# Sustainable intensification of crop–livestock systems through manure management in eastern and western Africa: Lessons learned and emerging research opportunities

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## Abstract

In the mixed farming systems that characterise the semi-arid zones of eastern and western Africa, low rural incomes, the high cost of fertilisers, inappropriate public policies and infrastructural constraints prevent the widespread use of inorganic fertilisers. As population pressure increases and fallow cycles are shortened, such organic sources of plant nutrients as manure, crop residues and compost remain the principal sources of nutrients for soil fertility maintenance and crop production.

In this paper, the effect of manure on soil productivity and ecosystem functions and services is discussed. This is followed by highlights of the management practices required to increase manure use efficiency. We end with a discussion of emerging new research opportunities in soil fertility management to enhance crop–livestock integration.

Although the application of manure alone produces a significant response, it is not a complete alternative to mineral fertilisers. In most cases the use of manure is part of an internal flow of nutrients within the farm and does not add nutrients from outside the farm. Furthermore, the quantities available are inadequate to meet nutrient demand on large areas. Research highlights have shown that efficiency is enhanced by different management practices including the timing and methods of manure application, its sources and integrated nutrient management.

Research opportunities include analysing and understanding the ecosystem functions and services of manure use, the establishment of fertiliser equivalency for different manure sources, the assessment of the best ratios of organic and inorganic plant nutrient combinations, the crop–livestock trade-offs required to solve conflicting demands for feed and soil conservation and the use of legumes to enhance soil fertility and for animal feed. The establishment of decision support system guides and assessment of the economic viability of manure-based technologies in farmer-focused research are presented as powerful management tools intended to maximise output while preserving the environment in the mixed farming systems of the semi-arid zones.

**Key words:** Cattle, crop–livestock, manure, phosphate rock, sustainable agriculture.

# Introduction

Rapid rural and urban population growth, changes in agro-ecosystems and increased market access in western and eastern Africa all provide the stimulus to drive agriculture towards intensification, where continuous cropping increasingly replaces pasture and fallows. Manure, forages and crop residues become more valuable as part of the intensification-oriented technologies, with increasing off-take from a fixed land base. The ultimate results of this dynamism are the emergence and evolution of mixed crop–livestock systems. The evolution process often includes:

- paddocking or corralling livestock on crop land in high-potential areas
- a shift to the system of collection, processing, storage and application of animal faeces and urine
- change from field-grazing crop residues and pastures to confined livestock feeding
- replacement of manual labour with animal traction and mechanisation
- intensification through growing multi-purpose legumes and forages.

This calls for a new research approach that allows replacement or refinement of old paradigms with new principles, notably the identification of 'best-bet' options and strategies using a whole farm or holistic approach to working with farmers. Such an approach has resulted in new lessons and insights in management and augmentation of nutrients through crop residue and manure management, including livestock-mediated nutrient cycling, crop combination and crop geometry, livestock feeding studies, the effect of the livestock component on soil fertility (chemical, physical and biological properties), and also gender, policy and institutional issues.

A major challenge facing researchers in their attempt to contribute towards sustainable intensification of the crop–livestock systems in sub-Saharan Africa (SSA) is that of soil degradation, where the poor quality and low inputs of crop residues, kraal manure and other amendments lead to a decline in soil productivity. Inorganic nutrient inputs are often too expensive for low-resource endowed farmers. In such systems, the demand for organic inputs such as manure is likely to increase in response to system intensification. The contribution of manure management to enhanced soil productivity is unquestionable (Murwira et al. 1995; Pankhurst 1990; Murwira, this volume). However, there is a need for research to be viewed realistically. This is especially true in the context of the evolving farming systems in arid and semi-arid areas, notably integrated (mixed) crop–livestock systems which may hinder or complement each other. There is a growing recognition of the need to develop technologies and policies that ensure optimal enterprise combination. Implicit in this strategy is the maximisation of the contribution of each livestock unit to soil fertility improvement while addressing the challenges of increasing intensity in crop–livestock systems.

In this paper we first discuss the effect of manure on soil productivity and ecosystems services. This is followed by highlighting the management practices needed to increase manure use efficiency. We then elaborate on emerging new research opportunities in soil fertility management to enhance crop–livestock integration.

## Effect of manure on soil productivity

In the mixed farming systems that characterise the semi-arid zone of Africa, low rural incomes, high costs of fertiliser, inappropriate public policies and infrastructural constraints prevent the widespread use of inorganic fertilisers (Williams et al. 1995). Under this situation, as population pressure increases and fallow cycles are shortened, organic sources of plant nutrients such as manure, crop residues and compost remain the principal sources of nutrients for soil fertility maintenance and crop production (Williams et al. 1995). Estimates of the nitrogen (N) contribution from manure to the total N input budget suggest that up to 80% of N applied to crops is derived from manure in both extensive and intensive grazing systems in eastern and southern Africa (Kihanda 1996; Mugwira and Murwira 1997).

Many scientists have reported on the effect of organic amendments on crop yield increases in western and eastern Africa (Abdullahi and Lombin 1978; Mokwunye 1980; Pichot et al. 1981; Padwick 1983; Pieri 1986; Powell 1986; Pankhurst 1990; de Ridder and van Keulen 1990; Bationo and Mokwunye 1991; Bationo et al. 1995; Gibberd 1995; Murwira et al. 1995; Probert et al. 1995; Kihanda 1996; Kihanda and Warren 1998; Kanyanjua and Obanyi 1999; Lekasi et al. 1999; Kihanda and Gichuru 2000).

Most of the literature has focused on the responses of crops to farmyard manure (FYM) applications. One of the earliest reported increases to FYM application in SSA was by Hartley (1937) in the Nigerian savannah. It was observed that application of 2 t/ha FYM increased seed cotton yield by 100%, equivalent to fertilisers applied at the rate of 60 kg N/ha and 20 kg phosphorus (P)/ha. In Embu, Kenya, FYM significantly increased maize and potato yields in a long-term trial (Gatheca 1970). The data in Table 1 (Panels A and B) summarises the results of a number of trials on manure and manure+inorganic fertilisers conducted at research stations in West Africa. The data

**Table 1.** *Results of manuring experiments at three locations in semi-arid West Africa.*

Panel A: Manure only

| Location | Amount of manure applied (t/ha) | Crop response[1] (kg of DM/t manure) | | | |
|---|---|---|---|---|---|
| | | Crop | Grain | Stover | Reference |
| MPesoba, Mali | 10 | Sorghum | 35[2] | NS[3] | Pieri (1989) |
| Saria, Burkina Faso | 10 | Sorghum | 58 | NS | Pieri (1986) |
| Sadoré, Niger 1987 | 5 | Pearl millet | 38 | 178 | Baidu-Forson and Bationo (1992) |
| | 20 | Pearl millet | 34 | 106 | Baidu-Forson and Bationo (1992) |

Panel B: Manure with inorganic fertiliser

| Location | Amount of | | Crop response[1] (kg of DM/t manure) | | |
|---|---|---|---|---|---|
| | Manure (t/ha) | Fertiliser (kg/ha) | Crop | Grain | Stover |
| MPesoba, Mali | 5 | NPK: 8–20–0 | Sorghum | 90[4] | NS[3] |
| Saria, Burkina Faso | 10 | Urea N: 60 | Sorghum | 80 | NS |
| Sadoré, Niger 1987 | 5 | SSP P: 8.7 | Pearl millet | 82 | 192 |
| | 20 | SSP P: 17.5 | Pearl millet | 32 | 84 |

1. Responses were calculated at the reported treatment means for crop yields as: (treatment yield – control yield) / quantity of manure applied, DM = dry matter.
2. Response of sorghum in the second year of a four-year rotation involving cotton–sorghum–groundnut–sorghum. Manure was applied in the first year.
3. NS = not specified.
4. Estimated from visual intrapolation of graph.

Source: Williams et al. (1995).

showed that manure collected from stables and applied alone produced about 34–58 kg of cereal grain and 106–178 kg of stover per ton of manure (Table 1, Panel A). The application of manure together with inorganic fertiliser resulted in yields of 32–90 kg of cereal grain and 84–192 kg of stover per ton of manure (Table 1, Panel B).

In Kenya, Kanyanjua and Obanyi (1999) under the Fertiliser Use Recommendation Project (FURP) observed that response to manure application, averaged over several locations and seasons, was in the order cabbages > potatoes > maize > cowpea and that crops grown on Nitisols responded more than those grown on Acrisols (Table 2). Kihanda (1988) evaluating the effects of inorganic fertilisers, lime, FYM and crop residues on the yield of maize in acidic Andosols of central Kenya found that FYM increased maize biomass by 210%, while lime increased yields by 115% and P by 57%. They concluded that the large response to FYM application might have been due to a reduction in exchangeable aluminium (Al) and manganese (Mn) allowing the plants to

**Table 2.** *Crop yields[1] (averaged over several locations in East Africa) as influenced by levels of FYM application and soil type, 1998.*

| Soil type/ crop | FYM rates (t/ha) 0 | 2.5 | 5.0 | 7.5 | Response equation | $R^2$ |
|---|---|---|---|---|---|---|
| | Crop yields (t/ha) | | | | | |
| Nitisols | | | | | | |
| Maize | 3.72 | 4.00 | 4.34 | 4.76 | Y = 3.68 + 0.138 FYM | 0.99 |
| Potatoes | 9.12 | 10.20 | 10.60 | 11.80 | Y = 9.16 + 0.337 FYM | 0.98 |
| Cabbages | 13.70 | 21.20 | 27.60 | 29.30 | Y = 14.97 + 2.128 FYM | 0.97 |
| Acrisols | | | | | | |
| Maize | 1.88 | 2.00 | 2.00 | 2.07 | Y = 1.90 + 0.021 FYM | 0.93 |
| Cowpeas | 0.77 | 0.78 | 0.83 | 0.82 | Y = 0.77 + 0.079 FYM | 0.88 |

1. Grain yield/ha for maize and cowpea; tuber yield/ha for potatoes; total dry matter (TDM) yield/ha for cabbage.

Source: Kanyanjua and Obanyi (1999).

establish better rooting systems in addition to providing nutrients, particularly potassium (K).

In the Sahelian zone of West Africa, Bationo and Mokwunye (1991) found no difference between applying 5 t FYM/ha or applying 8.7 kg P/ha (as single superphosphate, SSP) and a further application of 20 t FYM/ha only doubled the pearl millet grain that resulted from the application of 5 t FYM/ha (Table 3).

**Table 3.** *Effects of manure and phosphorus from different sources on pearl millet grain yield, at Sadoré, Niger, 1988.*

| Treatments | Grain yield (t/ha) |
|---|---|
| Control: 0 P, 0 FYM[1] | 0.362 |
| 8.7 kg P/ha as SSP[2] | 0.734 |
| 5 t FYM/ha | 0.723 |
| 8.7 kg P/ha as SSP + 5 t manure/ha | 1.093 |
| 39.3 kg P Parc W PR[3]/ha | 0.485 |
| 39.3 kg P Parc W PR/ha + 5 t manure/ha | 0.952 |
| 17.5 kg P/ha as SSP | 0.851 |
| 20 t manure/ha | 1.457 |
| 17.5 kg P/ha as SSP + 20 t manure/ha | 1.508 |
| SE | ±0.089 |
| CV (%) | 27.9 |

1. FYM = manure containing 0.405% total P and 1.21% total N.
2. SSP = single superphosphate.
3. Parc W PR = Parc W Rock Phosphate.

Source: ICRISAT Annual Reports (1984–1988).

Gatheca (1970) reported that an annual application of 5–6 t/ha of manure resulted in higher yields of maize in Kenya than heavy applications of 20–30 t/ha applied at intervals of 4–5 years. In the acidic soils of central Kenya, Mugambi (1979) noted that application of 5 t FYM/ha increased potato tuber yield by more than 50% above the control. A combination of the same rate of FYM and P at 100 kg P/ha increased potato yield by more than 100% above the control, an indication that P was also limiting in that soil. The data in Table 4 indicate that the application of 3 t/ha of FYM plus urine resulted in the production of grain and total biomass that were 3–4 times higher than when only manure was applied and that crop response to sheep manure was greater than to cattle manure. Research studies indicate that approximately 80–95% of the N and P consumed by livestock are excreted. Whereas N is voided in both urine and faeces, most of the P is voided in faeces (ARC 1980; Termouth 1989). In the P-deficient sandy Sahelian soil, the addition of P fertiliser increases the efficiency of FYM, and hill placement of both FYM and P fertiliser produce better responses than when they are broadcast (Figure 1).

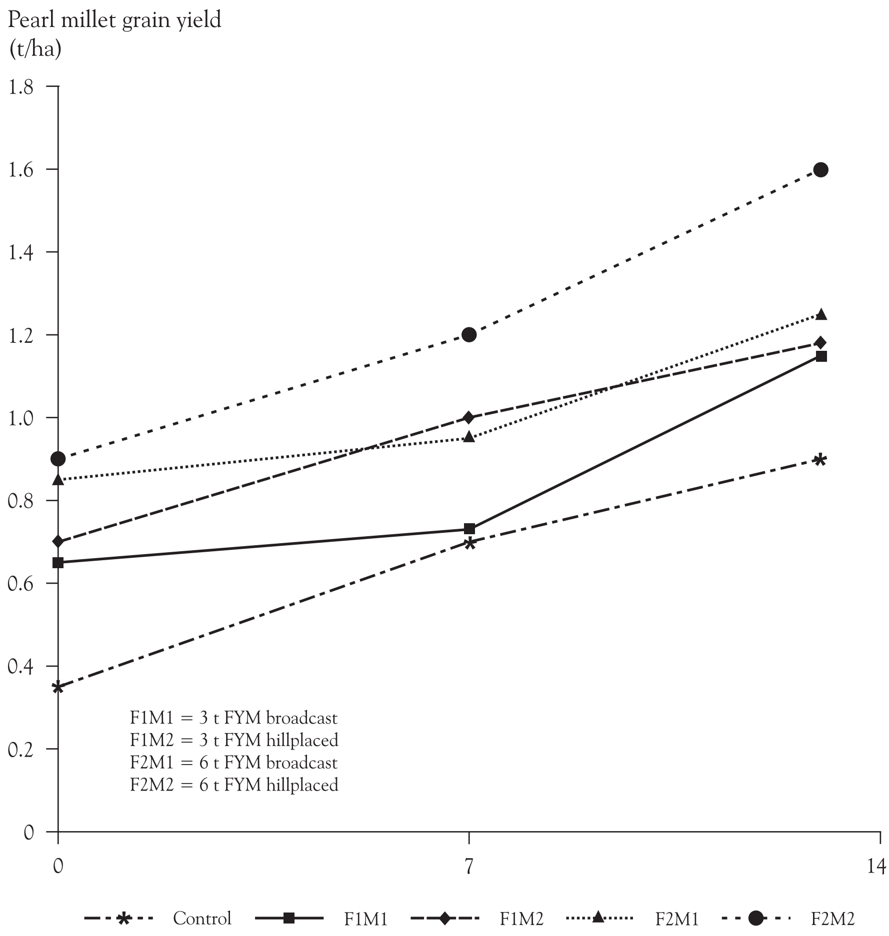
**Table 4.** *Effect of cattle and sheep dung and urine on pearl millet grain yield (t/ha) and total above-ground biomass (t/ha), Sadoré, Niger, 1991.*

| | | With urine | | Without urine | |
|---|---|---|---|---|---|
| Type of manure | Dung application rate t/ha | Grain yield (t/ha) | Total biomass (t/ha) | Grain yield (t/ha) | Total biomass (t/ha) |
| Cattle | 0 | – | – | 0.080 | 0.940 |
| | 2.990 | 0.580 | 4.170 | 0.320 | 2.170 |
| | 6.080 | 1.150 | 7.030 | 0.470 | 3.850 |
| | 7.360 | 1.710 | 9.290 | 0.560 | 3.770 |
| SE (mean) | | 0.175 | 0.812 | 0.109 | 0.496 |
| Sheep | 0 | – | – | 0.080 | 0.940 |
| | 2.010 | 0.340 | 2.070 | 0.410 | 2.440 |
| | 3.530 | 1.090 | 6.100 | 0.380 | 2.160 |
| | 6.400 | 1.170 | 6.650 | 0.480 | 2.970 |
| SE (mean) | | 0.154 | 0.931 | 0.078 | 0.339 |

Source: Adapted from Powell et al. (1998).

The data in Table 5 for eastern and Table 6 for western Africa give the variation in the nutrient concentration of manure samples from different locations, indicating that even on the same soil type and with the same rainfall, the response to manure application will greatly depend on the source of manure.

Pieri (1986; 1989) summarised the results of the long-term soil fertility experiments in sub-Saharan Africa. One important conclusion that emerged from the experiments is that the application of mineral fertilisers is an effective technique for increasing crop yields in the Sudanian zone of West Africa. However, in the long-term the use of mineral fertilisers alone will not increase crop yields but just sustain them. More




Source: AfNET (2002).

**Figure 1.** *Effects of manure placement methods and phosphorus fertiliser on pearl millet grain yield (t/ha), in Karabedji, Niger (1999).*

**Table 5.** *Nutrient content of FYM samples collected from eastern and southern African countries in sub-Saharan Africa compared to UK samples.*

| | Nutrient content (%) | | | | |
|---|---|---|---|---|---|
| Country (Reference) | N | P | K | Ca | Mg |
| UK (Hemingway 1961) | 1.76 | 0.24 | 1.29 | 0.74 | 0.34 |
| Kenya (Ikombo 1984) | 1.62 | 0.50 | 1.34 | 0.26 | ND[1] |
| Kenya (Kihanda 1996) | 1.19 | 0.24 | 1.46 | 0.97 | 0.26 |
| Zimbabwe (Mugwira 1984) | 0.6–1.3 | 0.1–0.2 | 0.7–1.0 | 0.2–0.3 | 0.1–0.2 |
| Kenya (Probert et al. 1995) | 0.23–0.70 | 0.08–0.22 | 0.28–1.14 | 0.58–2.02 | ND |

1. ND = not determined.

**Table 6.** *Nutrient composition of manure from selected locations in semi-arid West Africa.*

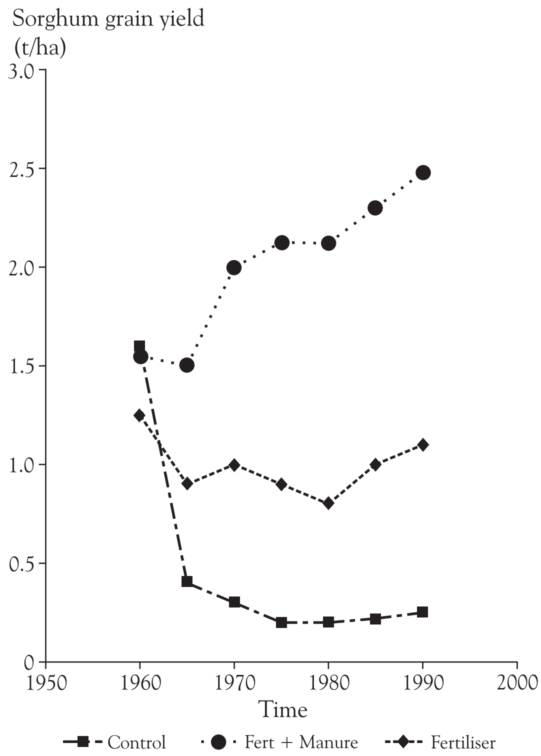
| | Nutrient composition (%) | | | |
|---|---|---|---|---|
| Location and type of manure | N | P | K | Reference |
| Saria, Burkina Faso | | | | |
| FYM | 1.5–2.5 | 0.09–0.11 | 1.3–3.7 | Pichot et al. (1981) |
| Northern Burkina Faso | | | | |
| Cattle manure | 1.28 | 0.11 | 0.46 | Quilfen and Milleville (1983) |
| Small ruminant manure | 2.20 | 0.12 | 0.73 | Quilfen and Milleville (1983) |
| Senegal | | | | |
| Fresh cattle dung | 1.44 | 0.35 | 0.58 | Landais and Lhoste (1993) |
| Dry cattle dung | 0.89 | 0.13 | 0.25 | Landais and Lhoste (1993) |

Source: Williams et al. (1995).

sustainable and increased production is obtained when inorganic fertilisers are combined with manure (Figure 2).

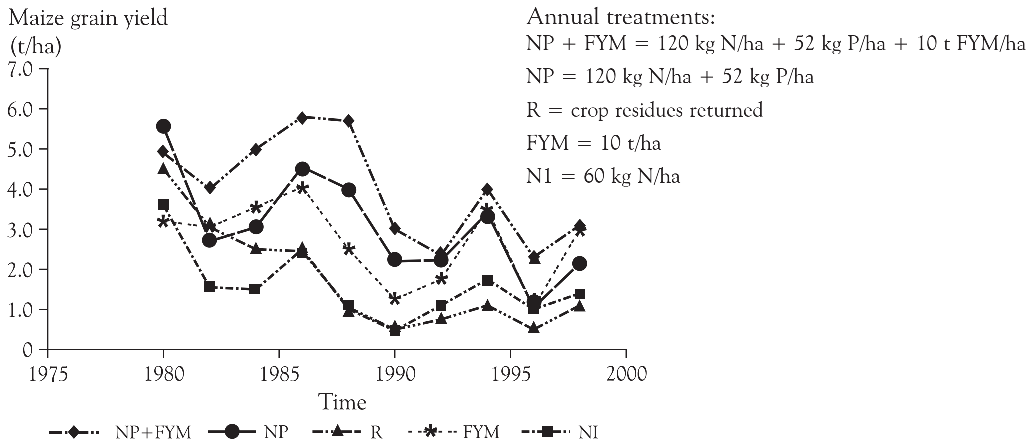
At Kabete in Kenya, Palm et al. (1997) obtained higher yields of maize in a long-term soil fertility management experiment when mineral fertilisers were combined with FYM (Figure 3).

To obtain a modest yield of 2 t/ha of maize the application of 5 t/ha of high-quality manure can meet the N requirement but it cannot meet the P requirements in areas where P is deficient (Palm 1995). Organic inputs such as manure are often proposed as alternatives to mineral fertilisers; however, it is important to recognise that in most cases the use of such manure is part of an internal flow of nutrients within the farm and therefore does not add nutrients from outside the farm. Also the quantities of available manure are inadequate to meet nutrient demand over large areas because of their limited quantities and low nutrient content, and the high labour demands for processing and application. The availability of manure for sustainable crop production has been addressed by several scientists. With the present livestock systems in West Africa the potential annual transfer of nutrient from manure is 2.5 kg N and 0.6 kg P/ha of cropland. Although the manure application rates are between 5 and 20 t/ha in most of the on-station experiments, the quantities used by farmers are very low and ranged from 1.3–3.8 t/ha (Williams et al. 1995). Hiyami and Ruttan (1985) reported that exclusive use of inorganic fertilisers in Africa will increase annual food production at best by 2%, well below the population growth rate, and not even close to the 5–6% required to reduce poverty and ensure food security. Organic sources of nutrients, however, will be complementary to the use of mineral fertilisers (Quiñones et al. 1997). Despite its vital role, the quantities of manure needed are not available on-farm for a number of reasons. There are simply insufficient numbers of animals to provide the manure needed, and this problem becomes more pronounced in post-drought years (Williams et al. 1995). The amount of livestock feed and land resources available are also limited. Depending on rangeland productivity, between 10–40 ha of dry-season




Source: Sedogo (1993).

**Figure 2.** *Sorghum grain yield (t/ha) in the Sudanian zone of West Africa as affected by mineral and organic fertilisers over time (1950–2000).*




Source: Palm et al. (1997).

**Figure 3.** *Maize grain yield trends (t/ha) from long-term trial at Kabete, Kenya (1980–98).*

grazing land and 3–10 ha of wet-season grazing land are required to maintain yields on 1 ha of cropland using only animal manure (Fernández-Rivera et al. 1995).

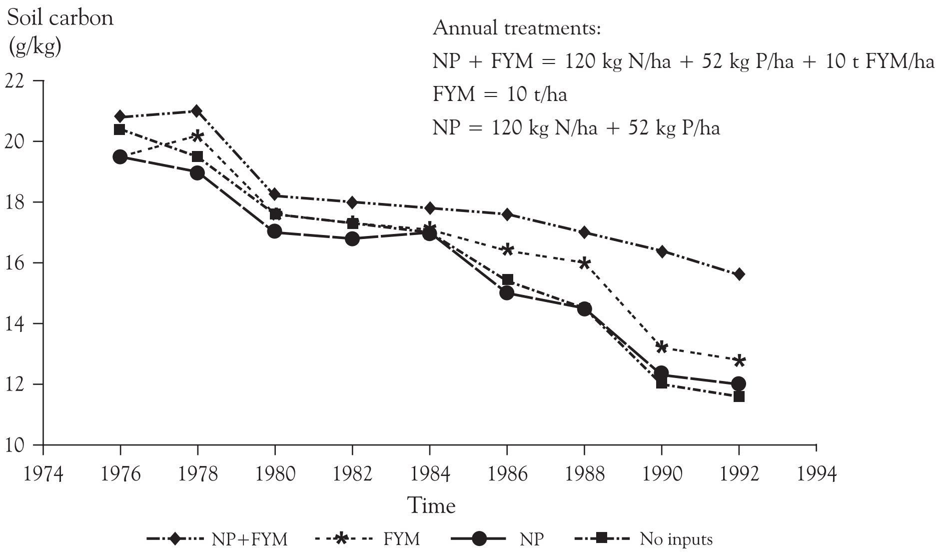
Annual manure production by zero-grazing cattle in Kenya has been estimated as 1–1.5 t/animal (Strobel 1987). Two animals are needed to supply enough to grow a 2 t/ha maize crop, if the manure is of high quality, but eight animals are required if the quality is low.

The data in Table 7 on the Sahelian zone of Niger clearly indicate that manure application will not only improve the organic carbon (C) content of the soil but by

**Table 7.** *Soil total nitrogen, pH, organic matter and Bray $P_1$ as influenced by manure additions, 1987.*

| Treatments | Total N (ppm) | pH | | Organic matter(%) | Bray $P_1$ (ppm) |
|---|---|---|---|---|---|
| | | $H_2O$ | KCl | | |
| Control | 153 | 4.98 | 3.88 | 0.29 | 5.33 |
| 5 t FYM/ha | 202 | 5.37 | 4.25 | 0.39 | 10.31 |
| 17.5 kg P/ha as SSP | 148 | 5.05 | 4.03 | 0.30 | 15.50 |
| 20 t FYM/ha | 285 | 6.21 | 5.03 | 0.58 | 22.90 |
| SE | 15 | 0.14 | 0.16 | 0.06 | 2.58 |
| CV (%) | 18.7 | 5.18 | 7.42 | 29.63 | 37.46 |

Source: Bationo and Mokwunye (1991)




Source: Nandwa (2001).

**Figure 4.** *Effect of application of farmyard manure and mineral fertiliser singly and in combination on soil organic carbon at 0 to 25 cm soil depth on a Humic Nitisol, Kabete, Kenya (1974–94).*

complexing iron (Fe) and Al it will also increase P availability. In long-term soil fertility management trials, although soil organic C decreased in all treatments over time, the organic C value was higher in the treatments where crop residues and manure were applied (Figure 4).

Past and on-going research has focused on the assessment of the relationship between land management practices and C storage. Our current understanding is that the C sequestration potential of different organic inputs is an analogous index to that of fertiliser equivalency. Further studies are needed to assess the trade-offs between the use of soil C for agricultural productivity and its value for C sequestration potential and environmental conservation. This is a relatively new area of research especially on assessing the effect of quantity and quality of organics (both organic manures and residues) on soil organic matter fractions and crop yields.

Expected benefits from manure application in the context of ecosystem functions include the non-nutritional effects on soil physical properties that in turn influence nutrient acquisition and plant growth. The resource, through interactions with the mineral soil in complexing toxic cations, helps to reduce the P sorption capacity of the soil (Bationo and Mokwunye 1991).

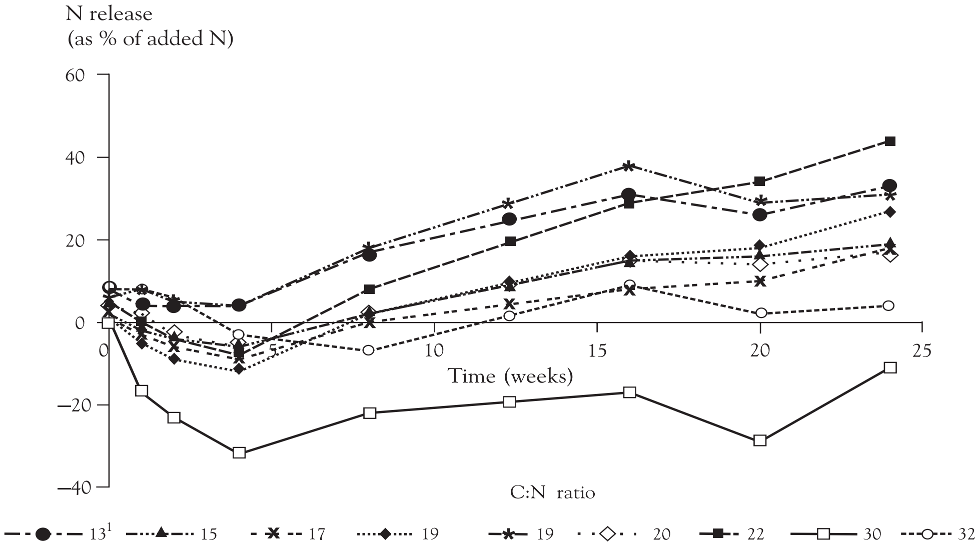
# Management practices to improve manure efficiency

## Improvement of manure quality

Manure quality varies widely and clear indices of quality determination are sometimes difficult to apply widely. Past research has focused on evaluating different ways of managing manure to improve its quality. Preliminary studies suggest that feeding of concentrates, zero-grazing rather than traditional kraaling, manure stored under cover instead of in the open, and on concrete rather than soil floors results in higher quality manure (Lekasi et al. 1998).

**Animal type and diet.** The quality of manure has been observed to vary with types of animals and feeds, collection and storage methods (Mugwira 1984; Ikombo 1984; Probert et al. 1995; Kihanda 1996).

In Kenya a study conducted by Lekasi et al. (1998) observed that the nutrient contents (especially N and P) of manure were in the order of chicken > pig > rabbit > goat > cattle, with manure mixed with urine having a higher quality than dung alone. Nevertheless, current characterisation studies (Williams et al. 1995) indicate that manure quality is very variable, e.g. 0.23–1.76 (N %); 0.08–1.0 (P %); 0.2–1.46 (K %); 0.2–1.3 (Ca %) and 0.1–0.5 (Mg %). High-quality manure has been defined as that with >1.6% N or C:N ratios of <10; while low-quality manure has <0.6% and C:N ratios of >17. Recent studies have shown poor correlation between manure quality and lignin, polyphenols and soluble fractions of C (Kihanda and Gichuru 2000). Figure 5 shows the effect of the C:N ratio on N mineralisation of manures. It was noted that the higher the C:N ratio, the slower the rate of N mineralisation. Figure 6 shows that the N fertiliser equivalency increases with N content.



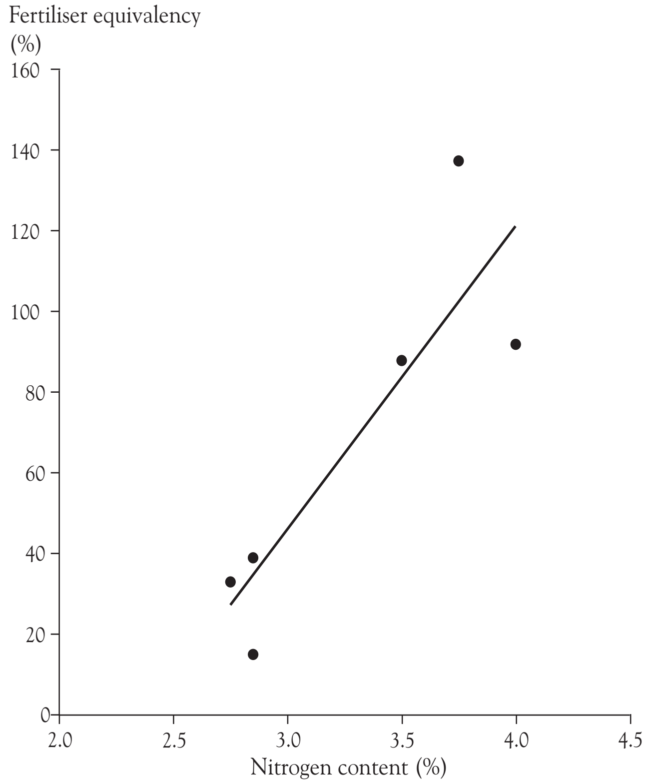

1. Numbers on right of legend indicate C:N ratio.

Source: Kihanda and Gichuru (2000).

**Figure 5.** *Nitrogen mineralisation over a 5-week period in manures with different C:N ratios collected from cut-and-carry systems in Kenya, 1998.*

Irrespective of animal type, the quality of manure can be enhanced through feed manipulation and is more favourable in intensive grazing systems (stall or zero-grazing units) than in extensive grazing systems (communal or range grazing). In a study carried out in eastern Africa on cattle, it was reported that manure-N concentration increased by more than two-fold when the basal diet of barley straw was supplemented with poultry waste and high-quality forage shrubs, e.g. *Calliandra* and *Macrotylama* spp. In another study, the P content in manure from cattle that received P supplements of Busumbu rock phosphate (0.70% P) and Minjingu rock phosphate (0.45% P) increased by two to four-fold above the basal diet of Napier grass (0.24% P) and bone meal (0.50% P). However, feeding animals with Unga commercial feed resulted in much higher values of P in manure (0.95% P) (Kihanda and Gichuru 2000).

**Composting techniques and materials.** While the quality of materials used to make composted manure determines its quality, composting techniques are equally important.



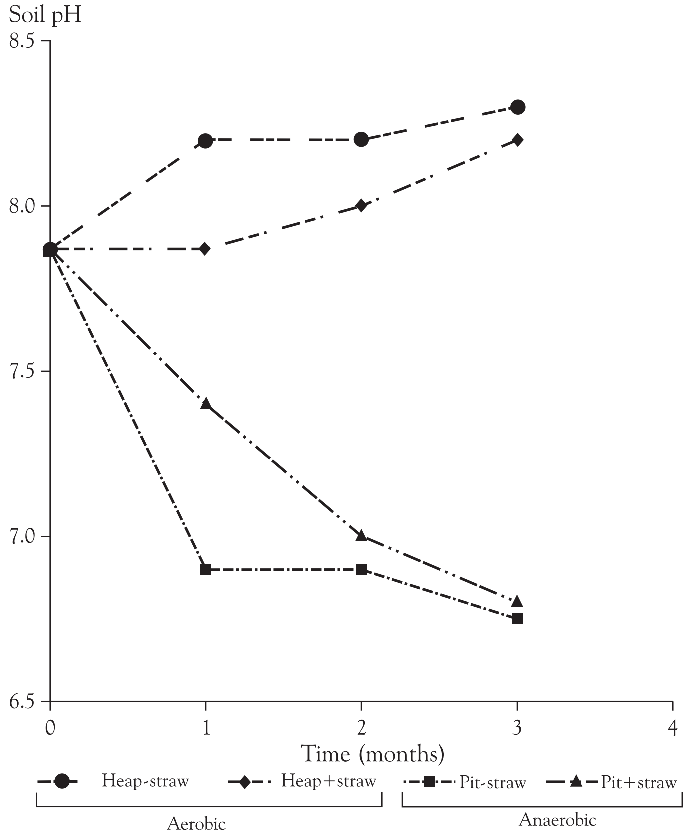

Note: Fertiliser equivalency is the specific amount of an organic material that can have the same effect on crop yield as a certain amount of inorganic matter.

Source: Mutuo et al. (2000)

**Figure 6.** *Relationship between fertiliser equivalencies (%) and nitrogen content (%) of organic materials (Regression line excludes* Calliandra *and maize stover) in Zambia and Tanzania, 1998.*

Higher-quality manures are often obtained from covered-shed composting than from open-shed composting; and similarly from pit composting compared to heap or surface composting (Murwira et al. 1995). Furthermore, crop residue incorporation has been found to minimise nutrient losses through aerobic volatilisation or anaerobic dentrification. For example, in a study in Kenya it was reported that by composting low-quality manure with different proportions of either *Tithonia diversifolia* or *Lantana camara*, the N content of manure was increased by between 10 and 40% depending on the treatment, but no changes in P concentration were found (Kihanda and Gichuru 2000).

In a study conducted in Zimbabwe investigating manure N changes during storage, Nzuma and Murwira (1999) showed that total N measured in anaerobic (pit) manure composts at the end of storage was significantly higher than in aerobic (heap) manure composts. The aerobic manure compost that incorporated maize straw had 0.9% N in April and 0.6% N in July, while the values for manure alone without incorporated straw were 1.4% N in April and 1.2% N in July as a result of the lack of N immobilisation.




Source: Nzuma (2002).

**Figure 7.** *Effects of methods of manure/compost storage and crop residue incorporation of soil pH, Zimbabwe, 1999.*

The results also showed that the pH in the anaerobic manure compost system ranged from 6.5–6.9 while the aerobic manure composts were more alkaline with a pH range of 8.2–8.6 (Figure 7).

The effect of composting on phosphate rock (PR) dissolution has been studied by Bado (1985) and Lompo (1984) in Burkina Faso. The local Kodjari PR alone or combined with urea was incorporated into two low-quality organic materials and composted for 6 months. The PR and urea were incorporated into the organic materials at the rate of 4 kg of PR (25% $P_2O_5$) for 100 kg and 12 kg of urea for 1 t dry organic matter (Lompo 1984). The first organic material was a mixture of 75% sorghum straw and 25% cattle manure (used as an inoculum). The second organic material was a mixture of sorghum straw, feed residues and the faeces of cattle usually collected by farmers in the cowsheds.

The results (Table 8) indicated that the composting of the organic materials with PR involved an enhancement of the total water-soluble P (WSP) balance. The total WSP

**Table 8.** *Effect of organic materials and Kodjari phosphate rock composting on water-soluble phosphorous (WSP) balance before and after 6 months of composting, 1985.*

| | Effect | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Before composting | | | After composting | | | WSP balance | |
| Organic material | Total DM (kg ) | WSP (mg $P_2O_5$/kg) | Total WSP (g $P_2O_5$) | Total compost (kg DM[1]) | WSP (mg $P_2O_5$/kg) | Total WSP (g $P_2O_5$) | (g $P_2O_5$) | (%)[2] |
| Sorghum straw (75%) + FYM (25%) | 60 | 120 | 7.2 | 51 | 230 | 12 | 4.8 | 67 |
| Sorghum straw (75%) + FYM (25%) + PR | 62.4 | 130 | 8.1 | 49.9 | 440 | 22 | 13.9 | 172 |
| Sorghum straw (75%) + FYM (25%) + PR + urea | 62.4 | 130 | 8.1 | 47 | 520 | 24 | 15.9 | 196 |
| Cowshed residues | 60 | 130 | 7.8 | 41.4 | 1370 | 57 | 49.2 | 631 |
| Cowshed residues + PR | 62.4 | 140 | 8.7 | 42.4 | 1710 | 73 | 64.3 | 739 |
| Cowshed residues + urea | 60 | 130 | 7.8 | 36 | 1260 | 45 | 37.2 | 477 |
| Cowshed residues + PR + urea | 62.4 | 140 | 8.7 | 31.1 | 1060 | 33 | 24.3 | 279 |

1. DM = dry matter.

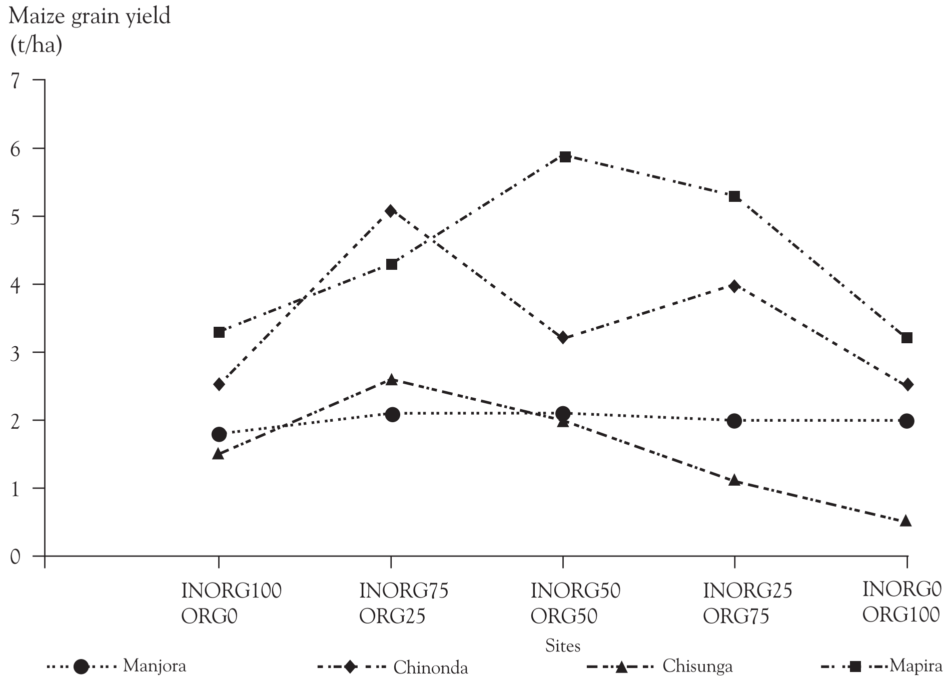
2. WSP balance (%) is expressed as a fraction of the total WSP before composting.

Source: Bado (1985).

was positive for all treatments and for the two organic materials. A positive balance of 67–740% of the total WSP was observed after 6 months of composting. The augmentation of the total WSP may be explained by an increase in the soluble P from organic matter. It may also be due to a probable dissolution of the P in the PR by the organic acids during composting. Two processes might have taken place during composting and these results cannot confirm the effectiveness of organic acid in dissolving P. Isotopic techniques using $^{31}P$ or $^{32}P$ would be necessary to determine the ability of the organic acids to dissolve P from PR during composting.

**Handling and storage techniques.** Besides heaps and pits, manure may be collected and stored in cattle kraals, bomas, open areas etc. Recent research shows that manure quality may be affected by the prevailing conditions. Murwira and Kirchmann (1993) reported that under the aerobic and high pH conditions found in kraals, volatilisation of ammonia can occur, while the wet soggy anaerobic conditions may lead to dentrification and leaching losses. Such losses are minimised under intensive grazing systems such as zero-grazing units with concrete floors and covered roofs. In such systems the provision of low-quality organics as bedding helps to trap the nutrients from the urine. Lekasi et al. (1999) reported that manure removed from grazing units with a soil floor had much lower N and P and higher ash contents than manure removed from barns with concrete floors. Factors responsible for enhanced gaseous N loss in composting include increased total N, high temperatures, low pH and frequent turning (Dewes and Hünsche 1998). On the other hand, high dentrification losses are often associated with increased pH and not with the increase of insoluble C compounds as opposed to reducing sugars under anaerobic conditions. Run-off and nitrate leaching losses can also be substantial from composted manure.

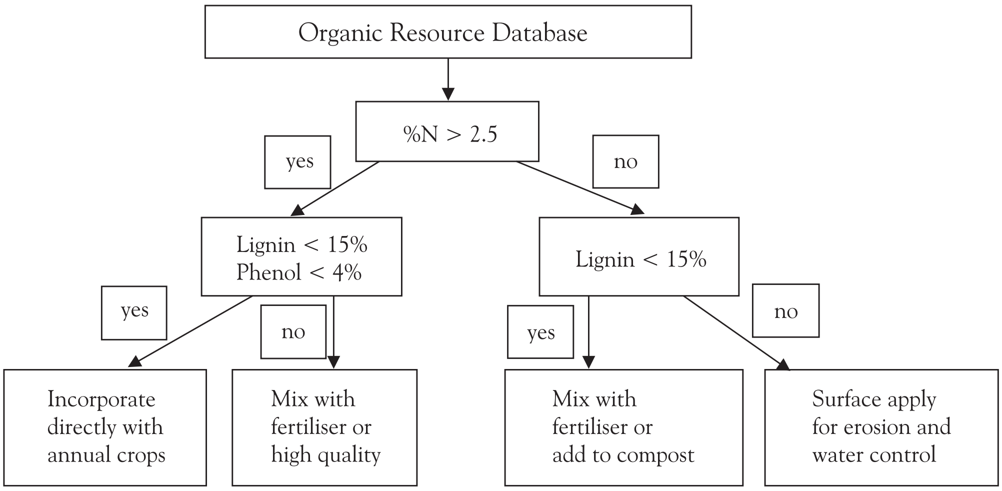
**Integrated nutrient management.** The beneficial effects of combined manure and inorganic nutrient sources on soil fertility have been repeatedly shown, yet there is need for more research on the establishment of the fertiliser equivalency of various manures and also to determine the optimum combination of these two plant nutrient sources [integrated nutrient management (INM)] taking into account the high variability in quality. Such information is useful in formulating decision-support systems and in establishing simple guidelines for the management and use of these resources. Studies investigating the benefits of sole versus combined application of manures and inorganic fertilisers have given variable and sometimes inconsistent results. At Chisunga in Zimbabwe, the application of N in 100% inorganic and 100% organic sources resulted in yields of maize lower than those from combining the two plant nutrients. For example, the application of 100 kg N/ha in the inorganic form resulted in maize yields of about 3.2 t/ha but the application of the same quantity with half N in organic and the other half in inorganic forms gave maize yields close to 6 t/ha. In Manjoro there was no advantage to combining organic and inorganic plant nutrients (Figure 8). Studies in




Source: Nhamo and Murwira (2000).

**Figure 8.** *Maize grain yield (t/ha) obtained after applying 100 kg N/ha applied in five different proportions of manure (ORG) and inorganic fertilisers (INORG) at four different sites in eastern Africa, 1998.*

Tanzania indicated that there was no significant difference in maize yields between sole and combined application of 5 t/ha of manure and 60 kg N/ha of mineral fertiliser (Richard 1967). Disparities in such responses are partly due to the addition of different rates and quality of nutrients through compared treatments and also to differences in the limiting nutrients and soil moisture at the test sites. Another cause of inconsistent results may be the depressing or antagonistic effects of the nutrient source combinations. For example, a study in Zimbabwe showed that while increasing rates of manure, lime and NPK mineral fertilisers increased the growth of pearl millet, lime alone had a depressing effect on the effectiveness of manure, but the NPK fertilisers increased its effectiveness (Mugwira 1985). Short-term trials do not give a true picture of the long-term effects of the treatments. Higher fertiliser equivalencies have been observed in sandier and drier soils that contain less moisture and that are less fertile (Kimani et al. 2001). Using data collected from different sites, Mutuo et al. (2000) as shown in Figure 6 found a linear relationship between the percentage fertiliser equivalency and the N content (2–0.67). This linear function indicates that with an increase of 0.1% N in the tissue of the organic amendment, there is a 6% increase in the fertiliser equivalency value and that the critical level of the N content of organic material for net immobilisation or mineralisation was found to be 2.2%. This is in agreement with the 2.2% suggested by Palm (1995) and Palm et al. (1997) in the decision tree for the selection of organic materials (Figure 9).




Source: Palm et al. (1997).

**Figure 9.** *An organic matter management decision tree for nitrogen.*

**Time frequency and method of application.** Low-quality manure is often observed to depress crop yields. This deleterious effect can be overcome by applying the manure ahead of planting the crop. In some cases, surface application has resulted in better results than incorporation, but often this depends on the quantity of manure applied. Some studies have investigated the potential to overcome this problem through megadose instead of annual applications. But studies from Zimbabwe suggest that there are no differences in crop yields between the two application regimes, e.g. 7 t/ha annual application, 14 t/ha applied every second year and 28 t/ha applied every fourth year (Mugwira and Murwira 1997).

**Fortification and pelleting.** The bulky nature of manure and its low quality constrain its transportation and returns from application. To convert manure to a biofertiliser that is easily handleable (less bulky) and applicable, some studies have shown granule pelleting to be a user-friendly packaging system for farmers (Kihanda and Gichuru 2000). Other studies have demonstrated that the quality and return to such biofertilisers can be improved by fortifying them with the addition of inorganic nutrient sources; composting under cover to minimise leaching and loss of nutrients via gases; and the use of high-quality biofertilisers on high-value crops solely or in combination with inorganic fertilisers (Kihanda and Gichuru 2000).

In high external input systems, large quantities of maize stover or wheat straw can be generated (8–10 t/ha), and this is frequently either burned or partly grazed, resulting in large nutrient off-takes unless the manure is recycled. To overcome this constraint, fortification trials have been conducted. Okalebo et al. (2000) found that the combined application of composts of 2 t/ha of wheat straw or soybean trash with 80 kg N/ha of mineral fertiliser resulted in higher maize yields (grain and stover) than from the application of 80 kg N/ha of mineral fertiliser alone. Sole application of residues depressed yields. In related studies Muasya et al. (2000) found that wheat straw composted with inorganic fertiliser (80 t/ha compost) resulted in slightly higher wheat yields (3.6 t/ha) than with the same rate of normal (no fertiliser) compost (3.0 t/ha).

**Strategies to increase manure quantity.** In both eastern and western Africa, manure is produced abundantly under extensive (pastoral and transhumant) systems. As these systems diminish, settled arable agriculture increases in importance. In the latter systems farmers keep their cattle under confinement or in paddocks. Lots of manure is accumulated in cattle kraals in the eastern Africa region. In West Africa, corralling, i.e. keeping livestock in selected areas over a given period of time, helps increase and accumulate manure through urine and dung voided in the field. Recent studies have shown that corralling for two nights results in between 5 and 13% higher crop yields from crops grown on coralled fields than those from crops on uncoralled fields (Powell et al. 1998).

# New research opportunities

## 'Best-bet' manure-based technologies

Past reviews of research on the use of organics (with or without mineral fertilisers) for soil fertility management in tropical agroecosystems (Padwick 1983; CABI 1994; Palm et al. 1997; Nandwa and Bekunda 1998; Palm et al. 2001) have shown widespread non-adoption or low adoption of emerging technologies. It has been reported that often the use of organic materials is based on trial and error (Palm et al. 2001). At the research and development level, presently and in future, there is a need to set priorities (Kilambya et al. 1998) and to target a potential 'best-bet' technology for smallholder farmers in the form of agronomically superior, economically viable, environmentally friendly and culturally acceptable options.

## Multidisciplinary/interdisciplinary research

Wider adoption of soil productivity technologies requires that their profitability for smallholder farmers be carefully evaluated. The imperative for future manure research is to adopt a holistic framework for closer interaction between soil productivity subject-matter specialists, economists, environmentalists, extensionists and policy makers. There is a need for more horizontal and, above all, vertical networking to create momentum and synergy in soil productivity management research. Lack of multidisciplinary research has been reported to lead to inadequate discounting of soil quality by economists in the context of a 'future generations sustainability quest' (Young 1998). Furthermore, other workers have reported a poor relationship between farm product price and nutrient withdrawal (mining) in the context of nutrient replacement costs. Recent work in Kenya showed that 32% of the average net farm income amounted to the mined nutrients of many farms owned by smallholder farmers, 54% of whom are estimated to live below the poverty line, i.e. on less than US$ 1/day (de Jager et al. 1998). The proposed new approach should provide synergies between applied or strategic research and adaptive research, and also between farmers' indigenous technical knowledge (ITK) and main scientific knowledge (MSK), thereby resulting in higher rates of technology adoption. Future multidisciplinary research should also investigate yield depression attributed to the phytotoxicity associated with manure management (Elliott et al. 1978), plant diseases (Cook et al. 1978) and pests (Musiek and Beasley 1978).

## Farmer/client participatory research approach

There is a need to shift from a top-down to a bottom-up research approach because the use of the former approach in soil productivity management research in the past has proved retrogressive, especially for heterogeneous, risk-averse farm households. Future manure and other nutrient input management research should use participatory research approaches, e.g. farmer field schools (FFS), or participatory learning action research in the context of the target farming systems, integrating different disciplines and with the participation of farmers (Haverkort and de Zeeuw 1991; Martin and Sherington 1997).

## Guidelines on the use of manures

Most manures are often characterised as intermediate–low-quality resources and hence are prescribed to be used in a mixture with mineral fertiliser (Palm et al. 2001). Future research is required to identify the 'best-bet' low-quality manure that can be mixed with high-quality inorganic resources to satisfy the short-term goal of nutrient availability and the long-term goal of building soil organic matter (SOM). Such research should come up with cases for proper discounting of resource conservation estimates (Smaling et al. 1997).

## Benefits of manure

Like other organics, the benefits of using manure over mineral fertilisers are both in the short-term effects and residual or long-term effects. Future research opportunities include the development of guidelines that link the quality of manures to their short-term fertiliser equivalency value and longer-term residual effects through SOM turnover and formation.

## Future research opportunities

- These should build on past organic resource databases (ORD) to develop decision support system (DSS) guides and simple tools, based on both scientist and farmer perspectives to guide the choice and use of manures depending on their varied qualities and quantities. This will require research that correlates scientific indicators (chemical content and nutrient release) with farmers' indicators of manure quality (texture, colour, smell, white fungi/sand, homogeneity and longevity of composts).
- The relationship between manure quality and a number of variables that influence quality, e.g. animal feed manipulation, composting techniques, manure handling and storage method, should be established. This type of research should include determination of strategies that minimise nutrient losses, leaching, erosion, volatilisation and dentrification.
- Development of a systematic framework for investigating integrated nutrient management based on fertiliser equivalence values and pertinent ecosystem services and functions. This research should determine the economic and social trade-offs of improved soil fertility management alternatives to manures, e.g. legumes, high-quality organics, green manures and forage legumes in traditional mixed farming systems.
- Determination of the biophysical and socio-economic boundary conditions for the adoption of manure management based techniques.

# Conclusions

There is considerable information on manure management in western and eastern Africa. The results of comparative analyses from the regions suggest that different lessons can be learned. As an example, it is clear that scientists in West Africa can benefit by learning more of the technologies developed in eastern Africa on composting with manure fortified with rock phosphate. Scientists in West Africa can also learn from the work done in eastern Africa on the assessment of manure fertiliser equivalency, technologies based on the identification of the best combination ratios of organics and inorganics, and the systematic characterisation of manure for its nutrient contents and lignins and polyphenols in order to use organic matter decision trees.

Crop response to manure alone or in combination with inorganic fertilisers is variable and site-specific. The difference in response may be due to several factors, e.g. soil fertility status, quality of manure and environmental factors. This means that modelling and decision support systems will have an important role in future research. Other new research opportunities include such topics as the crop–livestock trade-off to be gained by developing new strategies that minimise competition between crops and livestock, such as the conflicting demands of crop residues for feed and soil conservation, the use of legumes for soil fertility management *per se* or as feed for livestock, increased inorganic fertiliser use efficiency due to better management of manure, the relationships between manure quality and buildup of SOM, other benefits of manure use, and the socio-economic and policy implications.

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