# 1 Introduction

Agriculture in Zimbabwe falls into two distinct sectors: the predominantly private, commercial sector that is given over to large-scale agriculture, and the communal sector, which is dominated by subsistence farming. Most communal land is found in regions with low rainfall and poor soils, and the majority of smallholders farm on inherently infertile sands or sandveld soils. These soils are not only critically deficient in nitrogen (N), phosphorus (P) and sulphur (S) (Mashiringwani, 1983; Grant, 1981), but are also subject to widespread degradation and declining fertility caused by the loss of organic matter, the breakdown of soil structure and erosion (Elwell and Stocking, 1988).

One of the soil amendments used by farmers in communal areas is manure from livestock, a valuable source of nutrients that can improve the structure and water holding capacity of the soil, and also moderate soil temperatures. Continued applications of manure can increase the fertility of sandveld soils by progressively increasing their cation exchange capacity, exchangeable bases and pH (Grant, 1967). However, as manure is liable to significant nutrient losses through leaching and volatilisation when it is stored and handled, it is not always as effective as it could be.

Crop residues are also fairly widely used as a fertility input in communal areas, where they either remain in the soil as roots, or are left above the ground as stover at the end of the dry season. Some farmers also incorporate residues into the soil, although most seem to prefer to burn off any remaining crop residues at the start of the season, to clear the ground prior to tilling. This also helps to destroy pests, pathogens and weed seeds, and the resulting ash can enhance plant growth by reducing the acidity of the soil. However, the downside to burning is that it may also trigger nitrogen losses that then have to be made good with mineral fertiliser, which has become increasingly expensive since the introduction of structural adjustment policies (ESAP) in 1991.

There is a clear need to develop alternative, socially acceptable ways of managing crop residues that will make them more effective as a soil amendment. One possibility would be the old but little used art of composting, which seems to be most popular amongst the poorer households, who put compost on their maize and vegetable gardens (Carter and Murwira, 1995; Shumba, 1985). In 1985, only about 12% of farmers were reported to be using compost in Mangwende (Shumba, 1985), while a survey done in Guti village, Mangwende, in 1998 showed that it was used by about 50% of farmers (Chuma et al., 2000).

There is considerable potential for recycling nutrients by feeding crop residues to cattle (Grant, 1970). Animals kept in kraals are fed residues during the dry season, and although maize stover is of little nutritional value (Topps and Manson, 1967), it produces manure that is rich in nutrients, as the cattle excrete 80-90% of the nitrogen, phosphorus and potassium they consume (Mentis, 1981). Manure also generally contains a certain amount of undigested residue, as some is dropped as it is eaten, some is laid down as bedding straw, and farmers often add grass and stubble as bulking agents. However, the capacity of the manure to improve soil fertility depends not only on the crop residues used to produce and amend it, but also on the outcome of the biological processes of decomposition, which determine the rate at which carbon and nutrients are released into the soil (Swift et al., 1979). Its value to plants is largely determined by its nitrogen content, and any nutrients lost through leaching and volatilisation when the manure is stored and handled will significantly reduce its effectiveness.

Analysis of the manure used in communal areas shows that its nitrogen content may range from 0.5% to 1.8%, and is usually less than 1.2% (Tanner and Mugwira, 1984; Murwira et al., 1995). This low N content is probably due to the fact that the feed used to produce the manure is of poor quality, and because nutrients are lost while manure is stored. Indeed, several studies have reported substantial nutrient losses during storage and handling. Kirchman (1985) found that between 8 - 40% of nitrogen is lost during storage, and Lauer et al. (1976) measured losses of between 61 - 99% of ammonium nitrogen. Adding stover (with initial C/N ratios above 30) to cattle manure can significantly reduce N losses during storage, while adsorbents such as peat and zeolite have been found to reduce the loss of ammonia during decomposition by 59% and 16% respectively (Witter and Kirchman, 1989).

In a series of field experiments, Kirchman (1985) found that the uptake of N from aerobically treated manure was lower than from manure with the same C/N ratio that had decomposed under anaerobic conditions. The concentration of nitrogen initially increased over the first six months of storage, but then declined. Cecchi et al. (1992) concluded that organic fractions could be converted to fertiliser of excellent quality by anaerobic composting.

There is little information available on how the quality of manure may be improved by manipulating biological processes during decomposition, although it has been noted that storage conditions affect its quality and the subsequent release of nutrients. Mugwira (1985) noted that the N uptake increased when anaerobically decomposed manure was used, but that there was little difference in the uptake of phosphorous.

Anaerobically decomposed manure had a positive nitrogen effect on crops in the short term, while those treated with aerobically decomposed and dried manure showed a net immobilisation of N in the first eight weeks after application. Aerobically decomposed manure-N is organically bound and has to be mineralised before uptake is possible (Murwira et al., 1995).

Studies undertaken in communal areas of Zimbabwe on the decomposition of cattle manure have shown that less than 10% of the total N is mineralised in the first season of application (Murwira and Kirchmann, 1993). This suggests that a high C:N ratio slows down the release of nitrogen. If this is the case, N could be released more quickly if storage and handling techniques were improved, or when the C:N ratio was reduced by adding inorganic nitrogen. This would accelerate decomposition by increasing the availability of N to microbes.

Farmers in the communal areas have developed complex and sophisticated soil fertility management strategies, improving their soils with a variety of inputs ranging from manure and compost to leaf litter, soil from termitaria and fertilisers. Mineral fertilisers account for 64% of all the N used by smallholders and manure 32 %. Manure provides 57% of the mass and 87% of the total N content of locally available inputs (Murwira et al., 1995). Manure therefore contributes significantly to the overall N budget, even in farms that use large amounts of mineral fertiliser.

We feel that it is important to increase the value of those inputs already available to farmers. The aim of this study is to improve traditional methods of soil fertility by developing storage and handling systems that minimise losses and enhance the quality of manure. Increasing the nitrogen content by 0.1% would provide an extra 10kg N (or about 30kg of ammonium nitrate) at application rates of 10t/ha.

The following activities improve the contribution of manure and crop residues to soil fertility management:

1) Improve the quantity and quality of manure by giving animals more, better quality feed;
2) Improve the quality of manure and crop residues by using more efficient composting techniques. This will involve changing the way that residues are collected and processed, and focus on reducing nutrient losses;
3) Improve the on-field management of organic materials by changing the methods and rates of application, applying this scarce resource more efficiently, combining with mineral fertilisers etc.

This paper focuses on the second intervention.

## Methodology

Our work in the Mangwende communal area can be broken down into three phases:

**Phase 1:** A multi-disciplinary team carried out a detailed survey on 100 farms, to determine how farmers manage their manure and crop residues, and to identify possible interventions to improve their practices. Using a combination of participatory rural appraisal, informal interviews, wealth ranking and bio-resource flow modelling techniques, the team analysed the situation and developed a research agenda that was sensitive to the needs of the target communities. They then worked with the farmers to identify feasible interventions for testing in the next phase.

**Phase 2:** In a series of experiments, various combinations of cow dung and maize stover were stored outside under a range of conditions. Fresh manure was mixed with different proportions of this locally available crop residue, and left for varying lengths of time to decompose aerobically in heaps or anaerobically in pits.

The manure was then used in field experiments designed to establish whether the different storage conditions affected the availability of nutrients, their uptake and effect on maize yields, and how this compared with the methods currently used by farmers. A total of 11 trials were established in the 1997/1998 growing season.

**Phase 3:** In this phase the focus shifted to on-farm work, and the extension service became increasingly involved in the process. In the second year, parallel trials managed by farmers were set up to screen and adapt technologies in the study areas. Working collaboratively, farmers and researchers designed simplified versions of the experiments carried out in Phase 2, which were then implemented in at least fourteen trials managed by farmers. These have been carried out in four districts of Zimbabwe, with over two hundred farmers testing improved techniques for handling and storing cattle manure. Moreover, demonstrations on composting were arranged to disseminate the new techniques. This phase will not be discussed in this paper, but a manual is in preparation on 'composting of organic materials and manure in low input agricultural systems'.

# 2 The management of soil fertility in Mangwende

Mangwende is a maize producing area and farmers here sell more than 60% of their harvest. Almost all of the farmers interviewed stated that the fertility and organic matter content of sandy soils had declined since 1980 and was now very low, and some said that yields would be poor or growth stunted if they did not use any fertilisers. They attribute the decline in soil fertility to continuous cultivation, soil erosion, increased soil acidity[1] and failure to apply adequate nutrient inputs (Chuma et al., 2000).

A variety of practices are used to manage soil fertility, such as winter ploughing to incorporate crop residues and conserve moisture, crop rotation, fallowing and the application of mineral fertilisers, compost, manure, ash, leaf litter and soil from termitaria. Farmers choose their methods according to the amount of material available, the labour requirements and the availability of land and draught power. Their strategies are closely related to their wealth. Wealthier farmers generally possess more farming implements, apply more cattle manure and compost and recycle more stover, while poor households rely more on household waste and leaf litter. While winter ploughing is practised by 82% of the households in Mangwende, very few farmers rotate their crops as land is in short supply and the farming system is dominated by cereals. Fallowing is used by 35% of farmers, but it is often only employed because they lack the necessary labour, oxen or fertilisers to cultivate the land, rather than as a deliberate way of improving soil fertility (Campbell et al., 1997).

Cropping patterns have changed over the last few decades, and the constant devaluation of the Zimbabwe dollar has increased the price of agricultural inputs with imported components, such as mineral fertilisers. In nominal terms, farmers reported that input prices for cereals like maize and sorghum rose faster than output prices, particularly between 1990 and 1996. However, the price of other crops, such as cotton and paprika, increased faster than the price of inputs, giving farmers an incentive to diversify. In Mangwende they now allocate less land to cereals, and they have taken up vegetable gardening, which gives higher returns per unit area.

Before ESAP was introduced in 1991, most farmers in Mangwende used to apply fertilisers to maize at the recommended rates of 350 kg/ha of compound D[2] and 250

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[1] Soil acidity is mainly due to high rainfall, which leaches the exchangeable bases of sandy soils.

[2] Compound D: NPK 8-14-7

kg/ha of Ammonium Nitrate (AN). Nowadays most of them only use 250 kg of compound D and 125 kg of AN, which they apply as a mixture. Farmers reported that they used 50% less fertiliser in 1990 than they had in 1980, and that application rates had fallen another 50-60% by 1996, as fertiliser prices increased significantly between 1990 and 1996. They are aware that this method of reducing production costs also compromises their yields, but many simply have no other option (Chuma et al., 2000).

Farmers now buy less mineral fertiliser and apply it to a smaller area. This has not only reduced crop production, but has also resulted in fields being left fallow, because farmers cannot afford the inputs needed to cultivate them. The total area under cultivation in Mangwende has dropped from 50,000 ha in 1980 to 45,000 ha in 1996. Equally, many cattle owners have reduced the amount of land they cultivate, and now concentrate on smaller and more intensively managed areas. On average, each household in the area has six cattle and two goats, and 71% of all households own cattle (Chuma et al., 2000).

## The use of manure

While the use of manure in Mangwende declined between 1980 and 1990 as large numbers of cattle were lost to drought and disease, it rose again in the 1990s, and is now the main method used by cattle owners to improve the fertility of their soils. They try to increase their manure production by incorporating grass and stover in the cattle pens as bedding. Those without cattle either bought manure or were given some by close relatives. At present, 70% of the manure used in Mangwende is applied to the main fields rather than gardens, and it seems that this trend will continue. An increasing number of farmers use a mixture of manure and fertilisers, adjusting the combination according to how the rainy season develops. They recognise that the decline in soil fertility cannot be redressed with a single type of input, as fertilisers are too expensive and only limited amounts of manure are available (Chuma et al., 2000).

Almost all the farmers agreed that organic fertilisers improve crop yields and soil fertility, while half of them also noted that they enhance the structure of the soil and increase its organic matter content. Farmers said that the disadvantages of using mineral fertilisers were that they are expensive and need to be applied every year, while the main constraints on producing and applying organic inputs were the high labour and transport requirements. Many farmers could not get enough manure to make a significant difference to their soils. They also reported that it was not always possible to get sufficient material to make compost.

## Storing and handling cattle manure

After conducting a detailed survey to determine traditional methods of storing and handling cattle manure in Mangwende, it was concluded that current management techniques are poor and lead to large losses of potential nutrients.

Figures 1 and 2 below present the possible causes of nutrient loss from manure identified by farmers, and their suggestions as to how they might be remedied. Factors likely to result in the loss of nutrients included not kraaling cattle at night, poorly sited kraals, lack of bedding material in kraals. They also mentioned storing manure in small heaps, leaving it exposed to rain and other weather conditions, not keeping it sufficiently moist and storing it for prolonged periods. The possible solutions indicated by farmers are kraaling cattle at night, selecting the site of the kraal carefully and changing its position regularly, protecting it with stones or a wall, and trapping seepage. Adding bedding to the kraal, reducing the time of storage, and composting manure with mineral fertilisers were suggestions directly related to the handling and storing of manure

Figure 1. Farmers' perceptions of causes of nutrient losses from manure

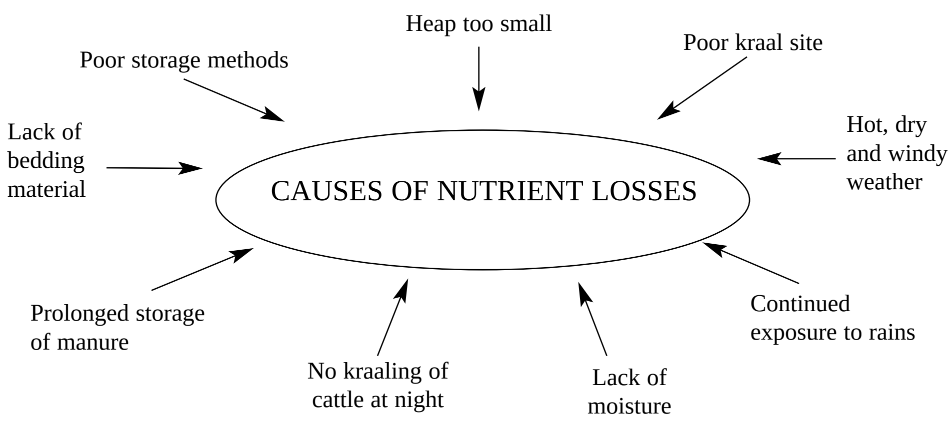
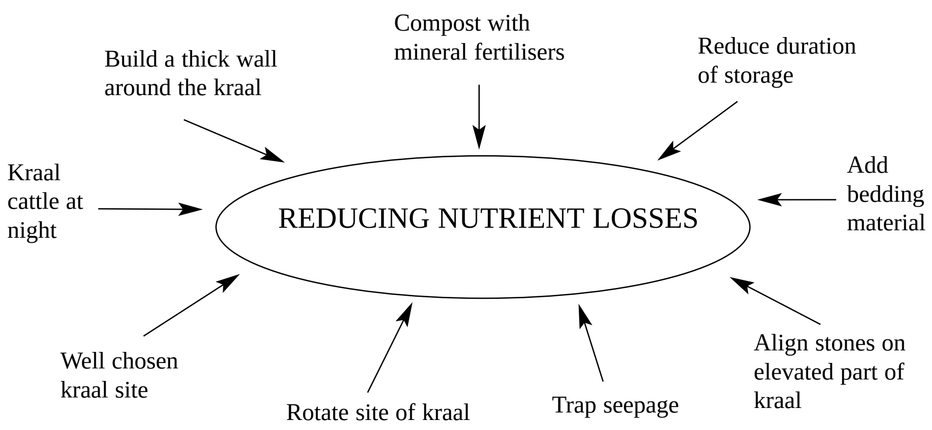



Figure 2. Farmers solutions for reducing nutrient losses



Heaping is the most common type of winter (dry season) storage, practised by 86% of farmers, 5% of whom add mineral fertiliser to the manure heap. Deep stalling, or keeping manure in the kraal until it is mature, was practised by 14% of the interviewed farmers, 29% of whom added litter (see Table 1). The deep stall method requires less labour than heaping and farmers cart the manure direct from the kraal to the field. The top and bottom layers are generally not well decomposed which can cause scorching of crops.

Table 1. Winter storage practices used in Mangwende (n=100)

| *Storage method* | *Duration* | *Frequency (%)* |
|---|---|---|
| Heaping | 1 week to 6 months | 82 |
| Heaping with fertiliser | 2 to 3 months | 4 |
| Deep stall without litter | 4 to 6 months | 10 |
| Deep stall with litter | 4 to 6 months | 4 |

The manure was left to decompose in heaps for periods ranging from 1 week to over 6 months (see Table 2). Table 3 shows that most farmers stored it in this way between August and October, the period just before the growing season starts. According to farmers, heaping in February and March allows the heap to benefit from the last rains, thus acquiring moisture, but it is hardly practised.

Table 2. Duration of heaping and frequency distribution amongst farmer

| *Duration of heaping* | *1 to 3 weeks* | *1 to 2 weeks* | *3 to 4 months* | *5 to 6 months* | *>6 months* |
|---|---|---|---|---|---|
| Frequency *(%)* | 17 | 32 | 32 | 9 | 10 |

N=86: 14% of farmers in the sample did not heap manure

Table 3. Time of heaping and frequency distribution amongst farmers

| *Period* | *January to March* | *April to June* | *July to September* | *October to December* |
|---|---|---|---|---|
| Frequency (%) | 3 | 13 | 56 | 28 |

N=86: 14% of farmers in the sample did not heap manure

Table 4 shows the ameliorative practices used to counter losses through run-off, which include rotating the site of the kraal (8%), trapping seepage in a pit (28%), and putting stones on the upper slopes of the kraal or constructing thick walls around it (52%). The location of the kraal was seen as a factor affecting the loss of nutrients, and kraals situated on anthills are generally considered to produce high quality manure. Feeding livestock in the kraal is considered to be a preliminary treatment in the process of handling manure, and various combinations of organic materials are used as bedding. This is laid down at different times of year, but with 40% of farmers only adding residues in the rainy season.

Table 4. Rainy season practices used to counter nutrient losses from manure

| *Main practice* | *Rotating kraal site* | *Trapping seepage* | *Wall around kraal* | *No ameliorative practices* |
|---|---|---|---|---|
| Frequency (%) | 8 | 28 | 52 | 12 |

## Nutrient status of manure

The nutrient status of manure samples collected during the survey was rather low, as 97% of the samples had an N content of only 1.2% or less (Table 5). This may have been due to several factors, such as the conditions of storage and handling, ambient temperature, moisture levels and exposure to the environment. Although the conventional practice of heaping requires less labour and produces decomposed manure in time for application, leaving it exposed to direct sunlight in aerated conditions triggers $NH_3$ volatilisation and results in a dry material with a low N content.

Table 5. Quality of manure from kraals in Mangwende (n=100)

| *Chemical composition* | *N (%)* | | | *P (%)* | | | *K (%* | | |
|---|---|---|---|---|---|---|---|---|---|
| | *<0.9* | *1.0 - 1.2* | *>2.25* | *<0.2* | *0.25 - 0.30* | *>3.0* | *<1.0* | *1.0 - 2.0* | *>2.5* |
| Frequency (%) | 67 | 30 | 3 | 51 | 43 | 6 | 65 | 39 | 6 |

There is also room for improvement in the way that crop residues are used in the kraal. In order to conserve nutrients, residues should be added at regular intervals and if little or no absorbent matter is added, there will be significant losses from urine (Witter and Kirchmann, 1988).

The weaknesses identified in the current management systems provided the basis for formulating a context-sensitive research agenda. It was decided to test if composting manure in a pit and adding in straw improved the quality of the end product, which would then be assessed in field experiments on maize.

# 3 Improving the quality of manure

## Using straw to absorb ammonia

When manure is handled, significant amounts of nitrogen may be lost through the volatilisation of ammonia. Incorporating the manure into soil largely stabilises the ammonia. As this greatly reduces its agronomic value, it is important to minimise such losses by using efficient management techniques. The greatest losses are often sustained before application, particularly when urine is lost or if manure decomposes aerobically (Murwira et al., 1995).

Different proportions of straw were used to determine the optimum quantity required to reduce the loss of ammonia from manure. In a set of experiments, ammonia losses were measured from samples of straw mixed with either urine or manure, which were placed in dreschel bottles. Ammonia-free air was then blown through the dreschel bottles at a pressure of 0.02 bars, and the captured ammonia was trapped in 2% boric acid. Incubation studies were also carried out to determine the quantities of $NH_3$ lost from freshly excreted dung and urine, and the time it took for such losses to occur.

These experiments showed that straw can absorb ammonia effectively, reducing losses from cow dung by up to 85%, and from a mixture of cow dung and urine by 50 % (Fig. 3). The most effective combination was found to be 3 parts straw to 25 parts manure. The results of the laboratory study therefore show that nitrogen losses can be reduced considerably by mixing straw and dung.

When losses of $NH_3$ from cattle kraals were measured it was found that they were 80% less in the pens where farmers had put down crop residues as bedding (Table 6). Cereal stover absorbs urine and has a high C:N ratio that temporarily immobilises N, so crop residues are an effective agent for conserving nutrients during storage and handling. The largest losses were recorded at mid-day.

Figure 3. Effect of straw in reducing losses of N from either urine and cowdung

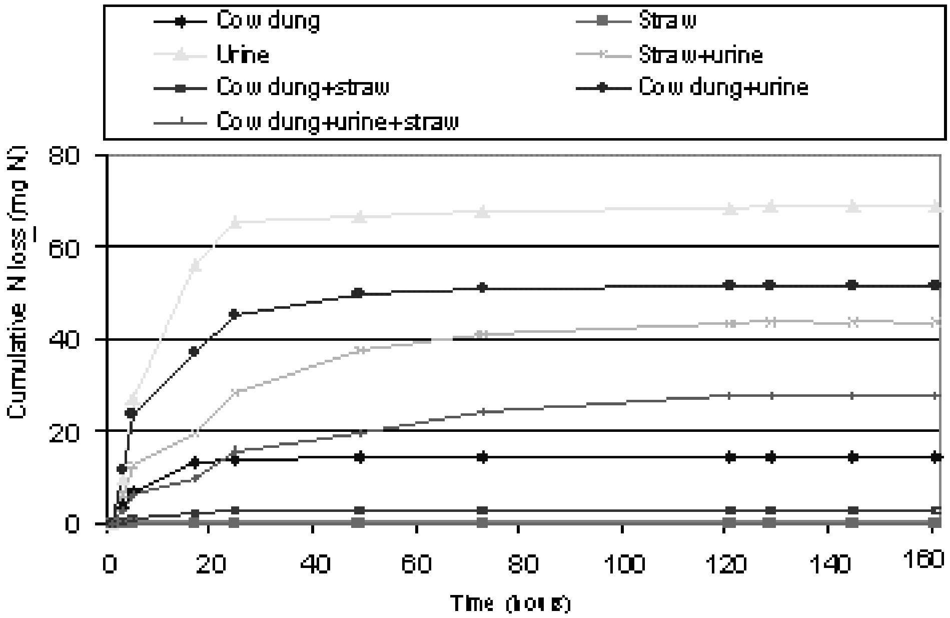



Table 6. $NH_3$ losses (ppm) from 3 kraals with crop residue and 3 without crop residue

| *Kraals* | *Time readings were taken* | | |
|---|---|---|---|
| | *8 am* | *12 noon* | *3 pm* |
| *Without Crop Residue* | | | |
| 1 | 15.5 | 37.6 | 13.1 |
| 2 | 13.1 | 47.2 | 15.0 |
| 3 | 7.9 | 28.0 | 13.7 |
| *With Crop Residue* | | | |
| 4 | 2.0 | 4.7 | 1.1 |
| 5 | 3.4 | 3.6 | 1.2 |
| 6 | 2.3 | 3.0 | 1.3 |

*Measured during a 4 week period, the figures given are mean values

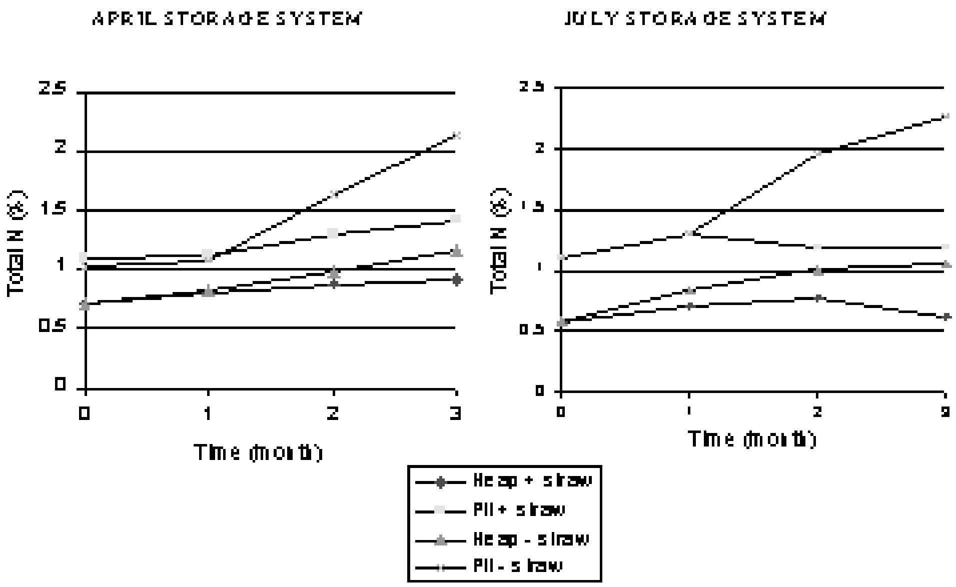
# Comparing aerobic (heap) and anaerobic (pit) composting

In order to improve the quality of farmyard manure we compared the traditional, aerobic method of composting manure in heaps with storing it anaerobically in pits, and adding crop residues. In a series of experiments, various combinations of cow dung and maize stover were stored outside under a range of conditions. Fresh manure was weighed and mixed with different proportions of crop residue, and left to decompose aerobically in heaps or anaerobically in pits for between four and six months.

The manure produced during these experiments was analysed to determine its lignin, N, P, K, Ca, Mg and micronutrient content, and the nutrient content and loss of dry matter were periodically measured.

It was found that the total N content of manure produced anaerobically in pits was significantly greater than that of manure composted aerobically in heaps (Fig.4). The total N concentration of manure in pits increased gradually with storage time, reaching three times the concentration of manure from heaps without added crop residue, which lost N during storage through the volatilisation of $NH_3$.

Figure 4. The effects of different methods of storage on total N



The highest concentrations of $NH_4$-N, amounting to 225 ppm and 380ppm for the April and July storage systems, were measured in pits without maize residues, while levels in the pits with maize residues were recorded at 155ppm and 280ppm for the April and July systems (Figure 5). This indicates that the incorporation of crop residues has a significant effect on the quality of manure. In contrast, the manure decomposing in heaps was found to have a much lower concentration of only 50ppm for both periods, which was not significantly decreased by the addition of straw.

In general, N levels rose as the composting period increased, and were higher in pit stored manure than in heaped manure. This is due to $NH_4$-N accumulating in the anaerobic conditions provided by the pit, where higher levels of moisture increased the capacity of the manure to store N in the form of ammonia.

Conversely, nitrate-N levels were higher in heaps than in pits (Fig 6), and the results also show that heaping facilitates nitrification. Soluble N levels rose as the storage time increased, particularly during the 3rd and 4th month.

Figure 5. The effects of different methods of ammonium N

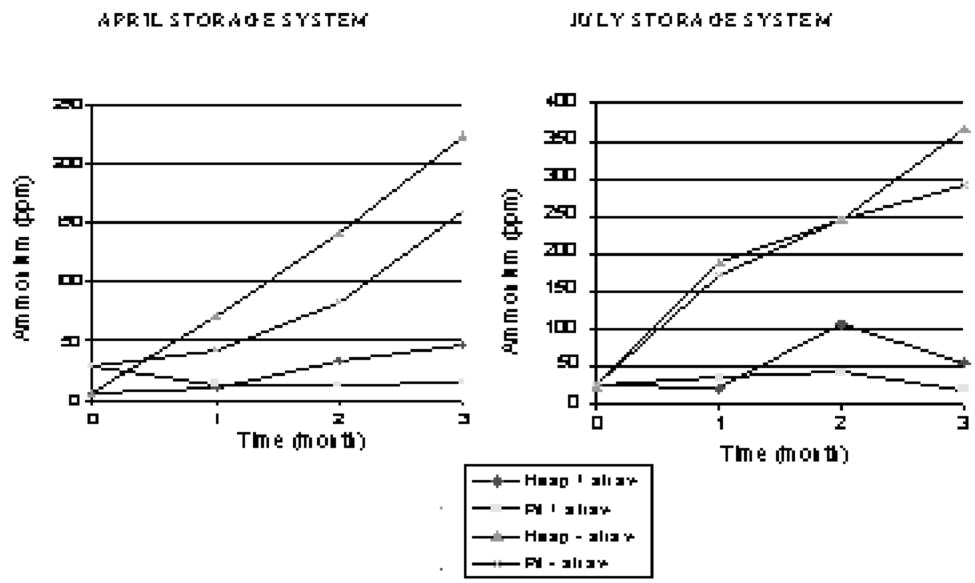
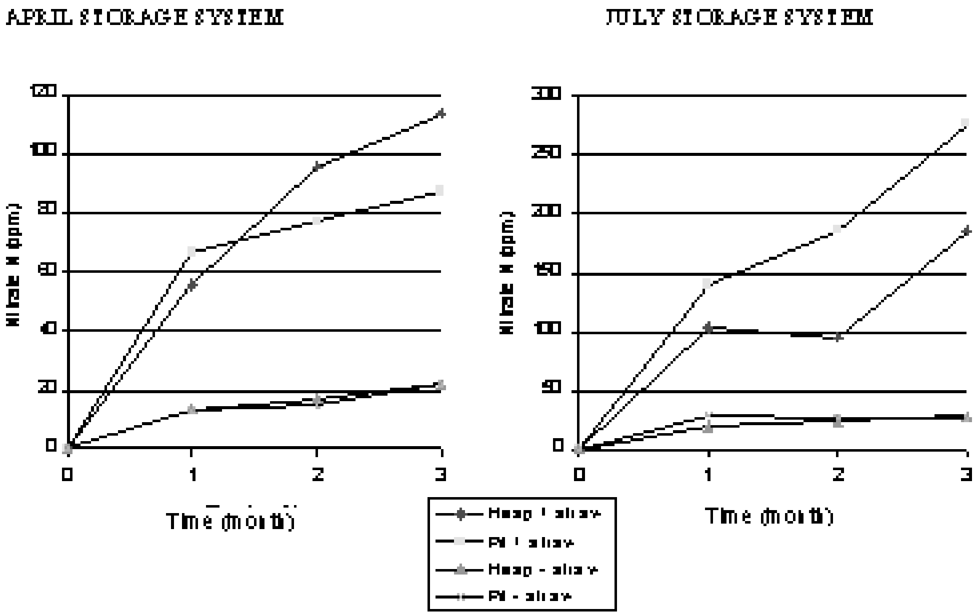


Figure 6. The effects of different storage methods on nitrate N




Little or no (P<0.001) N was lost from the compost decomposing anaerobically in pits due to volatilisation of $NH_3$, as the closed system allows hardly any air to circulate and prevents drying. With a pH of 7 or less, conditions in the pits remain slightly acidic or neutral, and the highest losses from this system only amounted to 7ppm, recorded in the pits without crop residues (Fig 7).

More $NH_3$ was lost from the manure composting aerobically in heaps, particularly over the last two months of decomposition. This is probably due to the fact that their exposure to the environment creates aerobic conditions, speeds up the rate of decomposition and results in the loss of moisture and high mineralisation of N. The heap without crop residues lost 35 ppm.

The pH values recorded for aerobic manure compost were above 8. Further, the NH4-N initially produced in the heaped manure might have been derived from the hydrolysis of urea and uric acids in the dung, and could have produced a temporarily high pH, facilitating the volatilisation of $NH_3$. However, the addition of maize straw in heaps significantly reduced $NH_3$ losses throughout these systems.

The moisture content of manure in pits gradually decreased over time, while in the heaps it dropped considerably as decomposition progressed (Fig 8), which partly explains the high losses of $NH_3$. Moisture was lost more quickly when crop residues were added.

Figure 7. The effects of different storage methods on losses of ammonia

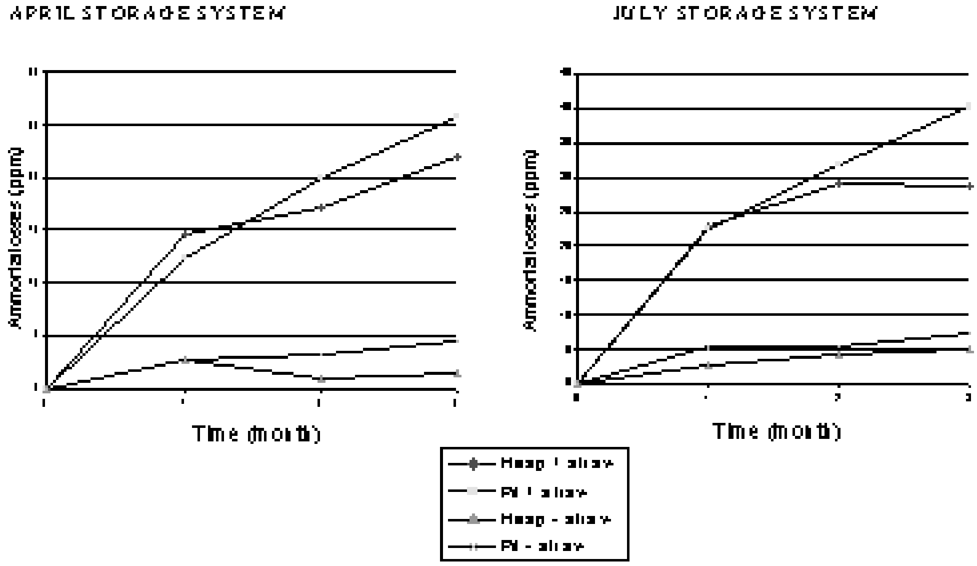
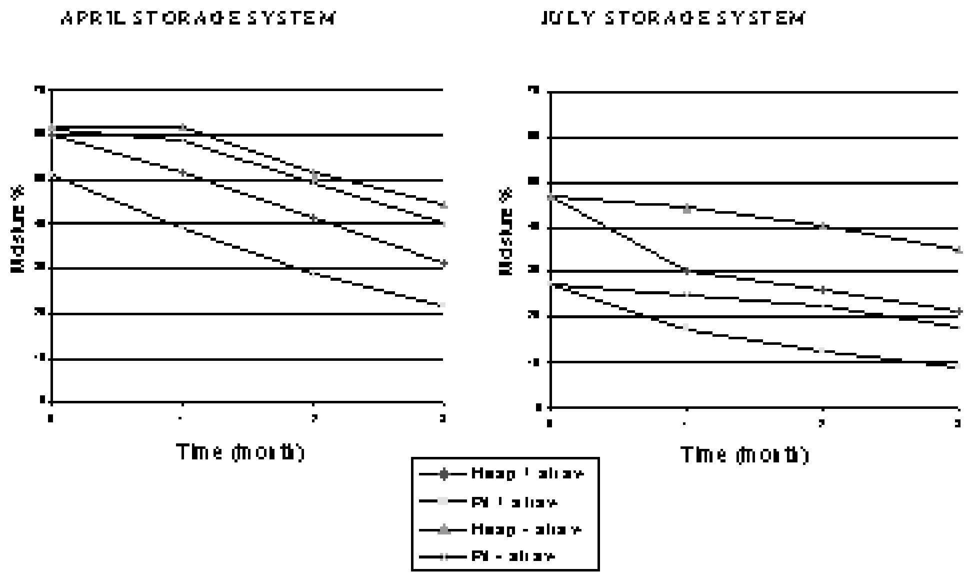


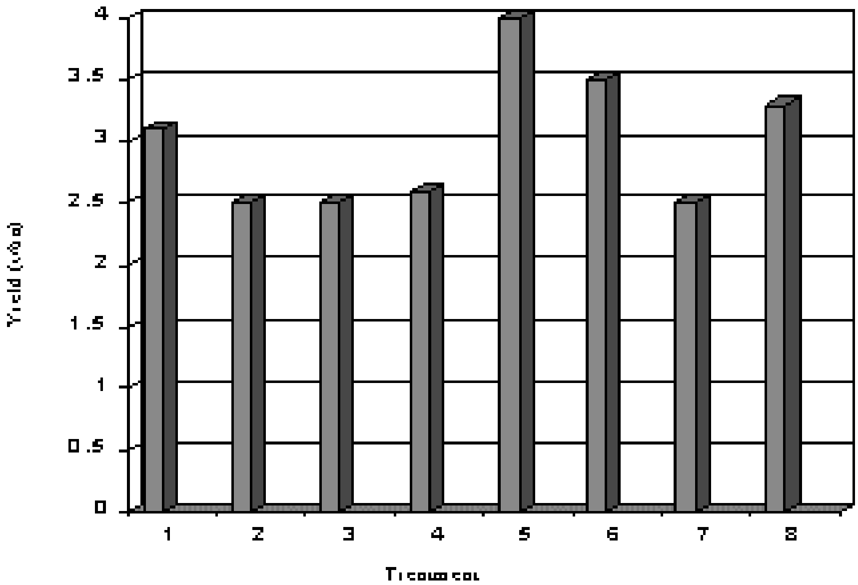

Figure 8. The effects of different storage methods on moisture levels



## Comparing the effects of heaped and pit stored manure on maize yields

Trials were carried out to determine how the different storage methods developed during the study affected the performance of manure in terms of its effect on maize yields. The experiments ran from November 1997 until the end of the rainy season in April 1998. Using an application rate equivalent to 100kg N/ha (see Figure 9), yields were significantly higher on the plots where manure stored in pits had been used than on the plots with manure that had been stored in heaps. As indicated above, aerobically decomposed manure-N is organically bound and has to be mineralised before uptake is possible

Figure 9. The effect on maize yields of manure stored under a variety of conditions




**Treatment Legend**

1= April heap - straw
2= July heap - straw
3= April heap + straw
4= July heap + straw
5= April pit - straw
6= July pit - straw
7= April pit + straw
8= July pit + straw

# 4 Conclusions

The results of the laboratory study carried out during the course of this study showed that nitrogen losses can be reduced considerably by mixing a degradable, nitrogen poor material, such as straw, with dung. Straw can absorb ammonia effectively, reducing losses from cow dung by up to 85%, and from a mixture of cow dung and urine by 50%.

The results of experiments clearly demonstrate that storing manure in pits can minimise $NH_3$ losses caused by volatilisation, enhancing the quality of manure. The addition of straw is essential in kraals to help in trapping of urine hence reducing ammonia losses, however it is not necessary to add it in the composting phase.

Pit composting of the manure in Zimbabwe should be done during the dry season instead of the wet season as this minimises losses. The widespread testing with farmers of the pit composting technique is on-going in Zimbabwe. Results from this work are not available yet, but preliminary adoption surveys are showing a 10% uptake of the technology by farmers in Mangwende.

What is needed now is to evaluate the residual effects of pit stored and heaped manure after application, to determine its value as a fertiliser, and to assess the management options for resource-poor farmers. These studies are important because efficient management of the nitrogen content of manure requires knowledge of the pattern of mineralisation and N transformations. An economic analysis of the technologies is required to determine potential constraints to the adoption of improved management systems.

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