and phosphoric acids, gypsum, calcium carbonate, rock phosphate and thiosulphate, that would minimise nutrient losses (Beckwith & Parsons, 1980; MacKenzie & Tomar, 1987; Stevens *et al*, 1989; Frost *et al,* 1990; Al-Kanani *et al*, 1992; Sallade & Sims, 1992). Such methods have been used in developed countries where slurries are widely used. A similar approach could be adapted and modified appropriately for the systems in Kenya but would require thorough investigation prior to implementation. However, this may not be a popular choice bearing in mind that additives may not be readily available, may be expensive, and handling of chemicals may require specialised technical knowledge. This approach would also require that the inorganic chemicals chosen do not interfere with desirable soil characteristic that promote crop productivity.

With cattle manure having originated mostly from fodder, both manure and fodder possess many similar chemical characteristics and may be expected to react similarly in soil. However, unlike fresh plant materials, manure applied to crops results from digestive, respirative and degradative processes inside the gastro-intestinal tract and in the compost heap. The loss of many soluble and volatile components renders it more stable than fresh uncomposted plant materials (Kemppainnen, 1989).

Criteria for predicting quality of organic resources is currently based on a decision tree for assessing quality of organic materials mostly of plant origin developed by the Tropical Soil Biology and Fertility Programme (TSBF, 1998). However, cattle manure does not seem to conform to outcomes predicted by the TSBF decision tree since manure is a low quality organic resource and yet it promotes crop performance to an extent similar to high quality resources of plant origin. This decision tree groups organic materials of lower N content than 2% as low quality and this happens to be the category that most livestock manures fall into. Therefore, this observation calls for the development of different criteria for predicting manure quality based on chemical characteristics unique to manures that can be linked to nutrient mineralisation and crop performance. Some simple physical parameters, which are easily discernible, do show significant relationships to some manure chemical characteristics.

There appears to be scope for the further development of decision tools for manure-compost quality. Further work is required to refine/qualify the physical parameter categories, to apply these to more specific sub-types of manure-compost, and to correlate these with chemical characteristics such as lignin and polyphenol concentrations that are better linked to crop response than even C:N ratio.

Time of manure application is important in determining crop performance, depending on the type of manure available at hand. Manures that are not well composted may perform better if applied well before sowing because decomposition can progress in the soil. But this choice may be useful only where soil fauna may allow storage of manure in the soil without damaging it before the crops are planted. Also, different crops may exhibit highest nutrient demands at different times of manure nutrient mineralisation. Therefore, a good understanding of manure nutrient mineralisation patterns could be used as a guide on deciding the time of application.

Once the farmer has decided that it is time the manure is applied in the field, then the next major concern would be the best method of application. Farmers normally prefer either hole or furrow application for most crops, not because they think the nutrients are better utilised but because it makes it easier to cover the manure when covering the seed. The danger with this kind application method is that if the manure compost was not mature, then the seed may be damaged or the seedling growth may be suppressed. In fact, yield suppression has been reported in Kandara and Gatuanyaga (Delve, 1998; Kimani, 1999) due to application of fresh manures that had not composted properly. When such manures are applied in the soil, composting continues which encourages nutrient immobilisation at the early stages of seed germination when the seedlings are most vulnerable.

The rate of manure application and how often manure should be applied to a field should really be based on the type and demands of the crop under consideration. However, the choice of farmers to apply for example, one or two handful per hole or continuously over a distance of the furrow complicates the issue of the actual amount that is applied and available to be utilised by the crop. Applying two handfuls rather than one handful means that the farmer is doubling the rate of nutrient application. This would only be useful if the manure is, once again, well composted, otherwise the choice of the higher rate would lead to higher nutrient immobilisation and hence greater competition between the crops and the microbes leading to depressed yields than with manure applied at a lower rate, especially in the immediate season after application.

The choice of whether manure should be incorporated or surface mulched also lies in compost maturity, which is normally reflected in the physical characteristics of the manure. Cattle manure composts that are not mature would normally contain organic materials that would sometimes be too big to be easily incorporated in the soil and the best choice of application method for this type manure would be surface mulching. On the other hand, it is also possible to have manure composts that are not mature but can easily be incorporated into the soil. In such circumstances, the best choice would be broadcasting over a large area so that, as the composting progresses, immobilisation takes places more evenly in the plot rather than just within the vicinity of the plants and hence minimise competition. This way, as the plants grow the roots will be able to reach out for nutrients over a wider area as mineralisation begins later in the season.

The research suggests that despite reduction in farm size units can remain viable both economically and environmentally as long as diversification into integrated crop/dairy production is possible. Obviously a crucial factor to successful diversification is sustained access to cattle feed. For the smallest farms that depend to a large extent upon common property forage resources to feed dairy cattle this is anticipated to become problematic as public- or waste-land from which forage is currently obtained is increasingly privatised. Where forage supply to small farms can no longer meet the requirements of large ruminants the question remains as to what livestock options remain that can guarantee the environmental sustainability of small-scale farming. Changing the livestock portfolio on a small farm from `forage-demanding' cattle to small ruminants and/or mono-gastric species will obviously have implications for the quantity of manure available to support continuous cropping. However, there is currently considerable uncertainty about (1) the dynamics in livestock populations on the smallest holdings, (2) whether these farms are already employing alternative strategies to cope with shortfalls in organic inputs and (3) what technical and economic interventions may be required to support access by poor farmers to organic matter be it through livestock or some other means.

As economic structural adjustments in Kenya result in the reduction of public-sector extension activities promotion of methods to improve the use of organic matter in the smallholder sector relies more heavily upon the NGO sector. At the same time the Government of Kenya is seeking to promote the involvement of the private sector in smallholder agriculture as an important step in the Poverty Reduction Strategy Plan. NGOs can be effective in promotion of improved farming practices but tend, due to financial limitations, to be localised in impact. For more widespread effect of knowledge transfer it is vital, therefore, that the rapidly proliferating private sector be encouraged to disseminate information.

Improved manure management as well as better use of organic matter as a soil ameliorant would not be a natural focus of advertising campaigns run nationally by fertiliser companies. Whilst it is well known that organic and inorganic fertilisers can be managed to interact synergistically in the soil, incentives over and above providing greater farmer satisfaction may be required to encourage the private sector to adopt more of a `farming-best-practice' stance in their dissemination activities. Determination of the policy and institutional settings most conducive to broadening the objectives of private sector advertising has yet to be systematically carried out. This research needs to be conducted in conjunction with efforts to seek alternative information transfer pathways in the public (education) and civil society (e.g. religious groups) sectors to ensure an unbiased and reliable flow of knowledge to end users.

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