CHAPTER 1

INTRODUCTION

1.1 The communal area farming system

About 70% of soils cultivated in communal areas (CAs) of Zimbabwe are predominantly sandy soils derived mostly from granite. These soils are inherently infertile, generally acidic, low in nutrients particularly N, P, and S and exchangeable bases due to low clay and organic matter contents. Maize yields on sandy soils in the CAs can be as low as 0.2 t ha^{-1} without fertilizer or manure, and yet with proper fertilization using manure and/or fertiliser, grain yields can be increased and maintained in the range of 3 to 5 t ha^{-1} (Grant, 1976; Grant, 1981).

In most farming systems of the communal sector of Zimbabwe, locally available organic fertilisers are used as low cost management options to sustain soil fertility and crop productivity. Manure provides a range of nutrient sources used by farmers to enhance soil fertility (Murwira, Swift and Frost, 1995). For many farmers, manure has been the main traditional substitute for inorganic nitrogenous fertilisers with substantial crop yields being realised after its application to the soil (Rodel, Hopley and Boultwood, 1980; Murwira *et al.,* 1995; Mugwira and Murwira, 1997). With the continued increases in inorganic fertiliser costs, manure is likely to remain the cheapest and relatively most important soil fertility ameliorant in the CA farming system.

1.2 Availability of cattle manure in crop livestock farming systems

The amount of manure available for use is influenced by factors such as diet, method of feeding (pen rearing, kraaling over night or free range) and the efficiency of collection. One livestock unit (1LU = 500 kg livemass) produces 7 t of manure a year when stabled all day (Rodel *et al.,* 1980). This declines to 2 – 3 t per year of usable manure (30 – 40% recovery) when animals are stabled overnight (Schleich, 1986). Though quantities of manure available on-farm are low, farmers apply higher rates of up to 110t/ha (Mugwira et al. 1997) by targeting nutrient deficient areas in the field.

1.2.1 Production of cattle manure

In the CA farming system, there is a systematic pattern of production of cattle manure. Cattle are grazed in areas demarcated for grazing during the day, and they are confined overnight in cattle pens (kraals) close to the homestead. The kraals act as sinks where manure accumulates throughout the year until the end of the dry season when it is either collected for storage or directly applied to the field at the on-set of the rainy season in late October or early November.

Cattle are also driven into the fields to feed on remains of harvested crops and in the process dung and urine excreted fertilise the soil (Murwira *et al.,* 1995). The crop residues are collected from the fields and fed to cattle in kraals and the nutrients recycled through the excreta rather than direct mulching. Non-cattle owners also collect manure from grazing areas and apply it directly to their fields (Carter *et al.,* 1993).

1.2.2 Partitioning of N in cattle excrements

Cattle excrete between 80 – 90% of the N they consume. The largest portion of excreted N is in the urea fraction, accounting for 80% of the total urinary N (Doak, 1952; Mentis, 1981). This implies that nutrient retention through excreta from cattle is important in nutrient cycling in the farming system. This has been confirmed by Murwira *et al.,* (1995) who showed that manure supplies up to 32% of the total N used by farmers in comparison to 64% N from inorganic fertilisers. Cattle owners without access to inorganic fertilisers can therefore sustain soil fertility and crop productivity through application of the manure to soil.

1.3. Cattle manure as a soil fertility ameliorant

The beneficial effects of manure on soil fertility are both in the short and long term. In the short term, the beneficial effect of manure is due to the availability of its N released directly after application. This is related to N present as free mineral N (NH_4^+, NO_3-N) (Murwira, 1995). Manure also enhances soil fertility in the short to medium term by supplying cations such as calcium which progressively increase soil pH and exchangeable bases, (Grant, 1967).

When applied in large quantities, manure can benefit the soil in the long term by increasing the soil organic matter levels, water holding capacity, hydraulic conductivity, infiltration rates and decrease soil bulk density (Grant, 1967; Murwira *et al.,* 1995).

1.4. Quality of cattle manure produced in CAs of Zimbabwe

1.4.1. Concepts of manure quality

The value of chemical characteristics to assess quality of organic resources and nutrient availability has been reported (Palm, 1995). Intrinsic factors that affect N release include the percent of N, lignin and polyphenols, C:N, lignin:N, polyphenol:N and lignin +

polyphenol:N ratios (Mafongoya, Dzowela and Nair, 1997). High quality organic inputs are characterised by low lignin (<15%) and polyphenol (<4%) contents and high percent N, with low quality materials having the opposite characteristics (Palm, Wangari and Gichuru, 1996).

In the Zimbabwean context, the term quality has been defined on the basis of N content of manure and plant response (overall fertiliser efficiency) (Mugwira and Mukurumbira, 1986). These workers classified quality of manure as follows: Low quality, less than 1 % total N; medium quality, 1 – 1.2 % total N and high quality, greater than 1.2 % total N.

1.4.2 Factors influencing effectiveness of manure

The quality of manure produced in CA farming systems varies widely ranging from 0.3 – 1.4% N of dry matter but generally containing less than 1 % N (Tanner and Mugwira, 1984; Mugwira and Mukurumbira, 1986). The effectiveness of manure as a source of fertiliser N depends on its N content, the location of N in organic fractions and its release during decomposition. In general, manures from CAs contain low amounts of N for high yielding maize crops, because of their inability to continuously supply large amounts of readily available N (Grant 1967, Mugwira, 1985). Greenhouse studies conducted by Tanner and Mugwira (1984) have shown that high applications of low quality manure (equivalent to 80 tha^{-1}) can depress maize growth and yields because of N immobilisation.

The quality of manure produced on-farm is influenced by several factors including quality of feed, age and species of the animal, storage and handling conditions, ambient temperature, moisture levels and duration of storage (Murwira, 1993; Mugwira et 1997). Manure obtained from cattle kraals comes from animals foraging on low nutritive quality veld and does not receive feed additives (Murwira and Kirchmann, 1993). The manure is often contaminated with sand as dung and urine accumulate on the unprotected soil (van Straaten, 1999).

During storage and decomposition of the manure, gaseous losses by ammonia volatilisation and leaching N losses occur contributing to poor quality manure. In most CA cattle production systems, excreta are handled as solid manure, which is heaped (aerobic composting) for extended periods prior to application. The heaping storage method has been found to increase the potential for N losses by ammonia volatilisation (Murwira, 1995; Kirchmann and Witter, 1992; Dewes, 1995). Poor nutritive grazing, storage and handling conditions thus combine to produce manure of low quality in terms of N content (Tanner and Mugwira, 1984).

1.5 NH_3 volatilisation as a major process influencing quality of manure

1.5.1. Mechanism of ammonia volatilisation

Ammonia volatilisation can be defined as the process by which gaseous NH_3 is released from an N-supplying source to the atmosphere. The loss of NH_3 from animal manure represents a large loss of valuable fertiliser N resulting in N deficit in the N budgets of fields that receive manure (Freney, Simpson and Denmead, 1981).

Ammonia – N in animal manure is derived from two sources:

i) hydrolysis of urea present in urine

ii) ammonification of organic N

The process of ammonia volatilisation occurs after the urea component of urine is enzymatically hydrolysed to ammonium carbonate, which dissociates into ammonium (NH_4^+) and carbonate ions (HCO_3^-). This process causes the pH of the solution to rise , shifting the equilibrium to the right and thus promoting ammonia volatilisation. The former process accounts for almost all the initial NH_4-N present in manure. The initial NH_4-N concentrations in manure are dependent on storage and handling practices of manure (Reddy, Khaleel, Overcash and Westerman, 1979; Vlek and Stumpe, 1978).

The basic equilibrium which govern NH_3 loss is represented as:

Adsorbed NH_4^+ < = > NH_4^+ (in solution) < = > H^+ + NH_3 in solution < = > NH_3 (gas in manure/soil) < = > NH_3 (gas in atmosphere). The rate of NH_3 loss from an aqueous solution is directly related to the partial pressure difference between NH_3 in the air and NH_3 dissolved in water and is related to the aqueous ammonia concentration by the Henry constant (K_H):

$P_{NH3} = NH_3 \text{ (aq)}/K_H$.

where P=partial pressure

If the system is open to a surrounding which has a lower P_{NH3}; then volatilisation losses occur to re-establish the equilibrium (Lauer, Bouldin and Klausner, 1976). Ammonium-N measured is the sum of the concentrations of NH_3 and NH_4^+ in solution, which is the total ammonical N (TAN).

1.5.2 Magnitude and extent of ammonia losses in storage and handling systems

In animal production systems, ammonia losses from urine are higher compared to losses from dung patches. MacDiarmid and Watkins (1972) found that only 5% of total N was lost as ammonia from a dung patch in 13 days, with 73% of this occurring in the first five days. This compares with N losses from urine patches of 14 – 60% in 14 days, with 26 – 50% of this being lost in the first 24 hours (Vallis, Harper, Catchpoole and Weier, 1982). The rapid loss of N excreted from urine suggests that strategies for conservation of urinary N should be put in place.

If manure is collected and stored, then the method of storage and length of composting will influence manure composition and magnitude of N. However, there are variations in losses reported for individual systems. Dewes (1996) indicated that ammonia losses constitute 95% of gaseous N losses from stored solid manure. Murwira, (1995) reported losses of 6% (excluding urine) during storage whilst losses of between 1- 44% of N have been reported during storage elsewhere (Eghball, Power, Gilley and Doran, 1997; Kirchmann and Witter, 1989). Less than 1% of manure-N can be volatilised as ammonia in anaerobic systems compared with 9-44% during aerobic composting (Kirchmann and Witter, 1989).

Dense storage achieved by wetting and compressing manure can lower N losses than aerobic decomposition (Archaya, 1935; Siegel, 1931). Russel and Richards, (1917) were amongst the first to recommend that in order to reduce N losses during storage, manure should be decomposed under anaerobic conditions. Adding stover (with an initial C/N ratio of 30) can be used for efficient retention of N during aerobic decomposition (Faassen and van Dijk, 1979; Kirchmann, 1985, Kirchmann and Witter, 1989). Other studies have shown a no reduction (Kohnlein and Vetter, 1953) and even increased N losses with stover addition (Bucher, 1943).

Comparative NH_4^+-N (50 –75% of total N), low organic bound N, and low rate of carbon dioxide production are typical of anaerobic decomposition. Anaerobic conditions have also been found to induce acid formation and a decrease in pH. When manure was stored under aerobic conditions, alkaline regimes prevailed. The water-soluble part of the total N decreased, with organic-bound N being the main form in which N was present (Archaya, 1935, Musa, 1975; Kirchmann, 1985; Kirchmann and Witter, 1992).

1.5.3 Factors affecting ammonia volatilisation

The extent to which NH_3 is lost from the manure or soil system depends on various physico-chemical factors. The volatilisation of urea has been described as a function of i) hydrolysis rate which depends on temperature, ii) equilibrium reactions (NH_{4+} (sol) <= > NH_3 (sol) < = >NH_3 (g) which also depend on temperature. iii) NH_3 exchange between soil and atmosphere, and iv) exchange between NH_4^+ in solution and on exchange sites in the soil (Sherlock and Goh, 1985).

Other factors affecting the rate of volatilisation include environmental factors (wind speed, rainfall), soil factors, (soil water content, soil type, pH, texture and urease activity) and fertiliser management (rate and timing of application, placement and irrigation) (Whitehead, 1995). Under acid conditions, the low CEC content of the soil accounts for substantial leaching of NH_4^+ ions due to poor retention (Diekmann *et al.,* 1993). The effect of some of these factors on NH_3 volatilisation is considered below.

1.5.3.1 Effect of pH on ammonia loss

The concentration of NH_4^+ and NH_3 are determined by the pH of the soil solution. An increase in pH above 7 (i.e. an increase in the hydroxyl ion concentration) drives the equilibrium to the right thereby producing more NH_3. The proportion of aqueous ammonical N ($NH_4^+{}_{(aq)}$ plus NH_3 present as $NH_{3\ (aq)}$ at pH 6, 7, 8 and 9 can be calculated as approximately 0.0004, 0.004, 0.04 and 0.3, respectively. This indicates that below pH 7, the $NH_{3\ (aq)}$ accumulation is very low and the potential loss of NH_3 could be insignificant (Kirchmann, 1985; Reddy *et al.,* 1979) while losses above pH 7 are very significant.

1.5.3.2. Effect of NH_4^+ concentration on NH_3 loss

The rate of NH_3 volatilisation from solutions is directly related to the $NH_{3\ (aq)}$ concentrations that is determined by solution pH and NH_4^+ concentration as shown in

Eq. (1) if all other factors are held constant. The increasing proportion of added N volatilised as NH_3 with increasing NH_4^+ or urea addition rate may result from elevated soil pH values obtained from application of high amounts of urea or NH_4^+ carriers or their interactions with $CaCO_3$ (Nelson, 1982). Factors that influence the NH_4^+ concentration in soil solution will also influence the potential for losses of NH_3 through volatilisation.

Mechanisms such as plant uptake, nitrification, denitrification, leaching, immobilisation and fixation of NH_4^+ by clay minerals in exchangeable and non-exchangeable forms can affect the chain of equilibrium that determine the extent of losses.

1.5.3.3. Effect of temperature on NH_3 loss

The effect of temperature on the rate of NH_3 volatilisation can be explained in part by the increase in the hydrolysis constant of NH_3 rendering a larger proportion of the NH_4^+-N as aqueous NH_3. Higher temperatures have also been reported to increase the speed of NH_3 diffusion from the soil thereby allowing a more rapid conversion from $NH_{3\ (aq)}$ to NH_3 (g) (Vlek and Stumpe, 1978).

Under field conditions, the rate of NH_3 volatilisation follows a marked diurnal cycle that follows that of solar radiation (McGarity and Rajaratnam, 1973, Denmead *et al.,* 1974 and Beauchamp et al., 1978). The extent of losses can also follow a seasonal pattern. Ball and Keeney (1983) reported NH_3 losses from urine patches amounting to 5, 16 and 66% of added urine N under cool moist, warm moist and warm dry conditions, respectively.

1.5.3.4. Effect of soil characteristics on NH_3 loss

If all other factors are held constant, more of the NH_4^+-N added to coarse-textured (sandy) soils is volatilised as NH_3 compared with that from fine-textured soils (Terry, Nelson, Sommers and Meyer 1978). According to these investigators, the effect of soil texture on NH_3 volatilisation is due to the higher CEC of fine-texture soils. With a high CEC, a greater proportion of added NH_4^+ would be adsorbed at the exchange complex, and less $NH_{3(aq)}$ would be present in solution as shown in the following equation:

$$NH_4^+{}_{(exc)} \Leftrightarrow NH_4^+{}_{(aq)} \Leftrightarrow NH_{3\,(g)}$$

1.5.3.5. Effect of aeration rate on ammonia loss

Rapid air movement across the soil surface promotes NH_3 volatilisation by maintaining a low partial pressure of NH_3 in the atmosphere adjacent to the soil, thus, permitting rapid diffusion of NH_3 in response to a large partial pressure gradient. Furthermore, rapid movement of low relatively humid air across the soil surface can promote rapid loss of soil moisture, thereby stimulating NH_3 loss through evaporation of water (Terry *et al.,* 1978; Vlek and Stumpe, 1978).

1.5.3.6. Effect of moisture content on NH_3 loss

Moisture content of the system influences the concentration of NH_4^+ and therefore NH_3 in solution. It has been shown that NH_4^+ concentrations at higher moisture contents are lower than those at low moisture contents leading to low net losses from the system (Wahhab *et al.,* 1956). Loss of water promotes NH_3 evolution by increasing NH_4^+concentrations in soil solution over time and preventing nitrification of NH_4^+ leading to greater losses than if no soil drying occurred. Drying also results in upward movement of water which helps transport dissolved NH_4^+ and NH_3 to the soil surface (Freney *et al.,* 1981).

1.5.3.6. Effect of fertiliser application rate and method of incorporation on NH_3 loss from soil

Different rates of fertiliser application can influence losses, since ammonical-N or nitrate usually accumulates in soil (or flooded water in lowland rice) in amounts proportional to the amounts applied. It has been shown that of fertiliser N lost depends on the agricultural systems under study. Increasing the amounts of ammonium nitrate applied to maize, for instance, did not greatly affect the proportion of fertiliser N lost by NH_3 volatilisation or denitrification. When urea application to rice was doubled from 30 to 60 kg N ha^{-1}, total N loss rose from 37 to 54% (Diekmann *et al.,* 1993). In absolute terms, however, the amount of N lost in gaseous emissions will increase when fertiliser rates are raised, even where there is little change in the extent of fertiliser loss (Peoples, Freney, and Mosier, 1995)

Placement methods of manure and urea significantly influence the processes that produce NH_3 loss. Several workers have demonstrated that much more NH_4^+ is volatilised from surface applications of the urea source than from incorporation into the soil (Thompson et al., 1987, Fenn and Hossner, 1985; Terman et al., 1968; Lauer, Bouldin and Klausner, 1976). Up to 50% of the total N in manure can be lost as volatile N during application (Heck, 1931).

Sub-surface incorporation or banding of the urea carrier has a potential to minimise NH_3 losses by reducing the ammonia-N concentration of the soil solution at the soil surface. In some studies increased yields have been observed following band application of the NH_4^+-N source (Heck 1931; Munguri, 1996; Mubonderi, 1999).

Overrrein and Moe (1967) demonstrated that increasing the depth of soil over urea band to at least 15 cm decreased NH_3 volatilisation but observed substantial losses even when a 2.5 cm layer of sandy soil (pH 5.7) was placed over the fertiliser. Lower NH_3 losses were obtained if overlying soil was moist rather than nearly air-dry.

1.6 Nitrogen mineralisation during decomposition of cattle manure

1.6.1 Decomposition of manure during storage and implications on ammonia volatilisation

Three decomposition pathways of manure have been identified namely: anaerobic fermentation, anaerobic-aerobic fermentation and aerobic fermentation (Kirchmann, 1985). The pathways occur under anaerobic, low oxygen supply, and aerobic conditions respectively. Anaerobic decomposition results in a higher content of humic substances being formed than in aerobically decomposed manures and can breakdown up to 40% of the organic carbon which is also higher than for anaerobic-aerobic fermentation (Coker, Hall, Carlton-Smith and Davies, 1987).

The production of humic substances under anaerobic decomposition induces an acid regime, which depresses the pH value, thus shifting the equilibrium between $NH4^+$ ions and NH_3 gas in the manure towards the ammonium side, and N is conserved in the system. High oxygen supply during aerobic decomposition change the redox conditions leading to mineralisation of N resulting in alkaline regime and consequently higher N losses. Due to faster rate of decomposition upon exposure to aerobic decomposition, organic matter and carbon losses are also high resulting in a rise in the concentration of cations (Kirchmann and Witter, 1992).

1.6.2 Nitrogen mineralisation from aerobic and anaerobic manure in soil

The beneficial effects of manure on soil fertility and in particular its role as a source of nutrients, are dependent on the outcome of biological processes of decomposition. These processes determine the rate of release of carbon and nutrients and the equilibrium between retention and loss from soil (Swift *et al.,* 1979).

Studies of N mineralisation in soil are necessary because efficient management of manure-N requires knowledge about the temporal pattern of mineralisation and of N transformations. The quantitative contribution of manure to soil N and the interaction between manure N and soil N also need to be known so that residual effects of organic input can be quantified.

Nitrogen turnover from aerobic and anaerobically decomposed manures in soil has been reported under laboratory and field conditions. After application of anaerobically treated manure in soil, immobilisation of N was observed in the laboratory (Sims, 1986). Immobilisation of inorganic N was also reported after incubation of anaerobically stored manure in the laboratory. Flowers and Arnold (1983) reported that 40% of the manure

NH_4^+ in pig slurry-amended soil was immobilised. Immobilisation of inorganic N in the soil following addition of anaerobically stored slurries was confirmed using ^{15}N. Kirchmann (1985) observed that net immobilisation occurred when ^{15}N labeled, anaerobically stored poultry manure was added to soil. The partial immobilisation observed with anaerobically decomposed manures was related to the presence of volatile fatty acids (VFA) which are easily decomposable and to high C/N ratio of the manure.
Work conducted by Murwira (1993) suggests an initial immobilisation period of 7 weeks for aerobically decomposed manures after planting. This implies that the application of aerobically decomposed manure might not coincide with rapid crop growth and N uptake resulting in depressed crop growth and yield (Nyamangara *et al.,* 1999).

1.6.2.1 Implications of aerobically and anaerobically decomposed manures to cropping systems

Anaerobically decomposed manure has been reported to increase crop growth and yield in the short term (Kirchmann, 1985). This compares with aerobically decomposed manure, that gives a net N immobilisation in the first 7 weeks after crop establishment (Murwira, 1993; Tanner and Mugwira, 1984). Grant, (1967) reported that aerobically decomposed manure cannot supply continuously large amounts of readily available N resulting in depressed crop growth and yield. In pot experiments conducted by Kirchmann, (1985), uptake of manure-N from aerobically decomposed manure was lower than from anaerobically decomposed manure. Mugwira, (1984) noted an increased N uptake by the second crop for aerobically decomposed manure. This implies that aerobically decomposed manures could benefit the crop in subsequent years after application to the soil.

1.6.3 Factors affecting decomposition of manure in soil

The classical approach to decomposition has been that resource quality influences the mineralisation potential. Resource quality is broadly characterised by C/N ratio, which determines whether net immobilisation or net mineralisation occurs. With the addition of plant residues to soil, net immobilisation generally occurs at C/N ratios above 20-30 (Alexander, 1977). Beauchamp and Paul (1989) proposed that net immobilisation in soil occurred with animal manures having a C/N ratio above 15. Data reported in Beauchamp (1986) suggested immobilisation of solid beef cattle manure N having a C/N ratio of 15.4 when applied to soil under greenhouse conditions.

Castellanos and Pratt (1981) observed immobilisation in soil with dairy cattle manure with a C/N ratio of 15.9 but not with other manures with C/N ratio varying from 6.5 to 14.4. Van Faassen and Dijk (1987) observed immobilisation with fresh cow faeces having a C/N ratio of less than 16. Kirchmann (1989) reported net immobilisation with poultry slurry having a C/N ratio of 13. Kirchmann (1985) concluded that anaerobically decomposed manures always caused a net immobilisation of N from soil and manure, whereas the C/N ratio of aerobically or undecomposed manure determined whether net immobilisation would occur.

Work reported by Hutchings and Martin (1934) and Rubins and Bear (1942) suggested that nitrogen mineralisation was not directly related to the C/N ratio for a wide range of organic materials as C/N ratio does not fully characterise either resource quality or availability of C and N to microorganisms (Parr and Papendik, 1978). Chromec and Magdoff (1984); Aoyawa (1985) and Suzuki and Kumuda (1976) all suggested that differences in availability of carbon and nitrogen is probably the major reason why nitrogen mineralisation from organic materials is usually not directly related to the C/N ratio.

There are indications that chemical characteristics of organic materials (other than C and N) play a crucial role in decomposition of the organic resources. These include lignin (L), polyphenol (Pp), L-to-N ratio, Pp-to-N ratio and L+Pp-to-N ratio. The Pp-to-N and the L+Pp-to-N ratios have been found to be more reliable in predicting residue N mineralisation in upland soils (Fox *et al.,* 1990; Palm and Sanchez, 1991). As the lignin or polyphenolic content to N ratio increases, the decomposition rate of the material decreases with subsequent reductions in short-term N availability. The Organic Resource Database (Palm *et al.,* 2001) suggest that for residues low in polyphenols, the L-to-N ratio seems to suitably predict their N mineralisation, but the relationship varies from soil to soil. Initial net NH_4^+-N mineralisation rates were higher for residues with relatively low L-to-N ratio than from material with higher L-to-N ratio. Manipulation of the L-to-N ratio of an organic material by mixing high quality material with crop residues can be an effective way to control residue N mineralisation (Becker et al., 1994).

Immobilisation of inorganic N sources would perhaps be more dependent on the amount of readily available C, rather than on total C. In soil incubated with cellulose, net immobilisation continued for the 8 weeks of incubation. Kirchmann (1989) suggested that rapid oxidation of volatile fatty acids (VFA) in anaerobic manures caused immobilisation of N. This was also ascribed to a shift in microbial population from predominantly anaerobic bacteria, causing a flush of readily mineral sable C. Readily available C in fresh manure is also transformed to VFA during anaerobic storage of the manure.

Rates of mineralisation of N have also been reported to be influenced by environmental conditions of the soil-manure system such as pH, moisture, temperature and soil texture. Higher temperatures generally promote increased mineralisation rates and a rapid turnover of organic N (Sims, 1986).

Moisture content determines aeration in soil and the activity of decomposer microorganism which influence the intensity of the process (Runge, 1983). The optimum pH for decomposition in the soil is between 5 and 7. Additions of organic materials to soil can affect the soil pH hence the mineralisation rate. The application of pig slurry or poultry manure to a moderately acid soil was found to increase the pH temporarily due to NH_4-N formation, which induced temporary nitrification (Cooper, 1975; Crane, Westerman and Overcash, 1981). The rate of mineralisation is also dependent on soil texture. Lower mineralisation rates have been reported in clay soils due to clay particles, which shield organic matter from decomposition (Saunders and Grant, 1962).

1.6.4 Decay series as an indicator of the percentage of N mineralised in successive seasons

Decay series or recovery rates are useful concepts in quantifying the percentage of nitrogen mineralised in successive cropping seasons (Pratt, Broadbent and Martin, 1973 and Castellanos and Pratt, 1981). These workers showed that 40% of the N from cattle manure becomes available in the first year, 25% in the second year and 6% in the third year after application. However, some investigators suggested variations in the decay series of manure being influenced by factors such as the feed and age of animals, and storage and handling conditions, volatilisation losses during application which may affect its properties of nitrogen mineralisation (Jokela, 1992; Kirchmann and Witter, 1989; Paul and Beauchamp, 1993; Delve, 1998; Thomsen 2000).

1.7. PURPOSE OF STUDY

The purpose of this study was to develop methodologies and practical interventions for improving quality of manure in smallholder farming systems. This was to be achieved through developing strategies for minimising N losses by NH_3 volatilisation during storage and handling. The study was also focused on improving the management of manure after field application to minimise N losses through volatilisation and synchronize nutrient release with plant nutrient uptake for improved yields.

The study objectives were to:

a) design and implement strategies for improving quality of manure

b) determine how manure storage and handling conditions influence NH_3 losses.

c) determine the efficacy of manures from different storage systems in increasing maize grain yields, N uptake and residual effects.

d) determine how placement methods of pre-treated manures affect N losses and the resultant maize grain yields.

e) determine net N mineralisation/immobilisation potential of aerobic and anaerobically treated manures and implications to cropping systems

This research work was based on the approach that local knowledge provides the basis for problem solving strategies for local communities especially the poor. Hence participatory rural appraisals were conducted to develop an inventory of farmer perceptions in the storage and handling of manure. Weaknesses in the system were used to formulate a research agenda that was context sensitive to the targeted community.

1.7.1 Structure of thesis

The thesis is made up of eight chapters. The first gives literature review, followed by an inventory of farmer perceptions in the storage and handling of manure. This chapter sights some weaknesses in the current manure management system and determines a research agenda. The third chapter investigates the effectiveness of straw as a urine absorbent in cattle kraals. In the fourth chapter, the effect of storage method, crop residue incorporation and length of composting on ammonia losses from, and quality of manure is presented. The fifth chapter is focused on nutrient release patterns from manures produced under different storage conditions and their implications to the cropping system. The sixth chapter investigates the efficacy of manures from different storage systems and their residual effects. In the seventh chapter, the effect of application methods of manure on N losses by volatilisation and subsequent maize grain yields is determined. Each chapter contains an abstract, introduction, materials and methods, results and the discussion section. Where possible, further research needs have been identified. The concluding chapter summarises the results and discusses their practical implications to the farmer based on systems interpretation.

CHAPTER 2

TRADITIONAL STORAGE AND HANDLING PRACTICES OF CATTLE MANURE IN MANGWENDE.

2.0 Abstract

A participatory rural appraisal (PRA) was conducted to identify manure storage and handling practices by farmers in Mangwende CA. Results from the PRA indicated that differences in the storage and handling practices accounted for wide variations in quality of manure ($P<0.05$). Low quality manure with N content of less than 1.2% was ascribed to heaping storage practice (85% of farmers) in comparison with high N content greater than 1.2% in pit stored manures. Results suggest that there is greater scope in pit storage of manure (practiced by 4% of farmers) in improving quality. Significant ($P<0.05$) variations in the months and length of composting were observed with a majority (47%) heaping in July. There were significant ($P<0.05$) variations in the use of straw in cattle kraals. A majority of farmers (55%) used straw throughout the year while 34% added straw during the rainy season. The remainder did not use any residues. Rotating the site of kraal (8%), trapping seepages in a pit (28%) and constructing earth walls around the kraal (25%) were practices used to counter runoff losses from the kraal during the rainy season. It was concluded that manure management options followed by a majority of farmers are susceptible to ammonia losses, which account for low quality of the manure. A research agenda for improving quality of manure was developed focusing on determining (i) the efficiency of straw in reducing N losses by volatilisation during storage and handling (ii) the effect of heaping and pit storage of manure on N losses and quality of the resultant manure (iii) the influence of incorporating straw in storage systems on N losses (iv) appropriate duration of storage.

2.1 Introduction

Manure is a key resource for soil fertility management in mixed livestock-arable farming systems. The effectiveness of manure as an N source is mainly influenced by the location of N in organic fractions and its release, and partly the application method. Analysis of manure used in communal areas has shown that N content is usually less than 1% which is indicative of poor quality (Tanner and Mugwira 1984; Murwira, Swift and Frost, 1995, Probert, Okalebo and Jones, 1995). The N content of manure varies widely due to various factors such as age and condition of the animal, type and amount of feed consumed, nature and amount of litter and storage conditions (Maclean, Miller and Robinson, 1983; Mugwira and Murwira, 1997).

In Zimbabwe, the quality of manure used by resource-poor farmers is low probably due to poor quality of the veld grass, lack of feed supplements and because nutrients are lost during storage and handling of the manure before application in the field (Murwira and Kirchmann, 1993). Several studies have shown substantial nutrient losses to occur during storage and handling. Kirchmann and Witter (1992) found that between 1 and 44 % of N is lost during storage. Lauer, (1976) measured losses of between 61 – 99% of NH_4^+-N through volatilisation, poor management techniques and leaching during storage, handling and application. Losses of manure-N amounting to 6 % of the total N content in manure have been shown to occur in Zimbabwe as reported by Murwira (1995). These losses are in fact high in the context of a low input agricultural system. Nitrogen losses are of particular concern because they reduce potential N for cycling required for sustainability of agricultural systems. The challenge is thus to improve efficient management of manure during the entire manure production cycle.

The purpose of this study was to develop an inventory of farmer perceptions in the storage and handling of manure, and to determine points of weaknesses in the current manure management system. A major objective was to develop a research agenda for improving quality of manure that was context sensitive to the needs of the target communities.

2.2 Materials and methods

A survey was conducted in May 1997 in Mangwende communal area using farmer participatory rapid appraisals, informal interviews, and wealth ranking and bio-resource flow modelling techniques to ascertain farmer circumstances in the storage and handling of cattle manure. A hundred farmers who owned cattle were randomly selected from 5 villages namely Chitemerere, Kadzviti, Chikowore, Zendera and Nherera in the study area. Twenty farmers from each village were selected and interviewed.

Different manure management strategies used during storage and handling were observed from kraals. Crop residue management practices were included in the survey to determine to what extent the use of crop residues was recognised as an essential tool in urine entrapment. Cattle numbers per interviewed household and quantities of manure produced per annum were established. A manure sample was collected from each storage system to determine the influence of storage practice on quality of the manure. Nitrogen was analysed using the semi-micro Kjedhal N method (Bremner and Mulvaney, 1982). Decision trees developed by farmers were used as a basis for developing crop residue and manure management strategies. Practical interventions were proposed following the survey for experimentation on-farm.

Statistical analysis

Data collected was analysed using the Statistical Package for the Social Sciences (SPSS). Analysis of variance (ANOVA) was performed to determine differences in storage methods followed by farmers and quality of manures produced from each system. Student's t test was used to compare means of data collected on strategies for mitigating nutrient losses during the rainy season and on crop residue use in cattle kraals. The standard error of difference was used to differentiate farmer perceptions of causes of nutrient losses from manure and possible solutions.

2.3 Results

Cattle ownership and manure production

Secondary data was used to quantify manure produced by each farmer. Table 2.1 categorises farmers into groups with different cattle numbers. Within each group are farmers producing specific quantities of manure per year. Most farmers interviewed (56, group 2) owned 5 to 7 head of cattle while 33 (group 3) had 8 to 10 head of cattle. Some farmers (5, group 4) had more than 10 head of cattle while others (6, group 1) owned 2 to 4 cattle.

Of the farmers who produced 3 t of manure, 5 were in-group 1, 8 were from group 2, while 2 were in group 3. Most farmers (48) who produced between 10 and 12t of manure were group 2 farmers. Some group 3 farmers' (11) produced similar quantities of manure produced by group 2 farmers. This observation was also typical of some farmers (7) in group 3 who produced similar quantities of manure as that by group 4 farmers (Table 2.1).

Table 2.1 Quantity of cattle manure produced under different farmer categories in Mangwende Communal Area.

Cattle ownership ranges	Number of Cattle	Quantity of Manure (t/year)	Number of farmers
Group 1	2-4	3	5
		10	1
Group 2	5-7	3	8
		10	24
		12	24
Group 3	8-10	3	2
		10	13
		12	11
		15	7
Group 4	>10	> 15	5

A total of 100 farmers was surveyed.

Use of crop residues by farmers

The survey established that farmers managed crop residues in several ways. Crop residues were used as cattle feed, bedding materials in kraals for composting, ploughed under as soil fertility amendment or simply burnt. Maize straw and groundnut haulms were commonly stored in raised platforms erected in or outside the kraal and were fed to cattle at regular intervals particularly in winter to supplement veld grass. Some farmers kept the straw intact till the onset of rains during which time it was used as bedding for animals.

Current manure management techniques

There was a general perception that quality of manure was low and that it was due to nutrient losses. Figures 2.1 and 2.2 below present the possible causes of nutrient losses 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 failing to kraal cattle at night, poorly sited kraals, and lack of bedding material in kraals. Farmers also mentioned other factors such as storing manure in small heaps, leaving it exposed to rain and other weather conditions, not keeping it sufficiently moist and storing it for longer periods. The possible solutions indicated by farmers were kraaling at night, selecting the site of the kraal carefully and changing its position regularly, protecting it with a wall or stones, and trapping seepages. Adding bedding to the kraal, reducing the time of storage, and composting manure with mineral fertilisers were other suggestions for handling and storing of manure.

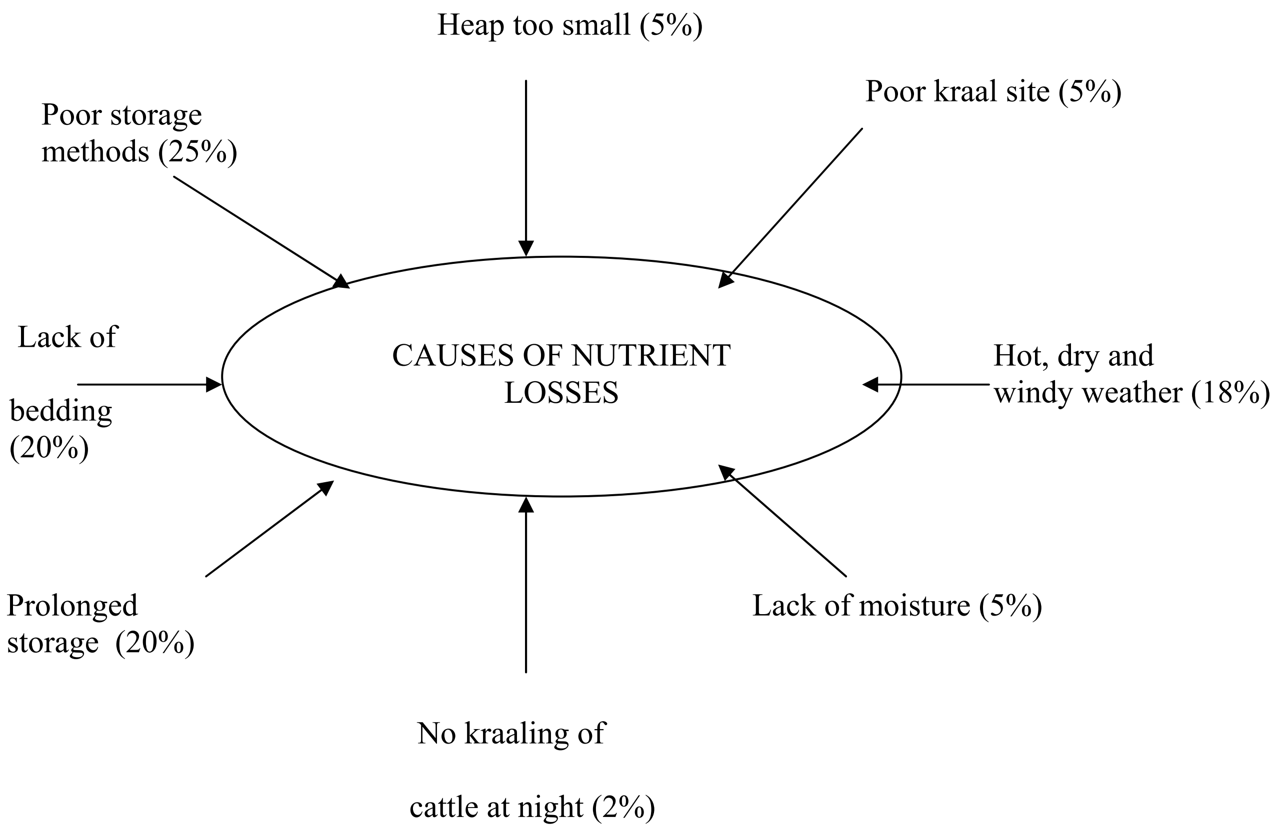


Figure 2.1. Farmers' perceptions of causes of nutrient losses from manure in Mangwende Communal Area. (n=100). SED = 4.85 (P<0.05).

Figure 2

Figure 2

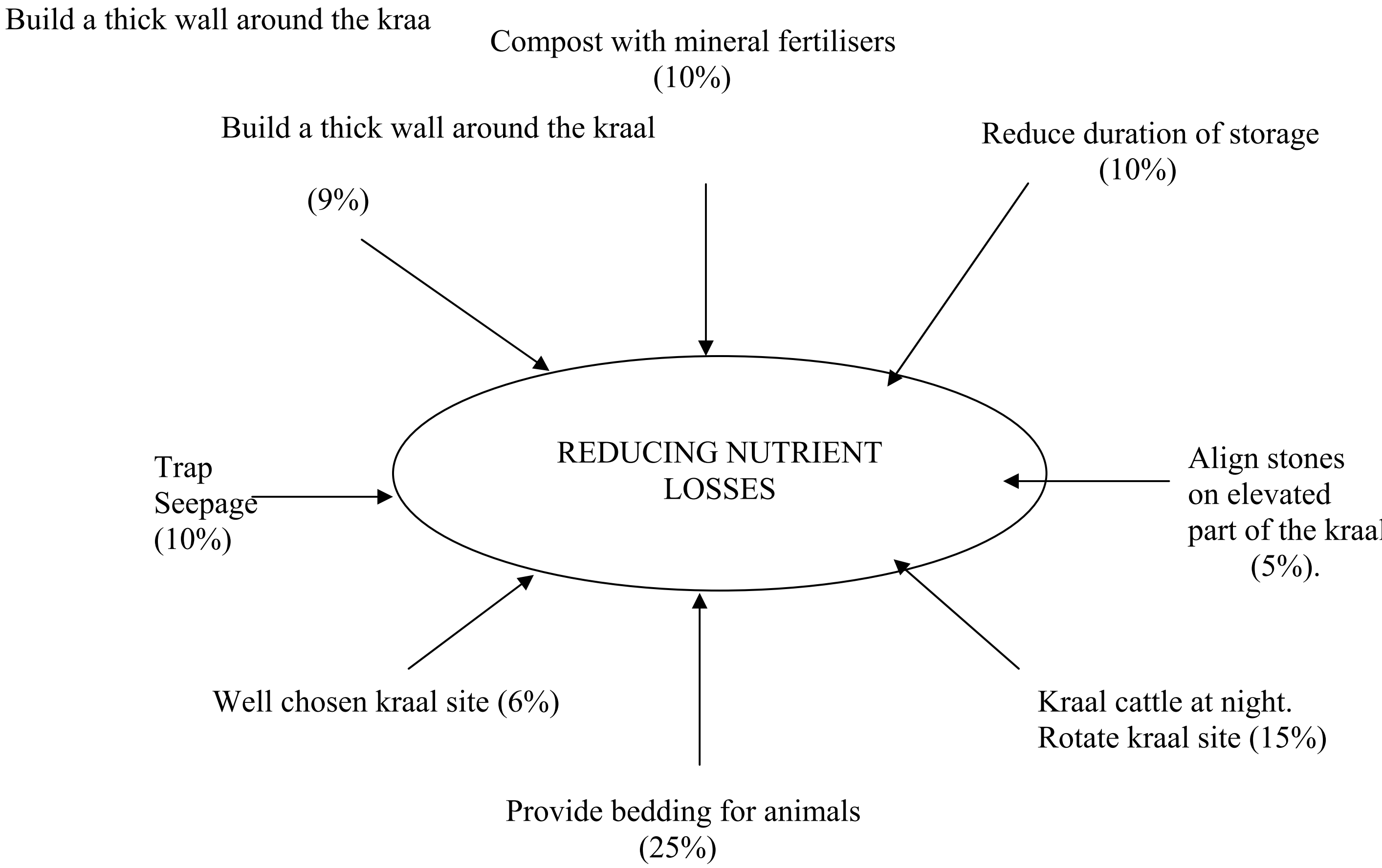


Figure 2.2. Farmers' perceptions of solutions for reducing nutrient losses in the manure production cycle in Mangwende Communal Area (n=100). SED = 5.25 ($P<0.05$).

There were significant variations in the storage methods practiced by farmers in Mangwende CA ($P<0.05$). Heaping was significantly practiced by many farmers (85%) than other storage methods ($P<0.05$). Keeping manure in the kraal till the time of application in the field (deep stall) was practiced by 10% of the interviewed farmers. Only 5% of the interviewed farmers stored their manure in the pit. The number of farmers who practiced deep stalling and pit storage were statistically the same.

Differences in the month of heaping manure were observed. The number of farmers heaping manure in July were significantly ($P<0.05$) higher (47% of farmers) than any other period. Heaping in October was practiced by 24% of farmers. Few farmers (14%) heaped manure between January and April. There were no statistical differences in the number of farmers heaping manure in October and between January and April ($P=0.056$).

Feeding crop residues to livestock in the kraal is important. It was considered a preliminary treatment in the process of handling. Results suggest significant ($P<0.05$) differences in methods of handling manure in cattle kraals. The addition of straw to the kraal all year constituted significantly ($P<0.05$) higher farmers (55%) in comparison with farmers adding straw only in rainy seasons (34%). Few farmers (11%) did not add any organic material in the kraal ($P<0.05\%$).

Strategies to minimise nutrient losses from manure during the rainy period included rotation of kraals, construction of an earth wall around the kraal and collection of seepages in the pit. Fig 2.3 shows the proportion of farmers using different ameliorative practices to mitigate nutrient losses from manure. The number of farmers constructing an earth wall was significantly ($P<0.05$) higher than any other strategy. There were no distinct differences between the number of farmers rotating kraals and those that did not take any action to prevent liquid losses from the kraal ($P=0.086$).

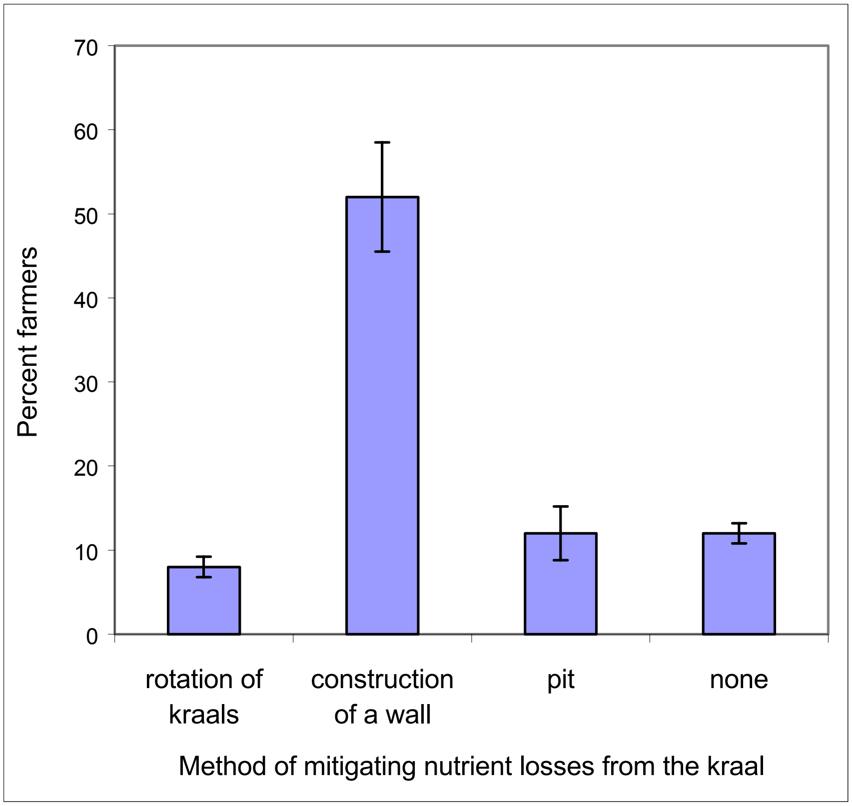


Figure 2.3. Practices used by farmers to mitigate nutrient losses from manure during the rainy season (N=100). P<0.05.

Nitrogen content of the manure

There were differences in the quality of manure collected from different storage systems (P<0.05). The N content of manure samples collected ranged from 0.5% -1.2%. Nitrogen content of manure from heap storage and deep stall practices was in the range of 0.5% – 0.9% N. Farmers who practiced pit storage had manure with N content greater than 1%. The quality of manure from pit storage was significantly ($P<0.05$) higher than that from the heap storage and deep stall practices.

2.4 Discussion

Nitrogen losses are potentially high in cattle kraals where crop residues were either not incorporated or only used at specific periods of the season. This is because NH_3 losses are influenced by exposure of manure to the ambient environment, which increases rate of hydrolyis of urea in urine and rapid diffusion of NH_3 from the manure (Denmead *et al.,* 1982, Peoples *et al,* 1995). Continuous use of crop residues prior to storage practiced by some farmers in the study, implies that losses might be minimised at the critical point of excretion where losses from dung and urine are reportedly higher (Kirchmann, 1985, Murwira, 1995). It has been shown that 80% of total N voided by an animal is from urine which can be hydrolysed to ammonia in exposed cattle kraals (Elliot and McCalla, 1973). There is greater need to determine to what extent N losses by volatilisation can be minimised during handling with the provision of straw.

Although heaping was the most common storage method for manure, the quality of the resultant manure was poor in comparison with pit manure. The challenge would be to explore how biological processes can be manipulated to improve quality during storage of manure. Studies conducted by Kirchmann and Witter (1989), Martins and Dewes (1992) sight changes in pH relative to storage conditions as a major factor regulating the equilibrium between NH_4^+ and NH_3 and magnitude of losses. It will be necessary to investigate the impact of pH changes in storage systems on N losses.

The study also indicated that few farmers heaped manure between January and March for use during the onset of the cropping season in October. In studies conducted by Kirchmann, 1985, composting manure for more than 3 months reduced quality of manure. It has been suggested that prolonged composting can convert the more readily decomposable organic N forms resulting in small amount of inorganic N available for uptake by the crop (Castellanos and Pratt, 1981). The implications are that application of heaped manure to soil might depress crop growth and yield as N release from this manure has been reported to be slow and cannot be synchronised with maize crop requirement (Murwira *et al.,* 1993, Nyamangara *et al.,* 1999).

Pit storage of manure might be advantageous to farmers as reflected by high quality of manure samples collected during the survey. The superiority of the pit in enhancing quality of the manure than the heap was possibly due to the closed nature of the pit which has a potential for conserving N from being lost through NH_3 volatilisation. As a greater proportion of the N from pit manure has been shown to be in the readily available form, the implications are that the crop can achieve better synchrony resulting in increased crop growth and yield.

The variation in manure storage and handling practices used by farmers and the resultant quality of manure samples collected from different manure management practices necessitates the need to further explore on-farm potential strategies for efficient management of manure that could enhance quality.

2.5 Conclusion

The study identified differences in the storage and handling practices followed by farmers in Mangwende CA. Variations in quality of manure produced were related to the storage method. The study suggests that pit storage (least practiced) had a potential in producing better quality of manure. Although heaping was the most common storage method, the bottleneck was that it produced manure of low quality.

Some socio-economic advantages linked to heaping such as minimal labour costs involved in producing the manure, accounts for the high frequency of farmers heaping the manure. The scale of differences found in the use of crop residues in cattle kraals points towards possible N leakages from the system particularly where residues were not incorporated or continuously supplied to the kraal. In such open systems, exposure of dung and urine often results in N losses from hydrolysis of urea. This combined with prolonged composting practiced by some farmers can reduce the quality of manure given that; the stability of nitrogenous compounds increases with the duration of composting. Less N would therefore be available for crop uptake.

It can be concluded that the potential for improving quality of manure is there. Proper manure management in the kraal can minimise losses during storage and handling and improve quality of the manure. The use of crop residues at all times of the year to absorb urine-N particularly at the critical point of excretion, when N losses through volatilisation are high needs to be encouraged. Pit storage of manure combined with the use of crop residues in both summer and winter storage could be a promising technology, which can minimise volatile N losses, thus enhance quality of manure.

It follows therefore that, many other factors will need to be considered before an informed decision can be made by the farmer; What is the optimum quantity of straw required to immobilise urine-N in cattle kraals? Is there enough crop residues available on-farm? Can manure be pit stored on a large scale to minimise N losses through volatilisation? To what extent are losses minimised if straw is incorporated in storage systems? What is the optimum length of composting that increases the value of manure as a fertiliser? What are the implications to the cropping system of nutrient release patterns from heap and pit stored manures? To what extent do different quality manures affect yield in the short and long term? The chapters that follow explore some of these questions.

CHAPTER 3

USE OF STRAW AS AN AMENDMENT TO IMPROVE MANURE QUALITY IN CATTLE KRAALS

3.0 Abstract

Nitrogen losses during storage and handling can result in manure of poor quality. Efficient handling techniques can be used to minimise such losses. In this study, the use of locally available maize straw, as an ammonia absorbent in kraals (cattle enclosures) was investigated. A laboratory incubation study using dynamic techniques was conducted to determine the efficiency of straw in reducing nitrogen losses by measuring the quantities and time course of NH_3 loss from cattle manure and urine. The optimum quantity of straw required to reduce ammonia losses from manure was determined. Maize straw was effective in reducing ammonia losses. A proportion of 4 parts straw to 25 parts manure by weight was found to be the most effective in reducing losses. Addition of straw reduced losses by up to 85 % in cow dung, and by 50 % in cow dung and urine mixtures. In a field study in Mangwende Communal Area, Zimbabwe, NH_3 losses were measured in cattle kraals with and without bedding. Losses of NH_3 from cattle kraals with crop residues were 88% less than in kraals without straw. It was concluded that maize straw was effective in minimising volatile N losses during handling in cattle kraals.

3.1 Introduction

Ammonia volatilisation and leaching from cattle kraals and grazing systems have long been recognised as major pathways of N loss following excretion of dung and urine (Dewes, Schmidt, Valentin & Ahrens, 1990) and during storage (Kirchmann and Witter, 1989).

Nitrogen losses contribute significantly to the N deficit observed in low input agricultural systems.

Studies conducted by Elliot and McCalla (1973) and Vuuren and Mejis (1987) indicated that the largest partition of excreted N was through the urine. This accounts for 80% of the total urinary N, the remaining 20% being split into amino-N and purine-N (Oak, 1952, Powel, 1996). The urea fraction is immediately converted by the enzyme urease to NH_3 upon exposure to the environment and in this form is highly susceptible to volatilisation.

Losses ranging from 20 to 50% of total N initially present in the urine have been reported from exposed cattle kraals (Vallis et al.1982, 1985). Ammonia losses from dung patches are small in comparison to losses from urine patches. MacDiarmid and Watkins (1972) reported 5% of total N losses from dung patches with 73% losses occurring within the first five days. This compares with 14 –60% of N losses from urine patches within 14 days and 26- 50% being lost in the first 24 hours (Vallis and Gardner, 1984, Vallis et al., 1985, Watson and Lapins, 1969).

The rate of hydrolysis of the urea fraction and subsequent transformation from NH_4^+ to NH_3 gas which volatilises is a function of bio-physico-chemical factors of the environment to which dung and urine are exposed. These include temperature, pH, air movements, rainfall, water content, relative humidity, NH_3 concentration, urease activity and microbial transformations (Lauer et al., 1976; Vlek and Stumpe 1978, Martins and Dewes 1992).

In cattle kraals in the communal sector of Zimbabwe, the potential for ammonia losses could be high, as there is inefficient use of straw to absorb urinary–N in these systems. The potential for losses is also high during storage as a majority of farmers practice the heaping storage method, which increases the potential for N losses (Chapter 2).

The manure handling chain with the potential intervention points in the communal area farming systems is shown in Fig 3.1. Management systems can be manipulated to conserve urine-N during storage and handling. Provision of bedding in cattle kraals and the use of N-poor degradable materials like straw during decomposition of manure could reduce N losses during storage and handling because they have a high C/N ratio which leads to temporary immobilisation of N (Faassen and Dijk 1979). However, there is limited knowledge on how biological processes can be practically manipulated during storage to reduce N losses and improve quality of manure in smallholder systems.

This study examined storage and handling systems that could minimise N losses and enhance quality of manure. This was done through assessing the efficacy of crop residues especially maize straw as ammonia and urine absorbents and incubation conditions during decomposition.

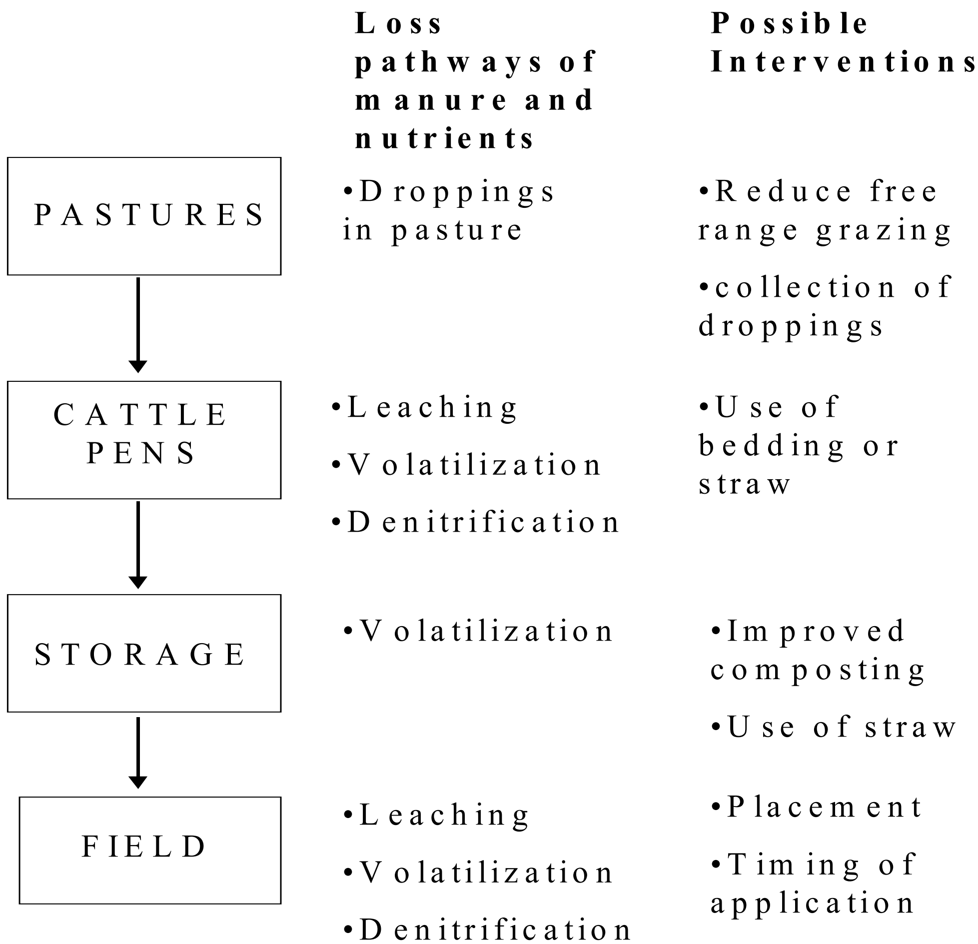


Figure 3.1. Manure management chain and potential interventions to reduce nutrient losses and improve quality. Arrows represent manure production and utilisation cycle.

3.2 Materials and methods

Experiment 1

Two laboratory incubations were set up in a constant temperature room at 25^{o}C to determine the efficacy of maize straw as an ammonia absorbent when mixed with urine or manure. In the first study, different amounts of straw were used to determine the optimum quantity of straw required to reduce ammonia losses from manure. Cow dung weighing 25 g, was mixed with straw (0, 1, 2, 3, or 4 g) and placed in Dreschel bottles. Airflow scrubbed free of ammonia, at a pressure of 0.02 bars was blown through the Dreschel bottles, and the ammonia produced was trapped in 2 % boric acid. Determinations of NH_3 losses were made daily for 7 days after which the experiment was stopped. The amount of NH_3 captured in the traps was determined by titration with 0.0025 M H_2SO_4.

Experiment 2

The objective of Experiment 2 was to determine if N losses could be minimised by mixing dung with straw. The optimum quantity of straw derived from Experiment 1 was used in this study. Ammonia losses were measured from urine alone, manure only, and from mixtures of straw with either urine or manure. Ammonia losses were measured as in the first experiment over a 7-day period until losses had stabilised to undetectable amounts.

Experiment 3

The field study was conducted in Mangwende communal area, Zimbabwe to assess the effect of using maize straw as a bedding material in cattle kraals (cattle enclosures) on nitrogen losses through volatilisation. Six kraals were used in the study. In half of the kraals, maize straw was applied as a mat to a depth of 5cm. No straw was applied to the remaining kraals. An average of three livestock units per kraal was continuously kraaled over night during a 4 week experimental period.

Ammonia losses were measured within each kraal. Measurements were taken at 3 randomly chosen points in each kraal at 0800hrs, 1200hrs and 1500hrs. The gas sample was collected at each randomly chosen point over an area of 30 x 20cm. Ambient air from within a 10 litre chamber placed on the surface was drawn using the Gastec Multi-stroke Gas Sampling Pump. The ammonia concentration in the ambient air was measured using a pre-calibrated NH_3 absorbent Gastec Detector tube (No. 3L) which provided a rapid, quantitative analysis of the concentration of ammonia in air. The readings were summed up for each week for the respective times.

Statistical analysis

Analysis of variance (ANOVA) in Genstat was done to determine treatment differences on effectiveness of straw in reducing losses under controlled environment. Data on N losses from cattle kraals was analysed using the multi-variate analysis of variance test (MANOVA) approach to repeated measures in Statistical Analysis Systems (SAS) computer programme (SAS Inc., 1988). In this experiment there was an explicit interest in the pattern of losses from cattle kraals with and without straw over time. The major problem in analysing this kind of data is that the measurements at a particular time may very well be correlated and the magnitude of correlations is usually unknown. It would be erroneous to ignore these correlations or to assume that they are equal and analyse the data as a split plot with time as the split plot factor. The MANOVA approach to profile analysis was applied after checking the structure of the error covariance matrix. A split plot analysis could not be applied, as the error covariance matrix did not have a spherical structure. It is important to note that the MANOVA analysis also has a limitation in that it is only powerful provided $N-M > k+9$; where N is the number of samples, M is the number of treatments and k is the number of dependent variables (in this case k is the number of time periods). (Maxwell and Delaney, 1990).

3.3 Results

Effectiveness of straw in reducing ammonia losses in laboratory incubations.

Losses of NH_3 progressively decreased with increasing amounts of straw added. A proportion of 4 parts straw to 25 parts manure was found to be the most effective in reducing NH_3 losses (Fig.3.2). Addition of straw reduced losses by up to 85 % in cow dung, and by 50 % in cow dung and urine mixtures ($P<0.05$) (Fig 3.3). Most of the losses occurred within the first three days and stabilised thereafter. Highest losses were recorded from urine alone. Negligible losses were measured from the dung fraction.

Effect of crop residue entrapment of urine in the kraal.

Results indicate significant differences in the magnitude of losses from the two types of kraals ($P<0.0001$) (Table 3.2). Significantly higher NH_3 losses ($P<0.0001$) occurred in kraals where residues were not used. NH_3 losses were reduced by 88% after addition of straw. Ammonia losses were strongly dependent on time of the day ($P<0.0001$) with the probability value being much smaller where crop residues were incorporated (Table 3.1). There were diurnal fluxes in the pattern of ammonia losses. The flux pattern exhibited maxima in the midday and minima towards the end of the day. Daily loss variations, particularly in kraals without straw were also observed in this study (Table 3.1).

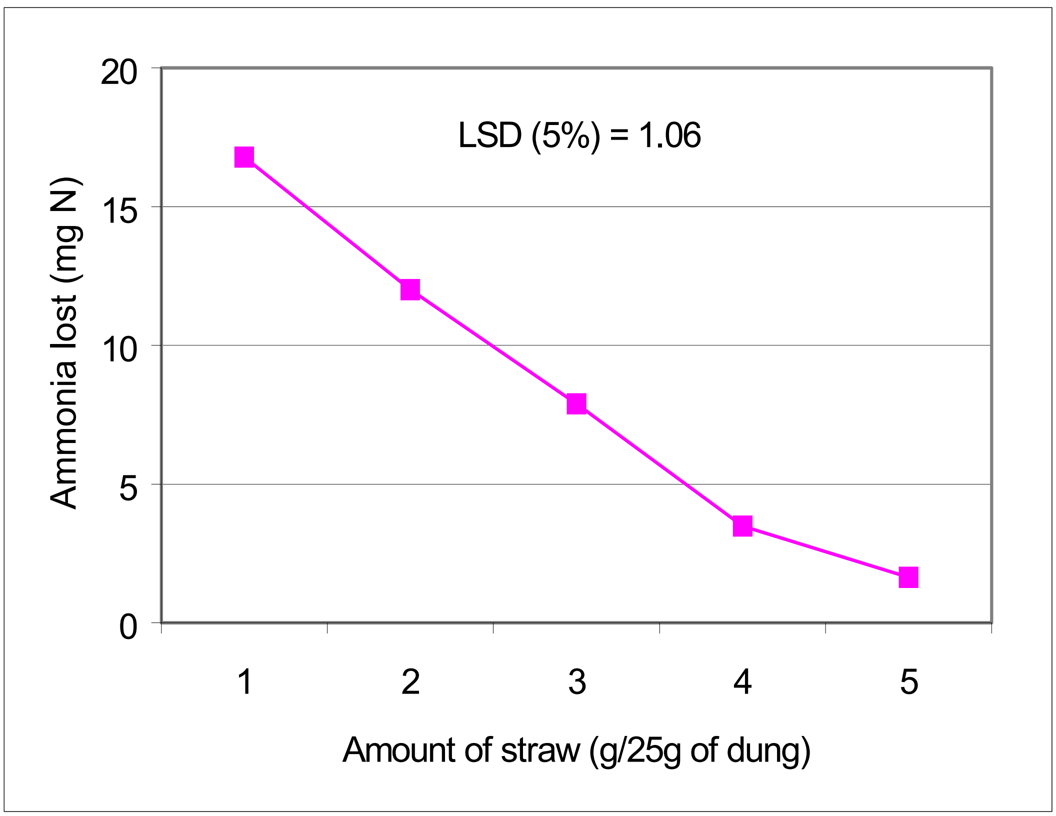


Figure 3.2. Effect of straw on ammonia losses from freshly excreted dung under laboratory conditions.

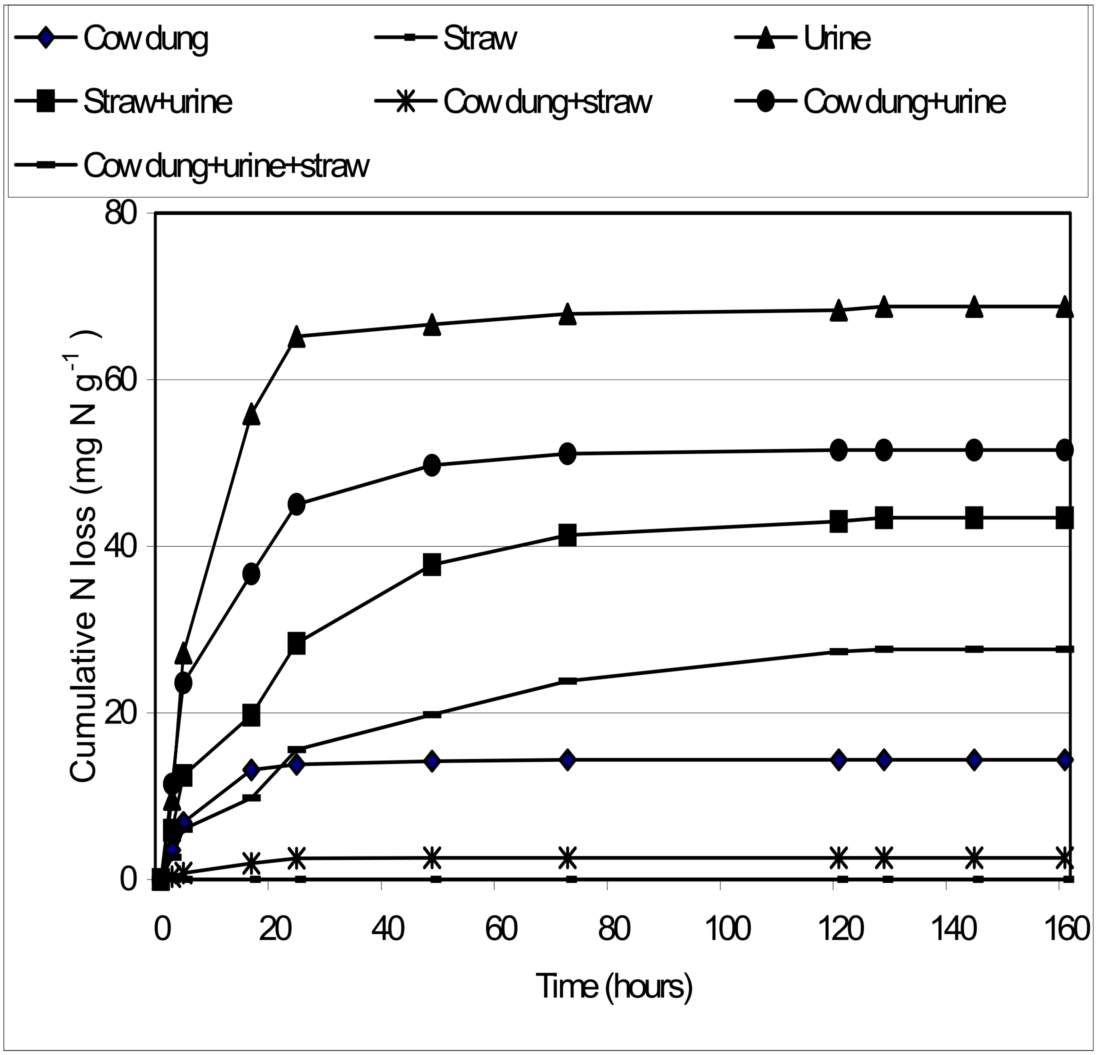


Figure 3.3. Cumulative N losses from urine and cow dung mixtures with and without straw amendment.

Table 3.1. Mean NH_3 losses (kg N 1000kg $^{-1}$ manure) in cattle kraals with and without straw.

	NH₃ losses (kg N 1000kg⁻¹ manure) WEEK 1			2			3			4		
TIME (HRS)	0800	1200	1500	0800	1200	1500	0800	1200	1500	0800	1200	1500
TRT												
NO STRAW	14.5	44.2	14.0	11.6	37.1	15.0	9.8	37.1	14.2	12.8	34.8	11.3
WITH STRAW	1.3	3.9	1.5	3.6	3.9	1.5	2.5	3.8	1.5	2.8	3.3	1.3
MEAN	7.9	24.1	7.8	7.6	20.5	8.3	6.1	20.5	7.8	7.8	19.1	6.3

TEST FOR SPHERICITY OF N LOSSES VARIANCE-COVARIANCE MATRIX:
MAUCHLY'S CRITERION = <0.0001

Table 3.2. MANOVA analysis of N loss differences between adjacent time levels (Wilks' Lambda Statistic)

	Adj Pr > F	
SOURCE	G – G	H – F
Time	<0.0001	<0.0001
Time * TRT	<0.0001	<0.0001

Key: Adj Pr = adjusted probabilities

G-G = Greenhouse – Geisser Epsilon

H-F = Huynh – Feldt Epsilon

3.4 Discussion

Results from the laboratory incubation studies indicated that a greater proportion of N that was volatilised came primarily from the urine fraction. High N losses from urine can be expected because the largest partition of excreted N is in the urea fraction accounting for 80% of the total urinary N (Mentis, 1981; Ryden et al., 1987; Van Vuuren and Meijis, 1987). When urine is exposed to the environment, the urea in urine can be immediately hydrolysed to ammonium carbonate, which upon dissociation increases the pH of the system resulting in diffusion of NH_3 from the manure greater N losses (Vallis et al., 1982, 1985).

The high N losses from the urine fraction suggest that it should preferably be used immediately after excretion. However, farmers lack information about how to collect and efficiently utilise urinary N before it is lost from the farming system. This study has shown that urine-N can be practically conserved through provision of straw as a bedding mat in kraals. Straw increases the C/N ratio of the excrements, which immobilises NH_4-N upon hydrolysis of urea (Faassen and Dijik, 1979 and Kirchmann, 1985).

Results from field studies confirmed the practical feasibility of using straw to minimise N losses during handling of dung and urine. When a bedding mat of straw is provided in kraals, dung and urine are deposited directly on the mat, which absorbs urine- N. This minimises exposure of urine-N from ambient temperature and windy conditions, thereby reducing NH_3 volatilisation. Diurnal fluctuations in the pattern of NH_3 losses were also observed in this study. This could have resulted from temperature effects induced by changes in the micro-climate around the kraals and normal variations in the urine and faecal production of penned animals. Farmers are therefore encouraged to provide a bedding mat at all times in order to capture any escaping N at any time of the day.

3.5 Conclusion

This study has demonstrated the efficacy of using maize straw as a viable strategy for minimising NH_3 losses through volatilisation during handling in cattle kraals. Whilst this has been shown to be effective, the implications of these results are that it is difficult to completely eliminate losses in the kraal. One hundred and sixty kilograms of straw per tonne of manure would be required to effectively reduce N losses by 50%. The amounts of straw required for use as a bedding mat may not be practicable in agricultural systems where crop residues have competing uses, such as supplementary stock feed and soil fertility amendment.

Possible practical options would be to provide a roof above the kraal and increase the number of shade trees around the kraal to minimise exposure of the excrements to the environment, thus reducing volatile N losses. Use of straw to absorb urine-N could increase the C/N ratio of the manure, resulting in temporal N immobilisation after application of the manure to the soil, and depressed crop growth and yield. This aspect is dealt with in subsequent chapters.

CHAPTER 4

THE EFFECT OF STORAGE METHOD, CROP RESIDUE INCORPORATION AND LENGTH OF COMPOSTING ON AMMONIA LOSSES FROM, AND QUALITY OF MANURE.

4.0 Abstract

The efficiency of pit storage (anaerobic decomposition) and conventional heaping (aerobic composting) in minimising NH_3 volatilisation and enhancing availability of N from manure were investigated. The effect of maize residue incorporation and duration of storage on quality of manure produced was also determined. Inorganic N occurred predominantly as NH_4^+-N in anaerobic manures and as NO_3-N in aerobic manures. Losses of NH_3-N were significantly higher ($P<0.01$) in aerobic manures (between 20*u*g g^{-1} and 40*u*g g^{-1}) compared to anaerobic manures (between 2*u*g g^{-1} and 5*u*g g^{-1}). The use of straw in storage systems significantly increased N loss ($P<0.01$) particularly in aerobic manure composts. The higher N losses measured in aerobic manure composts were due to ammonification of protein materials in the manure, which produced alkaline conditions to pH values greater than 7; prolonged composting and drying in response to moisture loss. In contrast, anaerobic decomposition resulted in low pH values below 7 and moisture conservation. It was concluded from the study that it is more beneficial in terms of mineral N concentrations to store manure anaerobically and without maize residue incorporation in July than in April.

4.1 Introduction

During storage and decomposition of solid cattle manure N losses by volatilisation can reduce the quality of manure (Kirchmann and Witter, 1992). Different decomposition processes can change the magnitude and extent of volatile N losses, and composition of the manure (Eghball, 1997; Kirchmann and Lundvall 1992; Petersen *et al.,* 1998; Thomsen, 2000).

Manure can decompose under anaerobic, aerobic or partially aerobic/anaerobic conditions. These conditions relate to availability of oxygen. Aerobic and anaerobic storage conditions occur under high and limited oxygen supply respectively (Kirchmann, 1985). Anaerobic decomposition results in a greater accumulation of humic acids, formation of low molecular weight compounds such as volatile fatty acids, negligible volatile N losses and high contents of NH_4^+-N (Archaya, 1935; Kirchmann and Witter, 1989; Thomsen, 2000).

Under aerobic storage conditions or aerobic composting, large amounts of manure N are lost through NH_3 volatilisation and the inorganic N content is generally low and mostly in the NO_3-N form. Organic materials of high stability are also formed during aerobic composting (Karlsson and Jeppsson, 1995; Kirchmann and Witter, 1992, Thomsen, 2000).

Losses of NH_3 during storage are influenced by physico-chemical factors such as storage conditions and length of exposure of storage systems to the environment, moisture loss and initial N concentration of the manure. Other studies have reported that pH of the manure is the major factor regulating the process of NH_3 volatilisation which occurs at pH values above 7. During anaerobic decomposition, accumulation of organic acids in the system can decrease the pH values below 7, resulting in decreases in NH_3 volatilisation (Kirchmann and Witter, 1989; Martins and Dewes, 1992; Petersen *et al.,* 1998).

In smallholder farming systems of Zimbabwe, manure is heaped for extended periods between January and October prior to application in the field in October or November (Nzuma, Murwira and Mpepereki, 1998). The heaping storage method increases susceptibility of manure to NH_3 volatilisation because of exposure of manure to ambient temperature and windy conditions, which induce N losses (Martins and Dewes 1992; Petersen *et al.,* 1998; Thomsen, 2000). Losses amounting to 44% of total N from manure have been measured during aerobic composting (Kirchmann 1985, Kirchmann, and Witter 1989). In smallholder sectors of Zimbabwe, N losses amounting to 6% of the total N present in aerobic manures has been reported (Murwira, (1995).

Nitrogen losses during storage can be minimised by decomposing manure under anaerobic storage conditions. Less than 1% of N initially present in manure have been measured during anaerobic decomposition (Kirchmann and Witter 1989). Reduced losses with increasing straw in storage systems have been reported by many workers (Kirchmann; 1985; Kirchmann and Witter; 1989; van Fassen and Dijik, 1979; Witter and Lopez-Real, 1988). However, other findings have reported high N losses with increasing amounts of straw in storage systems (Kohnlein and Vetter, 1953). Whilst there are indications that anaerobic decomposition can reduce N losses by volatilisation and enhance quality (Eghball; 1997; Kirchmann; 1985; Petersen *et al.;* 1998; Thomsen, 2000), there is lack of information on the practical management techniques for anaerobic manure composts for the smallholder farmers.

The purpose of this study was to determine the effect of method and period of composting on manure quality. The emphasis in these studies was put on the effect of pit storage of manure (anaerobic decomposition) and crop residue incorporation on quality and pattern of N losses.

4.2 Materials and methods.

Sites

The studies were conducted on-farm at 20 farmer kraal sites in Mangwende communal area, Murewa District, Zimbabwe. The sites were located a kilometer from each other. Farmers with an average of three livestock units per kraal were selected to participate in this study.

Experimental set up

Four methods of manure storage were studied.

1. pit storage with crop residue additions
2. heap storage with crop residue additions
3. pit storage without crop residue additions

4. heap storage without crop residue additions

The pits were 1.5m long x 1.2m wide x 1.0m deep. Heap dimensions were 1.5m long x 1.2m wide x 1.0m high. Manure amounting to 2000kg was used for each treatment. One hundred and fifty kilograms of maize straw cut into small pieces (less than 20cm long) were then added to the manures in treatments 1 and 2 at the point of storage thus altering the initial C/N ratio of these treatments.

Straw was incorporated in storage systems in layers alternating with manure. There were 3 layers of straw and 4 layers of manure. Each layer of manure was 500kg. A 50kg layer of straw was placed between two manure layers. The same proportions were used in setting up heap treatments with straw. For these treatments, the last layer of the heap consisted of manure. In treatments without straw, manure was placed in heaps or pits until a height or depth of 1.0m was attained. A 30cm layer of soil was then used to cover all pit storage treatments. The heaps and pits were located in an open space close to the kraal.

Throughout this study, treatments 3 and 4 will be referred to as without straw (- straw), whilst the remaining treatments with solid manure from the same kraals but with additions of straw at the point of storage will be referred to as with straw (+ straw).

The experiments were set up in April 1997 (early winter period) and the same treatments in July 1997 (late winter period). Ten farmers participated in each period. April and July storage times were chosen in this study because these were the times a majority of farmers stored their manure (Chapter 2).

Measurement of NH_3 losses

Ammonia losses by volatilisation were measured using the chamber technique (Watson et al., 1962) and the Gastec Multi-stroke Gas Sampling Pump and the Gastec Detector Tube No 3L. (Manufacturer: Gastec Corporation, 6431 Fukaya, and Ayase-City, 252, Japan). The measurements were taken on a daily basis and summed up for cumulative monthly values.

Collection of manure samples and analysis

Manure samples were collected during the establishment of the storage systems and at monthly intervals until October when the experiment was terminated. At each sampling, 5 sub samples were collected from the pit or heap at successive 20cm depth intervals using an auger and bulked. The composite samples were analysed later for total N, NH_4-N, NO_3-N, pH and moisture content. The Kjeldahl method (Bremner and Mulvaney 1982) was used for the determination of total N on moist samples to avoid NH_3 losses. Ammonium-N and nitrate-N were measured after extraction with 2M KCI using MgO Dervada-alloy procedure (Bremner, 1965). Manure pH was determined in distilled water using a soil:solution ration of 1:5. The gravimetric method was used to determine the moisture content of the samples collected at each period.

Mass balance study

Mass balance studies were run parallel to the present study using the manures established in July. The initial weights of the manures were subtracted from the weights of the manures obtained after 3 months storage and expressed as a percentage.

Statistic analysis

An analysis of variance (ANOVA) in Genstat 5.0 version was done to determine treatment differences. The (least square difference) LSD was used to make comparisons of treatment means.

4.3 Results

Total N in Manure From Different Storage Systems

Total nitrogen concentrations measured in the pit (anaerobically composted manure) at the end of storage was significantly higher than in heaps (aerobically-treated manures) ($P < 0.01$) (Fig 4.1). There was a marked increase in total N content with storage period particularly for anaerobic treatments during the first 2 months of storage for the July treatments. The total N content for anaerobically treated manure was significantly higher in systems without crop residue incorporation than in similar systems with straw. The values at the end of storage were 1.7% N for April and 2.2% N for July systems without straw. In anaerobic treatments with maize straw, the total N content recorded was 1.1% for April and 1.2% for July storage systems. The lowest amounts of total N were found under aerobic storage treatments. Aerobic manure composts incorporated with maize straw recorded 0.6% N for April and 0.9% N for July treatments. In aerobic treatments without maize straw, the total N content measured was 1.2% N for April and 1.4% N for July treatments (Fig. 4.1).

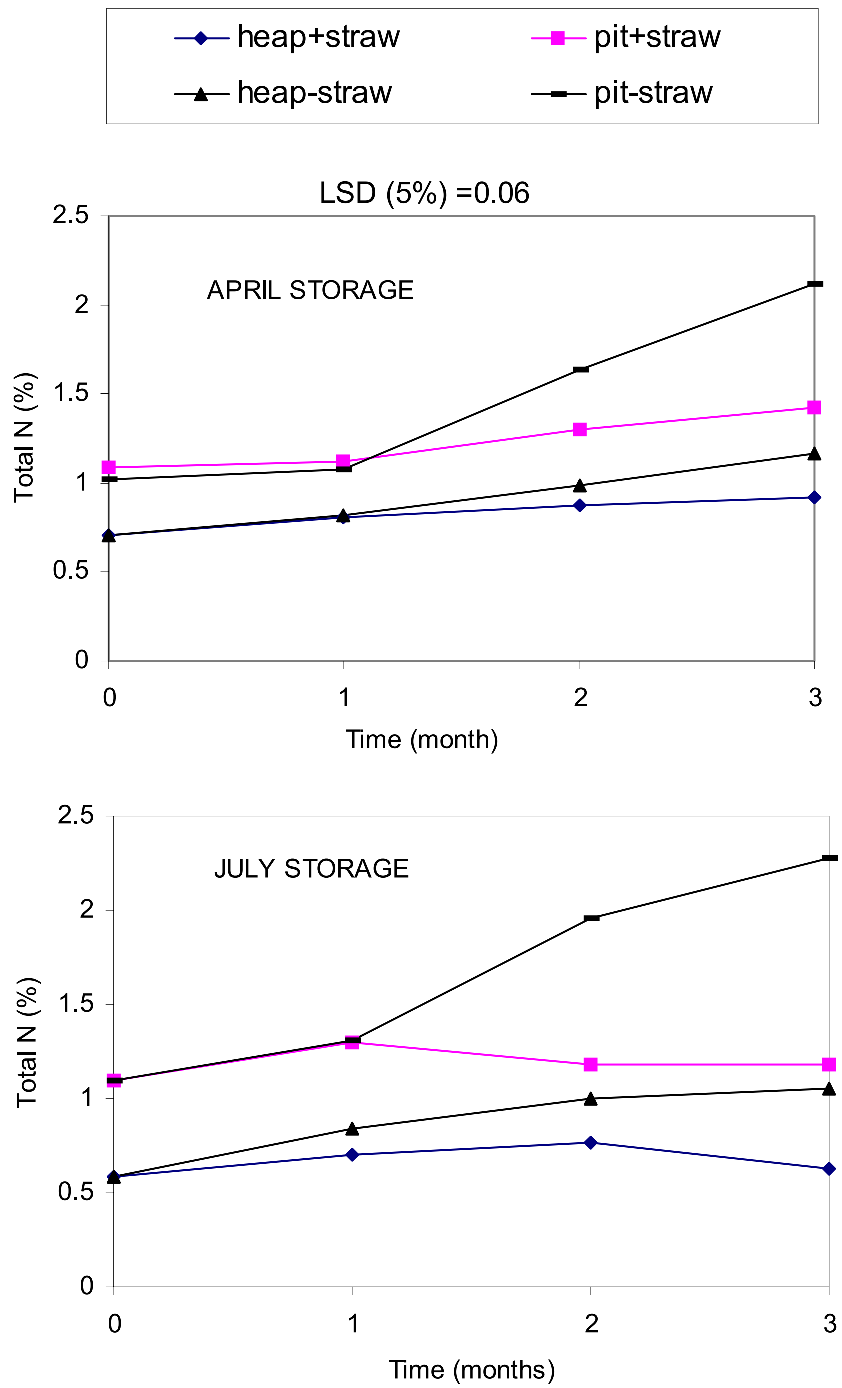


Figure 4.1. Total N response to method of storage, crop residue incorporation and duration of storage during manure decomposition.

NH_4^+-N and NO_3-N Changes During Storage

A substantial increase in the NH_4^+-N concentration was found under anaerobic conditions in treatments without straw. This amounted to 225 *u*gg^{-1} for April systems and 380 *u*gg^{-1}for July treatments over a three-month incubation period. (Fig. 4.2). Ammonium concentrations in systems incorporated with straw amounted to 158 *u*gg^{-1} for April systems and 290 *u*gg^{-1} for July storage treatments. In general, the ammonium-N concentration increased with length of composting period particularly during the last 2 months of decomposition. In contrast, the concentration of NH_4-N in aerobically treated manures decreased and amounted to 50 *u*gg^{-1}for both April and July storage treatments with or without straw. There was no difference in ammonium-N levels in aerobic systems with and without straw.

The opposite scenario was observed for the nitrate-N, which was higher in aerobic manure composts than in anaerobic treatments (Fig. 4.3). The results also show increased nitrate concentrations with extra additions of straw. There was also an increase in NO_3-N concentration with length of composting during the last 2 months of storage. Highest NO_3-N concentrations amounting to 275 *u*gg^{-1}were recorded for the July aerobic treatments with maize straw. In contrast, anaerobically treated manures, showed a decrease in the nitrate concentrations, which amounted to less than 30 *u*gg^{-1}.

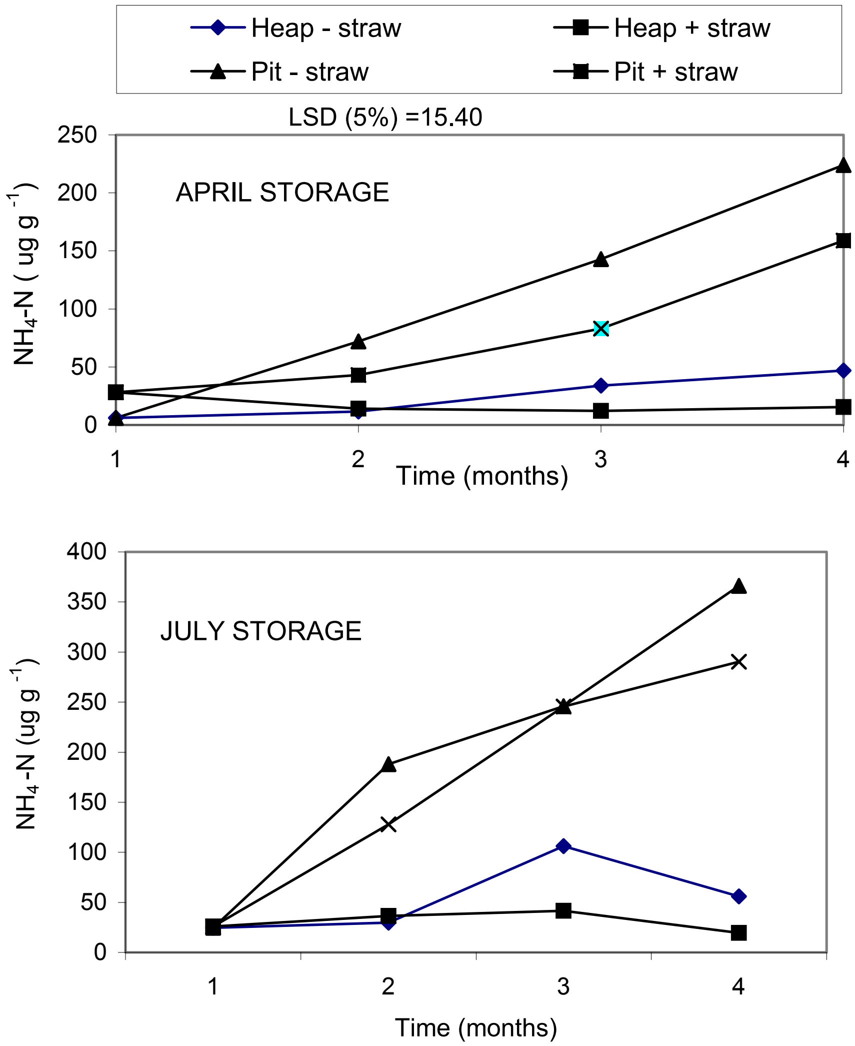


Figure 4.2. Ammonia-N response to method of storage, crop residue incorporation and duration of storage during manure decomposition.

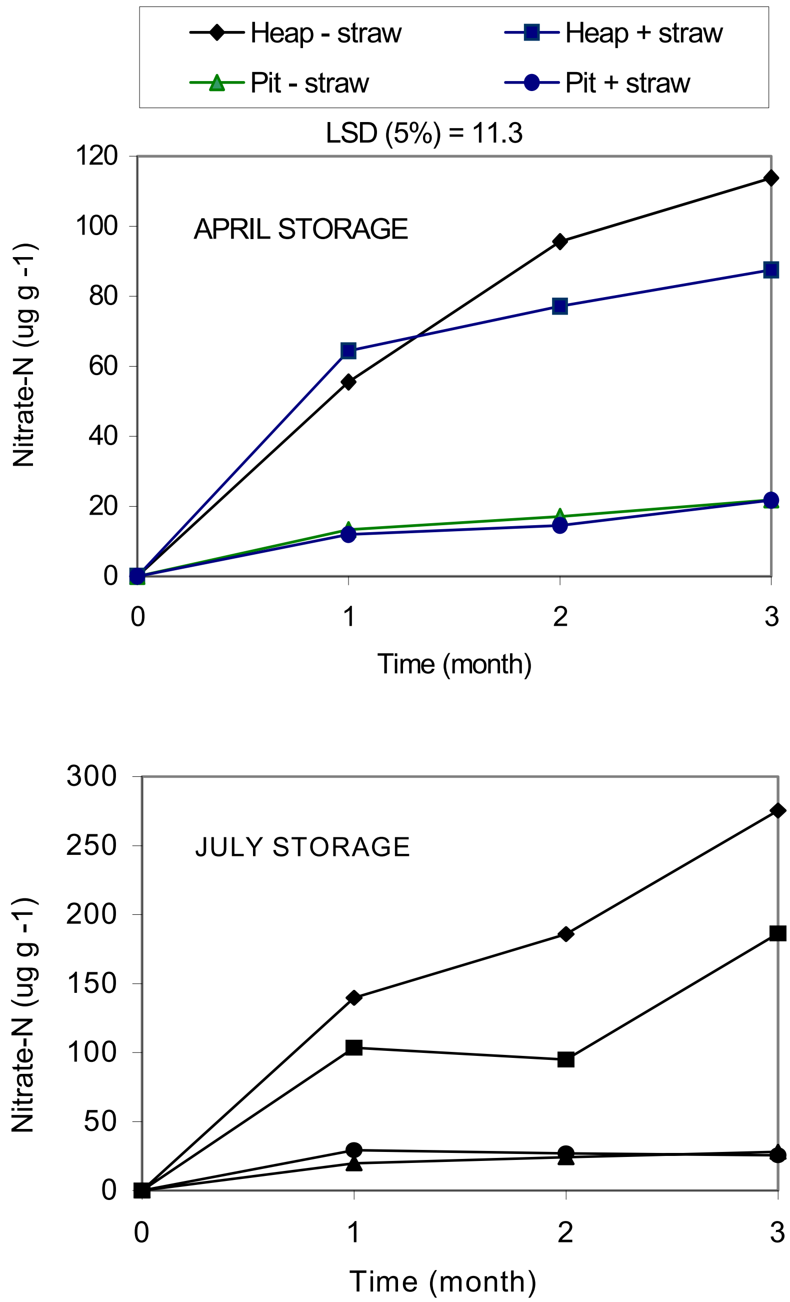


Figure 4.3. Nitrate-N response to method of storage, crop residue incorporation and duration of storage during manure decomposition.

Ammonia Losses and pH Changes from Aerobic and Anaerobic Manures

Cumulative ammonia losses during aerobic and anaerobic composting are shown in Fig. 4.4. Amounts volatilised were significantly different (P<0.01) between aerobic and anaerobic manure composts with highest amounts of ammonia measured in aerobic manure composts incorporated with maize residues. The total NH_3 losses over 3 months amounted to 40 *u*g g^{-1} in these systems compared to 22 *u*g g^{-1}in treatments without maize residues. Major losses occurred between the last two months of storage. Under anaerobic conditions, the volatilisation of ammonia was less than 8 *u*g g^{-1} (Fig. 4.4). Significantly higher losses (P<0.01) were measured from July storage systems than from storage treatments set in April particularly in aerobic treatments. Nitrogen losses were significantly increased (P<0.01) by incorporation of straw in storage systems. This was particularly amplified in aerobic manure compost.

The initial pH ($CaCI_2$) of the manures prior to storage was 7.9. Under anaerobic decomposition, acid conditions prevailed. The pH was maintained below 7 for both April and July storage systems. The opposite trend was observed under aerobic storage systems. In these systems, alkaline pH regimes (pH > 7) were consistent throughout the composting period. The pH increased from 7.9 to 8.3 for April storage systems and from 7.6 to 8.5 for July treatments. These results are presented in Fig. 4.5.

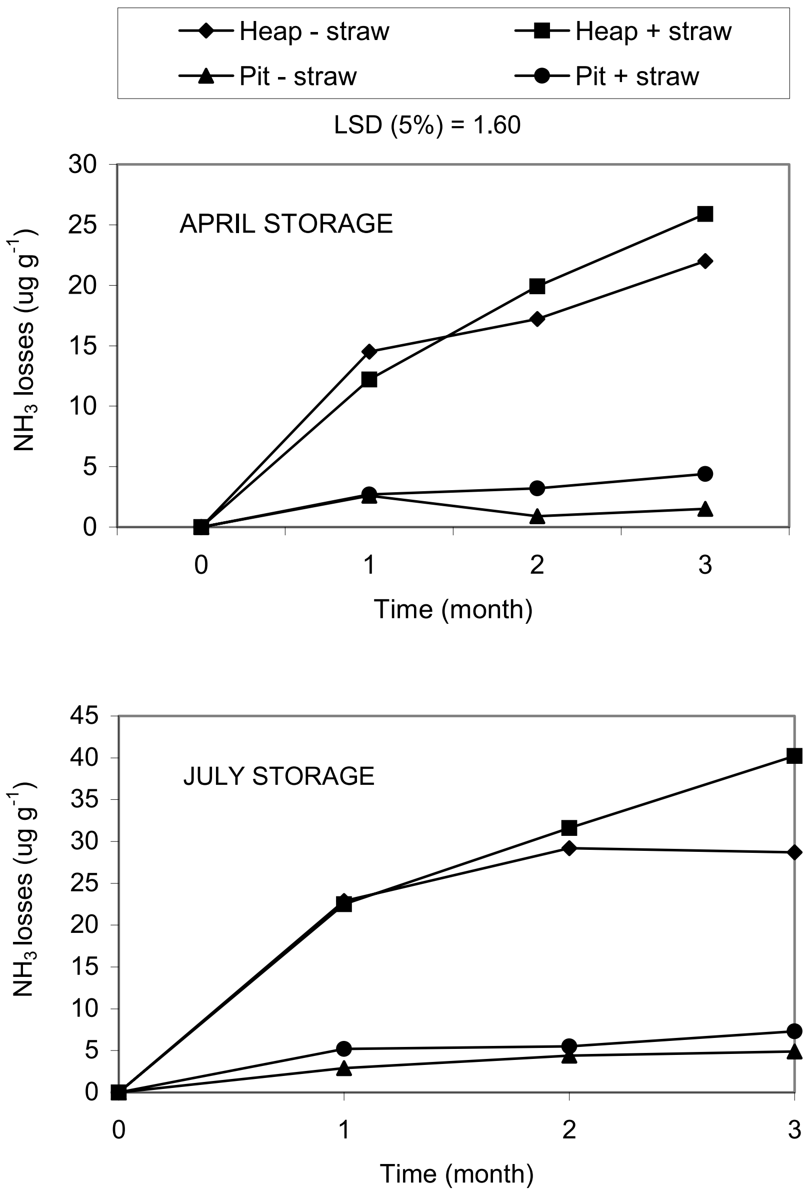


Figure 4.4. Ammonia losses as affected by method of storage, crop residue incorporation and duration of storage during manure decomposition.

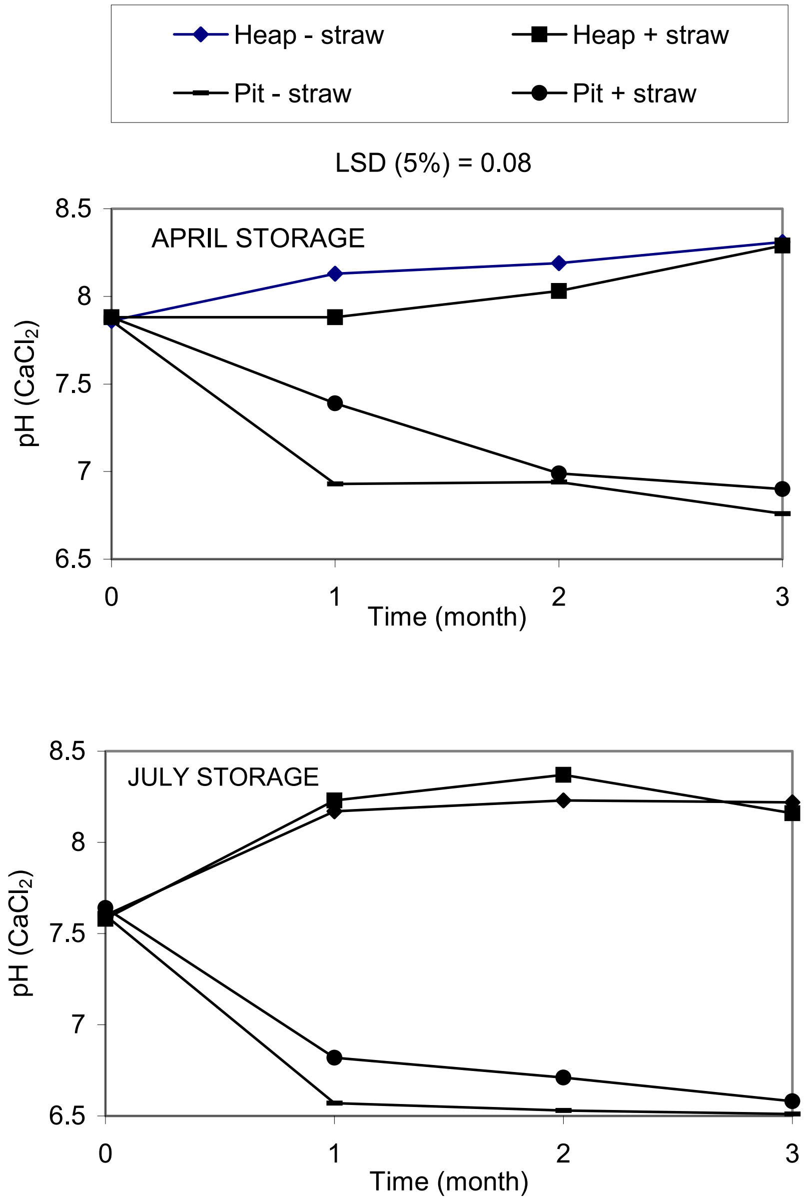


Figure 4.5. pH response to method of storage, crop residue incorporation and duration of storage during manure decomposition.

Generally an increase in pH was accompanied by an increase in ammonia losses. This was particularly noticeable for April aerobic storage systems right throughout the decomposition period and within the first two months of storage for July aerobic treatments. In contrast, in anaerobic systems, there was a rapid initial drop in the pH value within the first month, which was maintained below 7 throughout the decomposition period.

Effect of Storage Conditions On Moisture Levels

Figure 4.6 shows moisture levels during the course of aerobic and anaerobic decomposition of manures. There was a significant reduction in moisture levels ($P<0.01$) throughout the decomposition period in aerobically treated manures than in anaerobic manure composts, which lost their moisture gradually. Extra additions of straw were accompanied by a rapid moisture loss.

In aerobic treatments with maize straw, the initial moisture content of 51% was reduced to 22% at the end of the decomposition period for April treatments and from 47% to 9% for July treatments. In contrast, moisture was lost gradually during anaerobic decomposition (Fig. 4.6). Drying effects were more pronounced in aerobic systems due to exposure of storage systems. There was also a strong correlation between ammonia losses and water loss ($r^2=0.91$), the maximum flux occurred in the last 2 months of storage when moisture evaporation was greatest (Figures 4.4and 4.6).

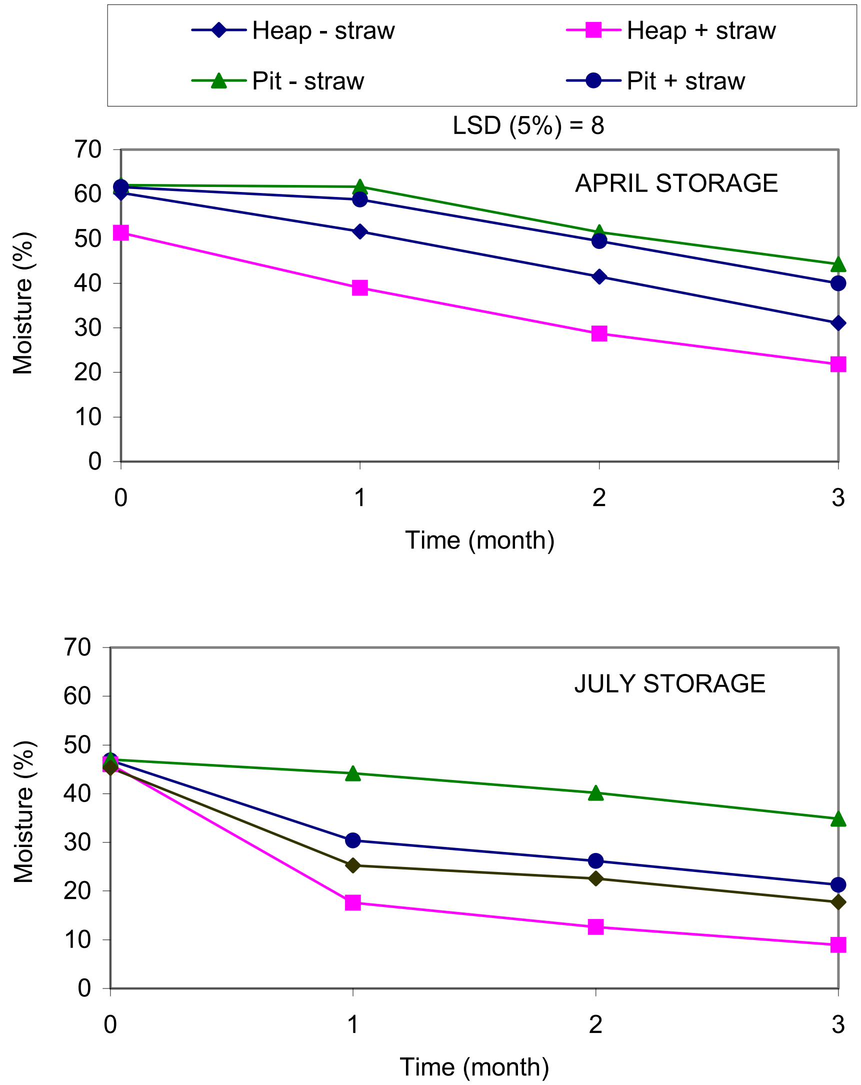


Figure 4.6. Moisture response to method of storage, crop residue incorporation and duration of storage during manure decomposition.

Effect of length of composting on quality of the manure

There were considerable differences in N concentrations with duration of storage. This was particularly observed with the readily available N (NH_4-N) which decreased with prolonged composting. The storage of manure in the pit without straw in April reduced the NH_4-N by 36% than in July. A 60% decrease in the NH_4-N concentration was found after pit manures with straw were composted in April than in July.

4.4 Discussion

The type of storage conditions influenced the magnitude of losses and the form in which N was available in the end product. The significantly low NH_3 losses found under pit storage system can be explained by the anaerobic conditions, which prevailed under limited oxygen supply in the pit. This resulted in mineralisation of organic acids leading to decreases in pH values below 7 found in this study. Other factors that could have contributed to accumulation of acids include increases in the concentration of the water soluble NH_4^+-N than in aerobic composts. Under acid conditions, the NH_4^+-N ion is predominantly in the ionic form and the activity of the hydroxyl ions is retarded. This effectively reduces the concentration of NH_3 in the aqueous phase to effect volatilisation and the conservation and retention of N in the system. Low N losses were also made possible by the tight covering of the manures, which prevented water produced from decomposition processes from evaporating and drying. These findings were also reported by several workers (Kirchmann and Witter, 1989; Martins and Dewes, 1992; Eghball *et al.,* 1997; Petersen et al., 1998 and Thomsen, 2000).

Inorganic N occurred predominantly as NH_4^+-N in anaerobic manures and as $N0_3$-N in aerobic manures. This possibly resulted from urea hydrolysis to NH_4^+-N. The mineralisation of the organic N in the excreta under anaerobic conditions would also increase the proportion of NH_4^+-N found in these manures as shown by Kirchman and Witter (1992) and Thomsen (2000).

The availability of inorganic N of anaerobic manures in the form of NH_4^+-N might be advantageous as NH_4^+ is not subject to leaching. This is because the NH_4^+ ion can be fixed within the clay lattice of some 2:1 clays (e.g. vermiculate) or held on cation exchange sites. Such soils might need a higher application rate of manure, since the fixed NH_4^+ becomes slowly available overtime. Knowledge on N uptake requirement will enable appropriate additions of N in a manner that will be synchronous with crop uptake. In soils with a 1:1 clay lattice such as sandy soils, NH_4^+ can be lost via leaching due to low CEC, thus reducing the potential nutrient value of the manure.

The low $N0_3$-N levels found in anaerobic manures are due to low nitrification, because of acidic conditions and partial inhibition of nitrifiers by ammonia due to unavailability of oxygen under anaerobic conditions. In aerobic composting, a greater proportion of N was lost due to exposure of the manure to the environment. Exposure of manure surfaces resulted in air supply in the system that was sufficient to cause N-releasing decomposition processes such as oxidation of organic N compounds. The former could have partially released CO_2 enriching the bases in manure, causing the presence of ammonia hydroxide in solution and a subsequent increase in pH with losses (Archaya, 1935; Groenestein, Oosthoek, and van Fassen, 1993; Vlek and Stumpe, 1978). Further, heat derived from the composting process might have increased in the manure heap causing high decomposition rates and further nutrient losses. These results are in agreement with those reported by other workers (Karlsson and Jeppsson, 1995; Musa, 1975; Poincelot, 1975; Thomsen, 2000).

There were clear and consistent differences in the ammonia losses measured in treatments incorporated with and without straw. The previous study (Chapter 3) demonstrated that the use of straw during handling resulted in the immobilisation of N and relatively low NH_3 losses. However, in this study further incorporation of straw prior to storage increased the magnitude of losses in both aerobic and anaerobic manure systems. This might suggest that the use of straw during the manure management cycle should be limited to the handling stage.

There are a number of possible explanations to the increases in the magnitude of NH_3 volatilisation with additions of straw at the point of storage. High straw additions not only make carbon sources available for microorganisms but also reduce the water content of the manure-straw mixture. This results in increases in air-filled pores which leads to better conditions for aerobic microbial decomposition and a higher subsequent delivery capacity of NH_3.

Extra straw additions might have led to increases in temperature of the decomposing manure through microbial self-heating processes, resulting in high NH_3 vapour pressure and subsequent ammonia losses as was reported by Dewes (1996).

The results from the present study also suggest that the amount of N losses and quality of manure depends on length of composting. There were better gains in NH_4^+-N concentrations from storage systems established in July than in April. This implies that the availability of N in manure declines with age of the manure. The longer the storage time, the greater the potential volatilisation loss of manure-N. This reduces the value of the manure as a source of N as nutrients available cannot meet crop and soil requirements and additions of synthetic fertilisers would be required to offset the N deficit in April treated manures. Other studies have reasoned that more readily decomposable organic N forms can be converted to stable forms with ageing of manure resulting in small amounts of inorganic N (Kirchmann, 1985).

4.5 Conclusion

The study has shown that storage conditions can influence the magnitude and extent of N losses through NH_3 volatilisation and subsequently quality of the resultant manure. Ammonia volatilisation was directly related to pH of the system and occurred at pH greater than 7. Low oxygen concentrations under anaerobic conditions minimised accumulation of NH_3 and induced an acidic regime which effectively reduced volatile N losses. From the study, it is clear that the potential of losses can be enhanced by aerobic storage conditions. An increase in the hydroxyl concentration stimulated an alkaline regime and higher concentration of NH_3 in the system, which was volatilised due to exposure of aerobic storage system to the environment.

Anaerobic decomposition of manure for 3 months was found to be more beneficial in terms of mineral N concentrations. By improving the quality of manure by 0.1% N, anaerobic manure can provide an extra 10 kg N at application rates of 10 tha^{-1}. This implies that application of anaerobic manure enhances farmer's investment returns in soil fertility. Accumulation of NH_4^+-N under anaerobic storage conditions might imply that the manure could be advantageous to farmers in low input agricultural systems. This is particularly so for soils with a 2:1 clay lattice where NH_4^+ can be fixed reducing leaching. However in soils with 1:1 clay lattice (low CEC) leaching after application of the manure can be enhanced due to poor retention of NH_4^+.

The use of crop residues during storage did not reduce losses in this study. Farmers should therefore be encouraged to pit store manure without adding extra straw. However, N losses during application and spreading might offset the potential benefits from the readily available N from anaerobic manure. It therefore becomes necessary to determine which placement method is efficient in reducing losses during application, for efficient utilisation of anaerobically decomposed manure. It would also be necessary to test the efficacy of the different manures in improving crop yields before the technology can be adopted on a large scale. These aspects are dealt with in Chapters to follow.

CHAPTER 5

NITROGEN MINERALISATION FROM AEROBICALLY AND ANAEROBICALLY TREATED CATTLE MANURES

5.0 Abstract

Incubation studies using the leaching tube method were conducted over 77 days to determine the effect of aerobically and anaerobically pretreated manures stored in April and July, with or without straw on N release patterns. Results showed significant variations ($P<0.05$) in the decomposition of manures from different storage conditions. The dynamics of N mineralisation were described by first order kinetics with high correlation of determination (R2 = 0.939 – 0.990). In general, the course of N turnover from aerobic manures was a slow linear immobilisation pattern. Curve fits for anaerobic manures suggested two different phases of N mineralisation, a rapid exponential initial immobilisation phase and a slow linear mineralisation phase. Straw effect was significant ($P<0.05$) particularly for July anaerobically treated manures.

The rate constants followed the following pattern: JP- (0.068 N day $^{-1}$) > JP+ (0.058 N day $^{-1}$) > AP- = AP+ (0.05 N day $^{-1}$) > JH- (0.038 N day $^{-1}$) > JH+ (0.028 N day $^{-1}$) > AH-= AH+ >0.00 N day $^{-1}$). After 77 days of incubation, N mineralised generally followed a similar pattern and ranged between 0 – 30.65%. It was concluded that in spite of the initial immobilisation that occurred in soil with anaerobically treated manures, mineralisation occurred close to the rapid crop growth stage reflecting that the manure-N could be synchronised with crop N demand in the short term. The negligible N mineralised from aerobically treated manures suggests that the release of N from these manures may be asynchronous with maize crop N requirements in the short term. It was assumed that the N that remained in organic bound form could be available in the residual years.

5.1 Introduction

During storage and before application to the soil, manure may undergo aerobic and anaerobic decomposition (Kirchmann and Witter 1992; Thomsen 2000). The decomposition processes not only influence N losses during storage but also the character of the end product. Aerobic decomposition generally accounts for reduced value of the manure as a source of N. Easily decomposable compounds used up during aerobic decomposition result in high stability of the manure. However, during anaerobic decomposition formation of low-molecular-weight compounds such as volatile fatty acids have been observed (Eghball; 1997; Petersen *et al.;* 1998; Thomsen 2000).

It has been shown that the out-come of microbial-activities (i.e. mineralisation/immobilization processes) after application of manure to soil, may affect nutrient availability from manures of different storage systems in the short and long term. The dynamics of C and N mineralisation of organic manures in soils have been described by first-order reaction kinetics (Chae and Tabatabai, 1986).

Previous studies on N mineralisation of manures in soils have been concerned with aerobically decomposed manures. The purpose of this study was to establish nutrient release patterns and N mineralisation rates from aerobically and anaerobically decomposed manures and their implications for nutrient availability in cropping systems. The study was based on the hypothesis that manures from aerobic and anaerobic storage systems will result in different N release patterns, which will influence availability of N for the crop in the short and long term.

5.2 Materials and methods

Soil and Manures

The experimental soil was collected from a site in Murewa. The soil was a deeply weathered and leached loamy sand with 4% clay, 4% silt, 92% sand and a pH of 4.5 ($CaCl_2$) classified as a Haplic Lixisol (FAO), Nyamapfene, (1991). The soil was air dried and passed through a 2 mm sieve and analysed for organic C using the modified Walkely and Black Method (Nelson and Sommers, 1982 and total N using the micro or semi-micro Kjeldahl procedure (Bremner and Mulvaney, 1982).

Manures from Nhapi, Musegedi and Mukudu farms in Murewa were investigated. The manures were obtained from four storage treatments namely:

1. pit manure with straw
2. pit manure without straw
3. heap manure with straw
4. heap manure without straw.

The manures had been composted in April and in July. The chemical composition of these manures is presented in Tables 5.1, 5.2 and 5.3. The manures were air-dried and passed through a 2mm sieve prior to use in this study.

Incubation procedure

The aerobic leaching tube mineralisation method (modified from Stanford and Smith, 1972) was used in this study. This method was employed to reduce the number of tubes that would be required if the static method was to be used. An added advantage of the leaching tube method is that it mimics the field situation where N is constantly removed from the soil crop system through crop uptake and leaching. The tubes can also be used over a long period without experiencing problems of accumulation of N and other toxic products of decomposition (Bremner, 1965; Stanford and Smith, 1972). One disadvantage of the leaching tube is that, it removes the soluble carbon, which drives the mineralisation process.

The leaching tubes consisted of a plastic transparent cylinder (200ml by volume) with a hole (0.5mm diameter) at the bottom. A narrow glass tubing (10cm long) was inserted at the base through the hole to allow drainage and secured with plasticine at the base. A glass wool 3 cm thick was placed at the base of the tube to prevent movement of soil-manure particles from draining out of the tube. Ten grams of acid washed sand was added on top of the glass wool before adding soil-manure mixture to ensure even distribution of suction. A further 10g of acid washed sand was added at the top of the soil-manure mixture to avoid movement of particles upon pouring leaching solution. A mass of 100g of soil was placed in each glass jar. This was mixed homogeneously with 8 different manures applied at quantities equivalent to 60 kg N/ha and transferred into leaching tubes. A set of control tubes with 100g of soil only was added. All treatments were replicated 4 times. To reduce moisture loss, a pierced aluminum foil was placed on top of the tube covering it loosely. After each leaching event, moisture content was adjusted using a mild suction to bring the water content of each tube to 70% of water holding capacity (WHC). Incubation was conducted in a constant temperature room at 25^{o}C.

Sampling

The tubes were leached at day 0 to remove background mineral N. They were then leached on day 3, 7 and every week thereafter for a period of 11 weeks. The tubes were leached with 100ml of a leaching solution in two 50ml aliquots and the leachates collected in conical flasks. The leaching solution contained 1mM $CaCl_2$, 1mM $MgSO_4$, 0.1 M KH_2PO_4 and 0.9 mM KCI. At each leaching date, moisture content was adjusted to 70% of WHC.

Concentrations of mineral N (NH_4-N plus NO_3-N) in the leachates were measured immediately after sampling using the micro Kjedhal N method (Bremner and Mulvaney, 1982). The mineralisation of manure nitrogen was determined by subtraction of the amount of inorganic nitrogen mineralized in the soil (control) from total inorganic N amounts mineralized in the soil-manure mixture.

Statistic analysis

Various non-linear regression models were applied to the cumulative N mineralisation N. The models were run using the General Linear Models procedure in Genstat. The model offering the most appropriate description of the data were selected on the basis of residual sum of squares left unexplained by the regression. The models employed are described in

Table 5.1. A non-linear least square regression programme was used to evaluate potential mineralisable N and rate constants.

Table 5.1. Kinetic functions for the fitting of cumulative experimental data by regression.

Type or function	Integral form	Processes described
Zero-order	$M = I + k\,t$	Linear mineralisation Linear immobilisation
First-order	$M = I + M_E\,(1-e^{-k\,t})$ $M = I + M_E\,(e^{-k\,t})$	Exponential mineralisation Exponential immobilisation
First-zero-order	$M = I + M_E\,(1-e^{-k\,t}) + (100 - M_E)\,k_L\,t$	Exponential/linear mineralisation
	$M = I + M_E\,(e^{-k\,t}) + (100 - M_E)\,k_L\,t$	Exponential immobilisation /linear mineralisation

(M = nitrogen; I = intercept; M_E = percentage of exponetially mineralised/immobilised fraction; k, k_E, k_L = rate constants; t =time)

5.3 RESULTS

Chemical composition of manures

Anaerobic manures were significantly ($P<0.05$) higher in total N concentrations than aerobic manures. A greater proportion of the total N in these manures was present in the form of NH_4-N and this differed significantly ($P<0.05$) from aerobic manures. The C/N ratio for Mukudu and Musegedi anaerobic manures was significantly higher than aerobic manures. These results are presented in Tables 5.2, 5.3 and 5.4 respectively.

Table 5.2. Selected chemical properties of manures from Mukudu farm in Mangwende Communal Area.

Storage Treatment	Lignin (%)	Nitrogen (%)	Carbon (%)	NH_4-N (mg/kg)	C/N ratio
JH-	1.32e	1.00d	9c	285d	9fg
JH+	5.31d	0.90de	7.8c	255de	8.6g
JP-	6.41d	1.86a	25.5ab	560a	14b
JP+	10.92b	1.48b	27.8a	400b	18.9a
AH-	0.41e	0.70ef	7.2c	230e	10.2f
AH+	1.68e	0.62f	7.8c	202e	12.5e
AP-	14.59a	1.22c	18.6b	335c	15.2b
AP+	8.37c	1.14c	19b	320c	16.6b

Means within each column with the same letter are not significantly different at P=0.05.

J = July storage   + = with straw   H = heap manure (aerobic)
A = April storage   - = without straw   P = pit manure (anaerobic)

Table 5.3 Selected chemical properties of manures from Musegedi farm in Mangwende Communal Area.

Storage Treatment	Lignin (%)	Nitrogen (%)	Carbon (%)	NH_4-N (mg/kg)	C/N ratio
JH-	3.75ef	0.88de	9d	205c	10.2d
JH+	6.67d	0.96d	11.9cd	155cd	12.3cd
JP-	16.11b	1.84a	28.2a	395a	15.3b
JP+	13.79b	1.54b	30a	345a	19.5a
AH-	1.5f	0.76ef	8.7d	145de	11.5cd
AH+	19.87a	0.64f	7.5d	115e	11.7cd
AP-	9.92c	1.18c	18.6b	300a	15.6b
AP+	8.37cd	1.12c	18.9b	270b	16.9b

Means within each column with the same letter are not significantly different at P=0.05.

J = July storage + = with straw H = heap manure (aerobic)
A = April storage - = without straw P = pit manure (anaerobic)

Table 5.4. Selected chemical properties of manures from Nhapi farm in Mangwende Communal Area.

Storage Treatment	Lignin (%)	Nitrogen (%)	Carbon (%)	NH_4-N (mg/kg)	C/N ratio
JH-	15.85a	1.04de	9e	148d	8.7d
JH+	2.99c	0.84e	8.6e	132def	10.2cd
JP-	11.9b	2.22a	35a	335a	15.7ab
JP+	12.55ab	1.5b	27b	304b	18a
AH-	4.12c	0.76ef	7.2e	125ef	9.5d
AH+	4.36c	0.66f	7.5e	115f	11.3cd
AP-	9.92b	1.18c	15.6d	289b	13.2bc
AP+	11.91b	1.06cd	17c	230c	16a

Means within each column with the same letter are not significantly different at P=0.05.

J = July storage + = with straw H = heap manure (aerobic)
A = April storage - = without straw P = pit manure (anaerobic)

Net N mineralisation

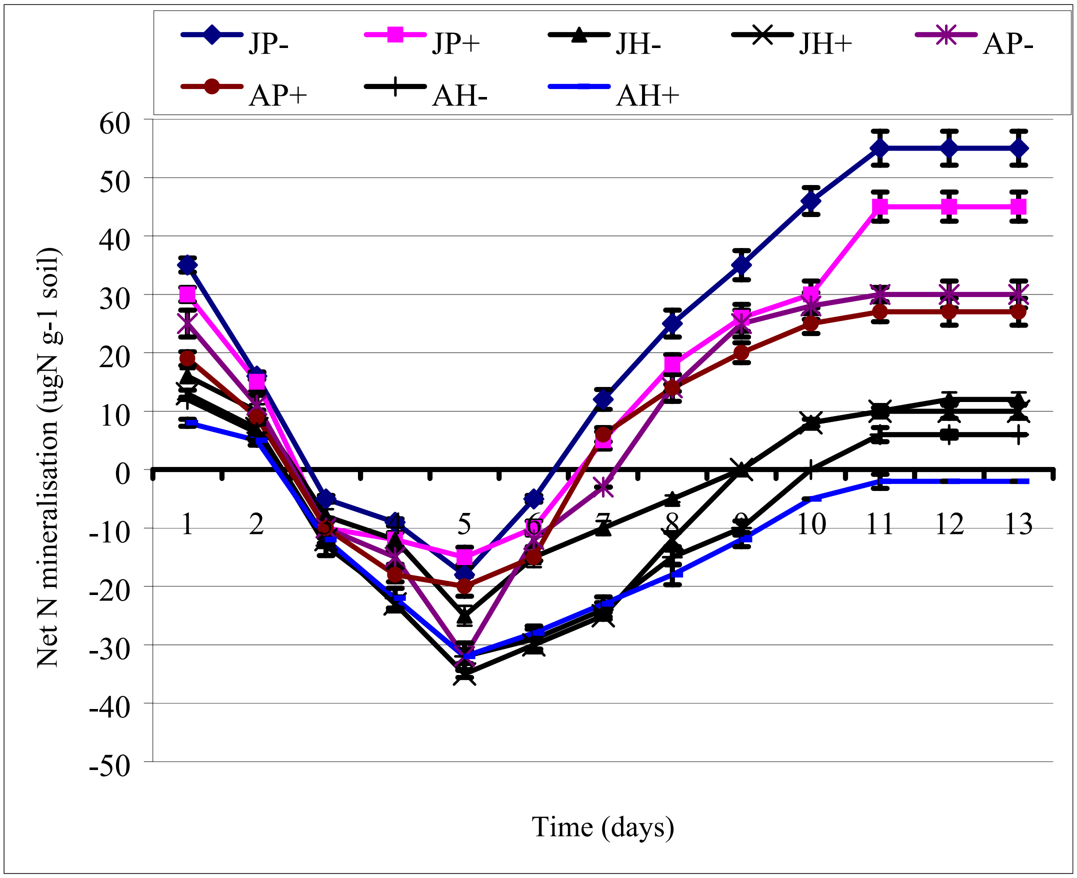
The course of mineralisation/immobilisation significantly differed ($P<0.05$) according to the different storage treatments applied to the manure samples prior to incubation. The mineralisation of anaerobic manures resulted in significantly ($P<0.05$) higher net N mineralisation than aerobic manures. In general, there were also significant month * straw and straw * storage method interactions ($P<0.05$). Straw effect was significant ($P<0.05$) and amplified in anaerobic manures in July. Nitrogen release from manures with straw amendments was significantly ($P<0.05$) lower than manures without straw amendments. These trends were observed for Mukudu, Musegedi and Nhapi manures (Figures 5.1, 5.2 and 5.3).

Mukudu anaerobic manures resulted in shorter periods of rapid initial immobilisation phase lasting between 4 and 5weeks (Fig 5.1) and 5 to 6 weeks for Musegedi (Fig 5.2) and Nhapi (Fig 5.3) manures. In general, the immobilisation period was increased in manures amended with straw. Mukudu aerobic manures amended with and without straw resulted in immobilisation, which lasted more than 7 weeks. A similar trend was observed for Musegedi manures without straw amendments stored in July. The remainder of aerobic manures immobilised till the eighth week after incubation with the exception of all April treated Musegedi manures and that with straw from Nhapi which, immobilised till the end of the experiment. (Figures 5.2 to 5.3).

Mukudu anaerobic manures without straw composted in July released 58 ugN^{-1}g soil of mineralisable N which was significantly ($P<0.05$) higher than similar manures with straw amendments (48 $ugN^{-1}g$ soil) at 11 weeks. April anaerobic manures from the same farm amended with and without straw released 25 and 30 *u*g N g^{-1} soil of mineralisable N at 11 weeks. There were no significant ($P>0.05$) differences in net N release between these treatments. Aerobic manures achieved a net N mineralisation of less than 15 *u*g N g^{-1} soil for manures from this farm (Fig 5.1). There were significant differences ($P<0.05$) in net N mineralisation between aerobic and anaerobic manures.

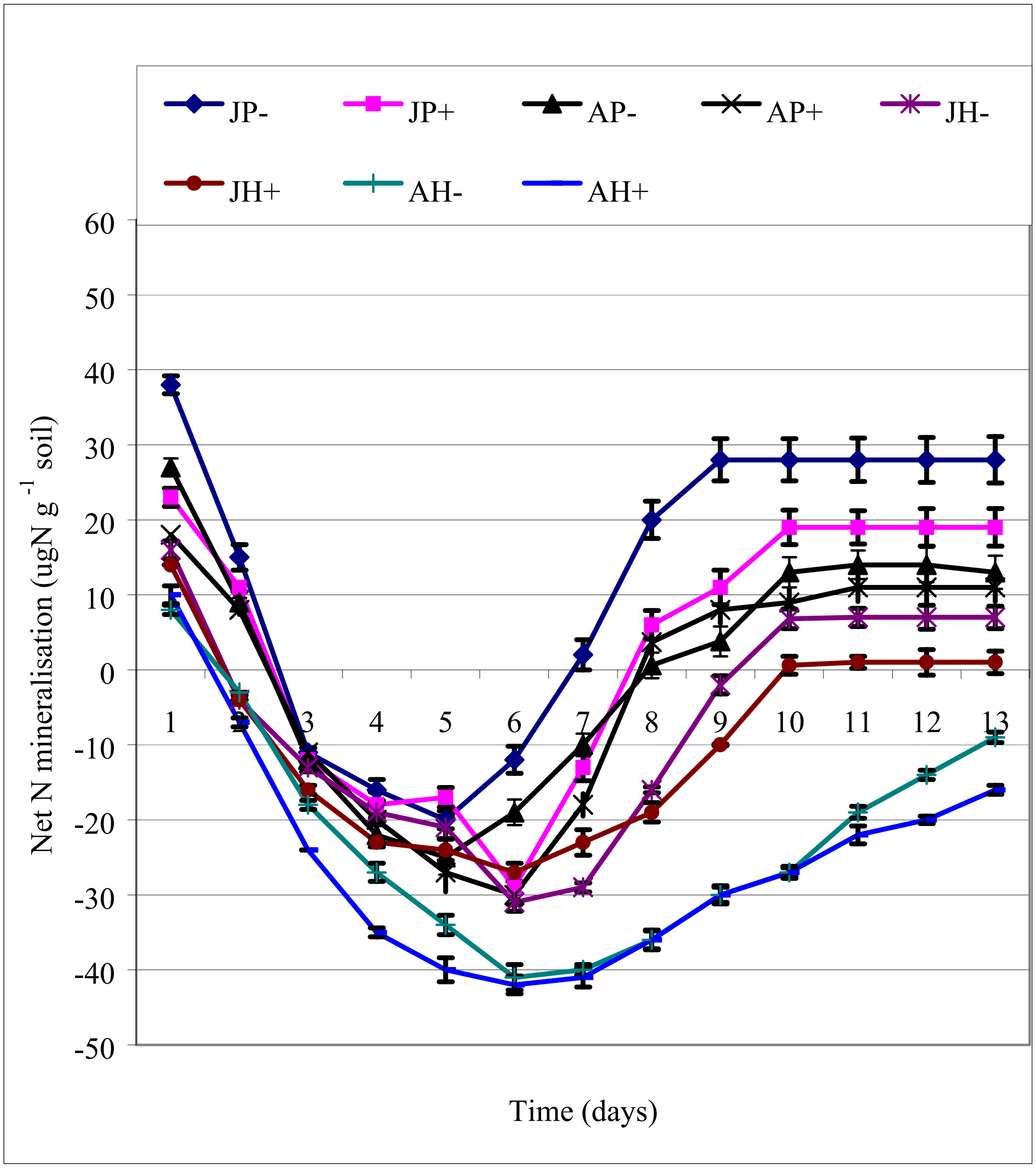
Musegedi anaerobic manures amended with straw and stored in July released 20 *u*g N g^{-1} soil of mineralisable N at 11 weeks which was significantly ($P<0.05$) lower than similar manures without straw amendments (28 *u*g N g^{-1} soil). Manures stored in April without straw released not more than 15 *u*g N g^{-1} soil of mineralisable N. There were significant ($P<0.05$) differences in net N release between aerobic manures stored in April and July. No N was released from April aerobic manures. Results suggest significantly ($P<0.05$) high N release from treatments with anaerobic manures without straw amendments stored in July (Fig 5.2).

Nhapi anaerobic manures amended with straw and stored in July released 18 *u*g N g^{-1} soil of mineralisable N. Similar manures without straw amendments released 28*u*g N *u*g N g^{-1} soil of mineralisable N. Differences between the two treatments were apparent ($P<0.05$). There were no significant differences ($P>0.05$) in mineralisable N between anaerobic manures stored in April. Less than 5*u*g N g^{-1} soil of mineralisable N was released from aerobic manures at 11 weeks with the exception of April stored manures with straw amendments which immobilised throughout the decomposition period. (Fig 5.3).



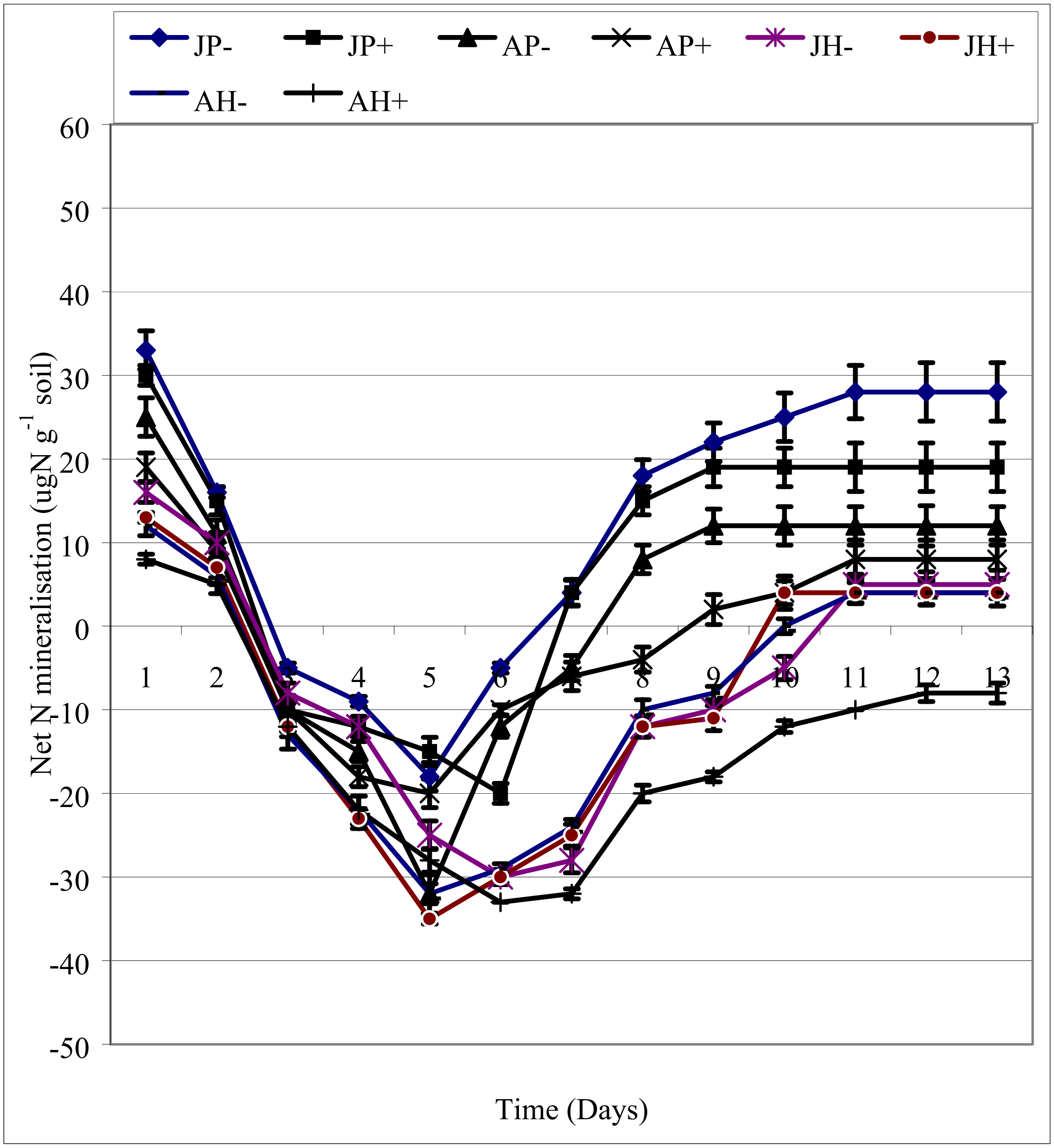
J = July storage + =with straw - = without straw
A = April storage H = heap manure (aerobic) P + pit manure (anaerobic)

Figure 5.1. Net N mineralisation from aerobic and anaerobic manures from Mukudu farm. Data excludes soil.



J = July storage + =with straw - = without straw
A = April storage H = heap manure (aerobic) P + pit manure (anaerobic)

Figure 5.2 Net N mineralisation from aerobic and anaerobic manures from Musegedi farm. Data excludes soil.

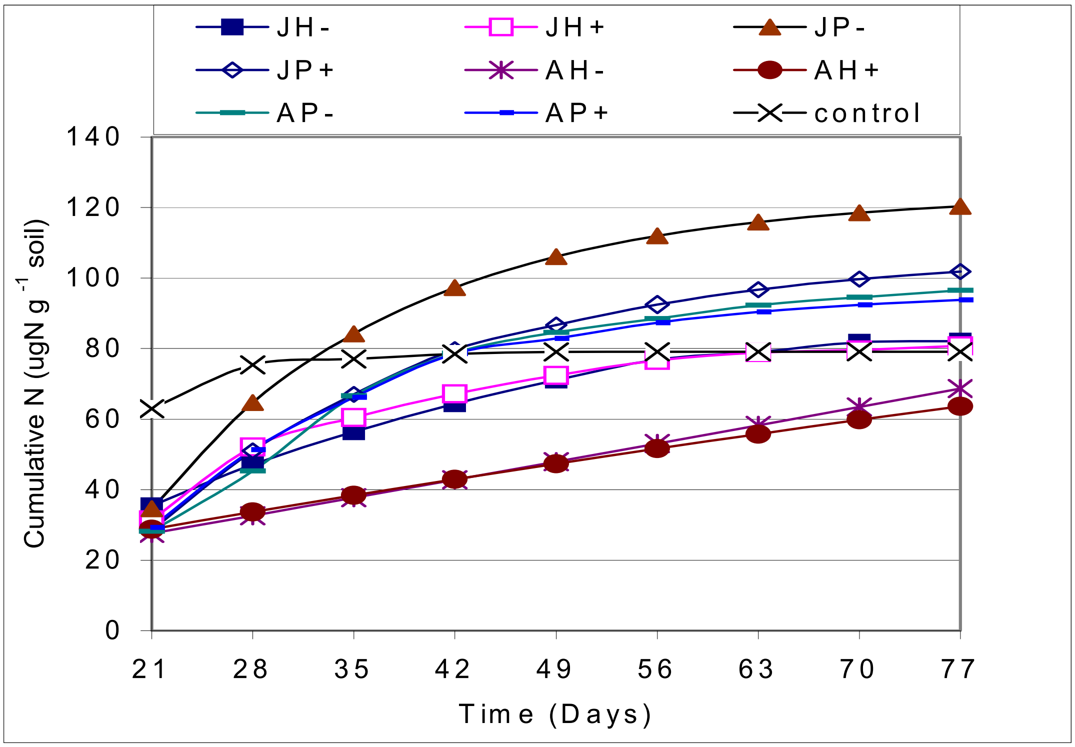


J = July storage + =with straw - = without straw
A = April storage H = heap manure (aerobic) P + pit manure (anaerobic)

Figure 5.1. Net N mineralisation from aerobic and anaerobic manures from Mukudu farm. Data excludes soil.

Cumulative N mineralisation

The cumulative N curves of aerobic and anaerobic manures were fitted to different kinetic functions. The first order kinetic function best described the release of mineral N from the manures (Fig. 5.4). Good fits were obtained as indicated by the high coefficient of determination, which varied from 0.939 to 0.990 (Table 5.5).



J = July storage + = with straw H = heap manure (aerobic)

A =April storage - = without straw P = pit manure (anaerobic)

Figure 5.4. Cumulative N mineralisation of aerobic and anaerobic manures. Lines represent the curve-fitting result. Symbols are experimental data (n=3).

Mineralisation was expressed as a percentage of the amount of total manure-N added. After 77 days of incubation, N mineralised showed the following pattern:

JP- (30.65%) > JP+ (25.59%) > AP- (22.75%) > AP+ (22. 60%) > JH- = JH+ =AH- = AH+ (0.00%). The order of percentages of total N that was mineralised over 77 days of incubation followed that of the rate constants for the slow mineralisation phase (Table 5.5).

Table 5.5. Nitrogen mineralisation/immobilisation kinetics in aerobic and anaerobic cattle manures mixed with soil (n=3).

Manure storage treatment	Course of N turnover	N min. (%)	Rate constant (day $^{-1}$)	R^2
JH-	Linear immobilization	-	0.038	0.969
JH+	Linear immobilization	-	0.028	0.945
JP-	Exponential; Imm; linear min.	30.65	0.068	0.990
JP+	Exponential; Imm; linear min.	25.59	0.058	0.984
AH-	Linear immobilisation	-	0.000	0.939
AH+	Linear immobilisation	-	0.000	0.942
AP-	Exponential; Imm; linear min.	22.75	0.050	0.984
AP+	Exponential; Imm; linear min.	22.60	0.050	0.972

J = July storage + = with straw H = heap manure (aerobic)

A =April storage - = without straw P = pit manure (anaerobic)

Imm = immobilisation min. = mineralisation

In general, all aerobic manures followed a linear course for either nitrogen immobilisation or mineralisation. The decomposition of anaerobic manures followed a two-course pattern, first and initial exponential immobilisation followed by linear mineralisation. The rate constants were low for aerobic manures as shown in Table 5.5. The decomposition of anaerobic manures was characterised by two different phases, a rapid exponential initial immobilisation phase followed by a slow linear re-mineralisation phase.

The rate constants for the slow re-mineralisation phase exhibited the following pattern: JP- (0.068 N day $^{-1}$) > JP+ (0.058 N day $^{-1}$) > AP- = AP+ (0.05 N day $^{-1}$) > JH- (0.038 N day $^{-1}$) > JH+ (0.028 N day $^{-1}$) > AH-= AH+ >0.00 N day $^{-1}$).

5.4 Discussion

Immobilisation phase

Initial immobilisation effects by anaerobic pretreated manures were observed in this study. The reason appeared to be three-fold; the high C/N ratio greater than 15 found in anaerobic manures which was similar to that reported by Beauchamp and Paul, (1989), Bernal and Kirchmann, (1992) and Castellanos and Pratt, (1981). Secondly, high microbial activity, which causes a shift in microbial population from predominantly anaerobic bacteria resulting in a flush of readily available carbon and consequently more C utilisation for microbial proliferation (Thomsen and OsIen, 2000). Thirdly, the presence of energy-rich easily degradable C compounds by microorganisms such as volatile fatty acids (Spoelstra, 1979) (though not measured in this study), when a shift into aerobic conditions occurred. The work of Paul and Beauchamp, (1989) showed that volatile fatty acids in slurry can be oxidized within 4 days after amending soil with anaerobic manure together with a parallel immobilisation of NH_4-N. Earlier findings reported by Sims (1986) and Flowers and Arnold, (1983) found that up to 40% of NH_4-N in anaerobic manures can be immobilised.

Prolonged periods of N immobilisation in soil with aerobic manures can be attributed to the stability of the organic materials in these manures. This is because easily decomposable organic compounds are respired during aerobic composting phase (Sana and Soliva, 1987). For example, water-soluble and easily hydrolysable sugars are degraded during composting. Immobilisation of N was also possible with aerobic manures because a greater proportion of N was organically bound (Chapter 4).

These results imply that the application of aerobic manures to soil could induce N deficiency during rapid crop growth leading to depressed yields (Murwira and Kirchmann, 1993; Nyamangara *et al.,* 1999; Paul and Beauchamp, 1994). These workers found N release from aerobic manures to be asynchronous with maize crop N requirements. The results from this study have also been demonstrated in the work of Thomsen (2000), Hadas and Portnoy (1994) and Hadas *et al.* (1996). Their findings showed low N mineralisation rates for composted manures as reported in this study.

Re- mineralisation phase

In spite of the initial immobilisation, which occurred in soil with anaerobic manures, there was re-mineralisation of inorganic N with highest rate constants for July stored manures. More inorganic N was released than similar manures stored in April. These differences can be attributed to a decrease in mineralisation rates with length of storage as shown by Bernal *et al.,* (1998) and more readily decomposable organic forms were converted to stable forms with prolonged duration of storage (Castellanos and Pratt, 1981; Chaney, Drinkwater and Pettygrove, 1992; Kirchmann, 1985).

The results in this study contradict findings reported by Thomsen and Oslen, (2000) in which soils with anaerobic manures showed net immobilisation only after 266 days of incubation. Because of high microbial proliferation that occurs after application of anaerobic manures, these workers suggested that it might be more difficult to synchronise N release from anaerobic manures with crop N demand. However, in the present study, re-mineralisation of the inorganic N occurred close to the rapid crop growth stage between the fourth and sixth weeks after incubation. This implies that the release of N from these manures can be synchronised with crop N requirements.

Because of slow mineralisation rates found in soil after application of aerobic manures, crop yield potentials in the short term can be adversely affected. This implies that aerobic manures are only beneficial to the crop in the subsequent years after application (Tanner and Mugwira, 1984; Paul and Beauchamp, 1993, 1994).

5.5 Conclusion

There were significant variations in the decomposition of aerobic anaerobic manures amended with and without straw. Anaerobic manures with their high initial NH_4-N contents were found to have highest rate constants. The decomposition of anaerobic manures in soil almost always resulted in initial immobilisation. The immobilisation period was prolonged in manures amended with straw and by the duration of storage. In spite of the initial immobilisation of the inorganic N that occurred in soil with these manures, mineralisation occurred close to the rapid crop growth stage suggesting that N released could benefit the crop.

Little or no N was mineralised from aerobic manures. The implications are that these manures could be an inefficient source of fertiliser N for the crop in the short term. However the fertilising power effect of aerobic manures should not be over-valued. Other beneficial effects from the manure may be more important in enhancing soil quality. These include build up of soil organic matter (SOM) which improves direct physical and chemical effects where processes such as nitrate leaching and NH_3 volatilisation are altered by changes in soil structure, water holding capacity and soil surface chemistry. The high turnover of SOM will also contribute to biological effects where processes such as mineralisation/immobilisation and denitrification/nitrification are primarily altered via physical and chemical changes associated with SOM accumulation and redox status.

Further studies are required to determine N uptake, grain yield potentials and N recoveries in the field from manures similar to those investigated in this study. It will also be necessary to investigate the residual effects from applying the manures. Information about the relationship between N uptake data and soil incubation data; rate constants and N recoveries will be required to generate and widen the menu of options for efficient utilisation of manure N from manures of different quality.

CHAPTER 6

MAIZE RESPONSE TO NITROGEN IN MANURES FROM DIFFERENT STORAGE SYSTEMS

6.0 Abstract

A three-year field study was conducted to develop a better understanding of relative availability of manure N from different storage systems. Manures tested were either aerobically or anaerobically decomposed, with or without straw in April and July. They were applied at 3 sites in 1997/98. Residual N effects were assessed in 1998/99 and 1999/2000 seasons. In July 1998/99 season, validation experiments were undertaken but with an additional treatment on the method of incorporating straw in storage systems. In 1997/98 all treatments, which received anaerobically decomposed manures, resulted in significantly high N uptake and grain yield responses ($P<0.05$). Less than 28kg of N were taken up by the crop from aerobically composted manures, compared with 35 kg of N in the control. Highest grain yields obtained from applying anaerobically decomposed manure were 4.18t ha^{-1} in treatments without straw in July in comparison with 1.35t ha^{-1} from aerobically composted manures without straw. The application of manures with straw depressed grain yields by at least 20% in both types of manure but there was no significant difference between the method of incorporating straw in storage systems ($P>0.05$). There was an increased supply of N in subsequent seasons for aerobic manures resulting in significant grain yield increases ($P<0.05$) than anaerobic manures. It is concluded that the application of anaerobic manures can enhance maize grain yield in the short term. Overall grain yield benefits can also be realised from applying anaerobic manure without straw composted for 3 months. Supplemental N fertiliser is therefore recommended where aerobic manures are applied to the crop.

6.1 Introduction

Cattle manure is an important source of N in crop livestock systems of Zimbabwe. A large proportion of the manure is applied to land in maize (Zea mays L.). (Mugwira and Mukurumbira, 1984; Campbell, Kirchmann and Swift, 1998). Understanding the efficacy of manures from different storage systems is critical for their efficient utilisation hence, optimisation of maize productivity.

As storage conditions influence both decomposition processes during storage and microbial activity after application of the manure to soil, varying N mineralisation-immobilisation turnover may affect the availability of N for crop uptake (Kirchmann and Bernal 1997; Thomsen 2001). High recoveries of N from anaerobically decomposed manures have been observed in the year of application (Mugwira, 1984; Kirchmann, 1985; Paul and Beauchamp 1994; Thomsen 2001). N release from aerobically composted cattle manure was found to be asynchronous with maize crop requirement (Murwira and Kirchmann, 1993) and grain yields were reduced in the year of application compared with urea and liquid manure. However, residual values for aerobically composted manures were found to increase in subsequent years (Mugwira, 1984, Paul and Beauchamp, 1993, Thomsen 2001).

The purpose of this study was to test a menu of manure management options developed in the study, by determining the efficacy of aerobically and anaerobically decomposed manures presented in chapter 4. This study complimented results from the mineralisation/immobilisation experiment (Chapter 5) in as much as it provided information about manure N release and resulting crop responses in both short and long term. This information was critical for the efficient management of manures in integrated crop-livestock systems.

The hypotheses central to this study were:

1. Improved crop responses to manure application can be obtained when crop residues have been added to kraals and manures have been stored anaerobically (pit manure) for three months or less.
2. Manure from anaerobic storage systems is of higher quality and will give higher yields in the first season, but subsequent benefits from anaerobically decomposed manure are lower than from aerobically composted (heap) manures.
3. There is no appreciable difference in maize grain yield benefits when straw has been incorporated in layers or mixed in storage systems.

Objectives were:

(i) to compare maize yields and nitrogen uptake in response to manures from different storage systems;

(ii) to investigate the effect of method of incorporating straw in storage systems;

(iii) to determine the residual N values of the manures in the subsequent years.

6.2 Materials and methods

The research was conducted in 4 phases as follows:

- manure storage experiments in April and July of 1997

- first season trials established in 1997/98 season to determine maize crop response to manures of different quality treated in 1997. This study was conducted on-farm at 3 sites namely: Mukudu, Musegedi and Nhapi.
- second season validation trials but with an additional treatment on method of incorporating straw in storage systems. Field studies were set up in 1998/99 season at Muzavazi, Manyani and Musegedi.
- maize crop response to first and second residual N from manures applied in first season trials. The residual effects were monitored at Mukudu, Musegedi and Nhapi during the 1998/99 and 1999/2000 cropping seasons.

Phase 1(a). Manure storage experiments

In 1997/98 cropping season, aerobic and anaerobic storage treatments with and without straw were established on-farm. The manure storage experiments were set up on 3 farms namely: Mukudu, Musegedi, and Nhapi.

In setting up the storage treatments, cattle manure used was obtained from kraals that had been supplied with a bedding of maize straw. Solid cattle manure amounting to 2000kg was used per treatment. Prior to storage, 150kg of straw were incorporated in treatments (H+ and P+). In incorporating straw in these treatments, 500kg of manure was alternated with 50kg of straw, making a total of 4 manure and 3 straw layers in one storage treatment. The treatments were:

1. aerobic manure without straw (H-)
2. aerobic manure with straw (H+)
3. anaerobic manure without straw (P-)
4. anaerobic manure with straw (P+)

These manures were set up in April (A) and replicated in July (J). The manures were evaluated along with a control where manure was not applied. All manure samples were collected in October 1997 prior to application in the field for analysis of their nutrient composition. The same manures used in the mineralisation-immobilisation studies in Chapter 5 were used here and are described in Tables 6.1, 6.2 and 6.3. Additional analyses of these manures only included the concentrations of exchangeable bases.

Table 6.1. Chemical characteristics of aerobically and anaerobically decomposed manures used at Mukudu site.

Chemical parameter	Anaerobic	Aerobic Mean
Nitrogen %	1.43a	0.81b
NH_4-N mg kg^{-1}	403.8a	242.8b
Lignin %	10.07a	2.18a
Carbon %	22.73a	7.90b
Phosphorus %	0.29a	0.14b
Potassium %	0.84a	0.28b
Calcium %	0.63a	0.25b
Magnesium %	0.13a	0.03a

Means within each row with the same letter are not significantly different at P=0.05.

Table 6.2. Chemical characteristics of aerobically and anaerobically decomposed manures used at Musegedi site.

Chemical parameter	Anaerobic	Aerobic Mean
Nitrogen %	1.42a	0.81b
NH_4-N mg kg^{-1}	287.5a	130.0b
Lignin %	12.05a	7.90a
Carbon %	23.0a	9.3b
Phosphorus %	0.25a	0.15b
Potassium %	0.72a	0.20b
Calcium %	0.30a	0.10b
Magnesium %	0.23a	0.13b

Means within each row with the same letter are not significantly different at P=0.05.

Table 6.3. Chemical characteristics of aerobically and anaerobically decomposed manures used at Nhapi site.

Chemical parameter	Anaerobic	Aerobic Mean
Nitrogen %	1.49a	0.83b
NH_4-N mg kg^{-1}	332a	150b
Lignin %	11.6a	6.8a
Carbon %	24a	8.07b
Phosphorus %	0.25a	0.11b
Potassium %	1.20a	0.30b
Calcium %	0.69a	0.15b
Magnesium %	0.22a	0.22a

Means within each row with the same letter are not significantly different at P=0.05.

Phase 1(b). First season trials (1997/98) to determine maize crop response to manures of different quality.

Field trials to determine the efficacy of manures produced in experiment 1(a) were planted on the 28th October in 1997/98 season on the same farms where manure storage treatments had been set up namely Mukudu and Musegedi and Nhapi. The sites used for the experiments were characterised for soil physical and chemical properties (Table 6.4) using soil samples taken from a plough depth of 30cm. All sites were on a medium grain sand soil (MS) with a particle size of 0.5-0.2mm. The fields had no history of manure use for the past 3 years and had been planted to maize, the previous year.

Table 6.4. Initial soil characteristics at trial sites used in 1997/98 and1998/99 seasons.

Site	**pH** ($CaCl_2$)	**N** ------ Available---	**P** (mg kg^{-1})	**K**	**Ca** ------ (cmol kg^{-1} soil) ---------	**Mg**
1997/98 season						
Mukudu	3.7	27	26	0.08	0.64	0.17
Musegedi	4.2	38	29	0.30	1.63	0.42
Nhapi	4.5	28	24	0.28	2.10	0.63
1998/99 season						
Muzavazi	4.3	19	32	0.14	1.23	0.29
Manyani	4.1	8	11	0.09	0.64	0.14
Musegedi	4.2	10	6	0.13	0.88	0.24

The experiment was a randomised complete block design with 3 replicates per treatment. Each plot was 4.5m x 6m in size (minimum 5 rows x 6m of maize crop). All manures were applied at a rate equivalent to 60kg N^{-1} ha based upon their total N concentrations. The manures were thoroughly mixed prior to application in open furrows (15 cm deep) or bands. A basal dressing of compound D (7:14:7 –NPK) at 250kg ha^{-1} and muriate of potash (0:0:60 –NPK) at 50 kg ha^{-1} was also applied according to soil test recommendations. A short medium maize variety SC 501 was planted at an inter-row spacing of 0.9m and within row space of 0.3m giving a plant population of 37 000 ha^{-1}. Inorganic N was applied as ammonium nitrate (AN) and split applied at 40 kg N ha^{-1} with half of the inorganic N at 4 weeks after crop establishment and half at eight weeks after crop emergence.

Phase 2. Second season validation trials but with an additional treatment on method of incorporating straw in storage systems.

This study was conceived to compliment results presented in chapter 4 in asmuch as they provide information about effect of straw in storage systems on resulting crop responses. The work in chapter 4 focused on the effect of storage method, crop residue incorporation and duration of storage on pattern of ammonia losses and quality of manure. Among several conclusions drawn from that study was that losses of N through volatilisation were higher in manures incorporated with extra straw (+) resulting in low total N and NH_4-N concentrations in these treatments.

In the validation trials, an additional storage treatment on the method of incorporating straw was included. The straw was incorporated in layers (+L) or thoroughly mixed (+M) with manure during storage. It was hypothesized that method of incorporating straw would affect the mineral N concentrations of the manure and subsequent maize grain yields in comparison to treatments where straw was not used. The hypothesis is based on the fact that the use of straw prior to storage increases the N immobilisation potential and hence retention of N. The treatments were:

1. heaped manure without straw (H-)
2. heaped manure with straw incorporated in layers (H+L)
3. pit manure without straw (P-)
4. pit manure with straw incorporated in layers (P+L)
5. heaped manure mixed with straw (H+M)
4. pit manure mixed with straw (P+M)

The storage treatments were set up in July 1998 at Musegedi, Manyani and Muzavazi farms. July storage was considered only in the validation study since the conclusions drawn from chapter 4 suggested that July storage was superior to April treatments in terms of N conservation and quality of the resultant manure. The same quantities of manure and straw used per treatment in the first season storage experiments were applied here.

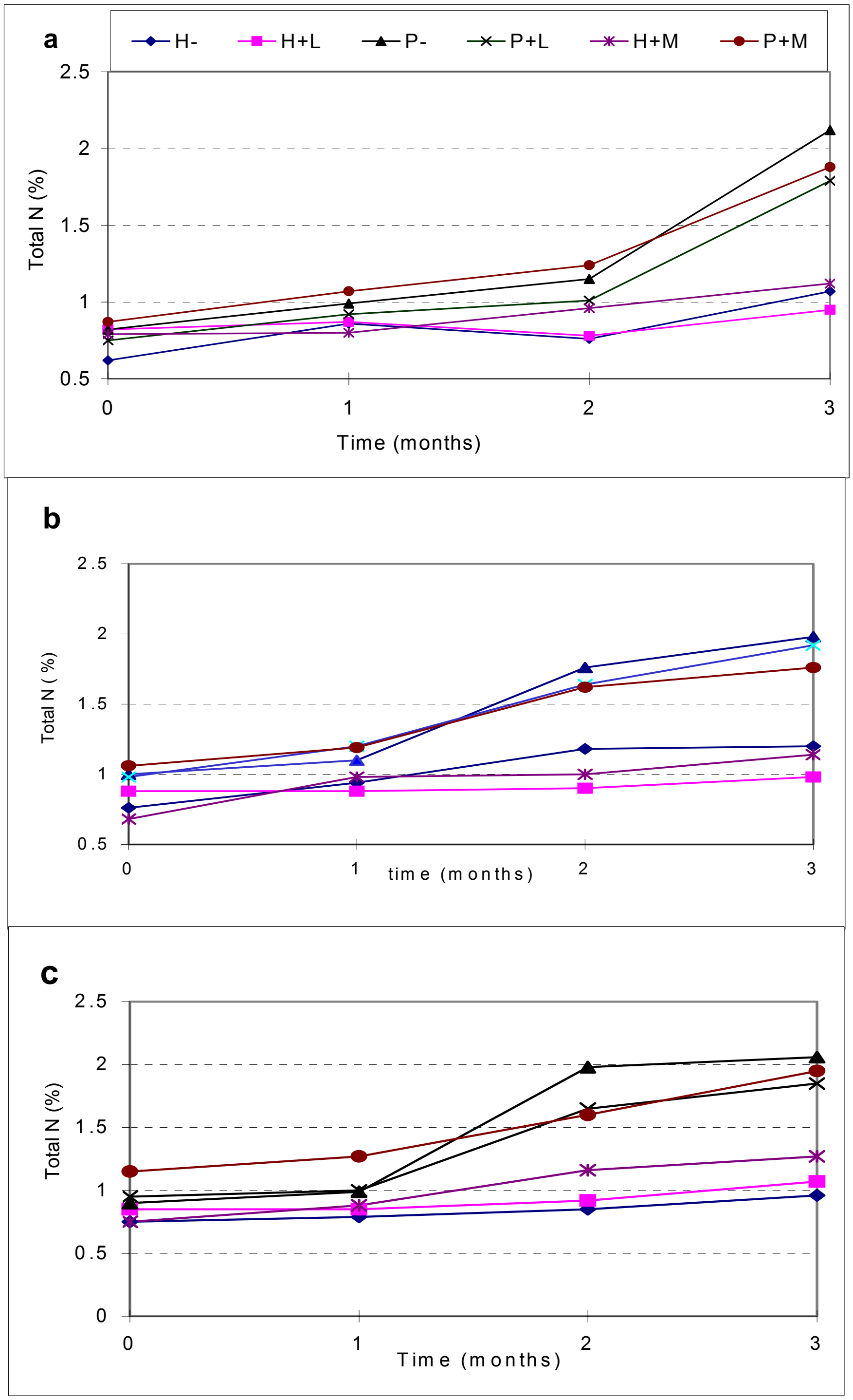
Manure samples were collected in October, 3 days prior to application for analysis of total N to calculate field application rate equivalent of 100 kg N^{-1}ha. Total N was determined by the Kjeldahl method and concentrations from individual treatments are shown in Figure 6.1 for Mukudu, Muzavazi and Musegedi manures. The same procedure used in the first season trials to establish field experiments was applied here. The only differences were in the application rates as indicated. Maize grain and stover samples were collected at maturity during harvesting.

Phase 3. Maize crop response to first and second residual N from manures applied in first season trials in phase 1 (b).

The response to residual N availability from manures applied in the first season trials of 1997/98 (Phase 1(b)) was also monitored over a period of two years in 1998/99 and 1999/00 seasons. This was done by measuring maize grain yields and N uptake from Mukudu, Musegedi and Nhapi sites where the response to manures had been evaluated in the year of application in 1997/98 season (Phase 1(b)).

Field management of trials

Land preparation was done using an ox-drawn plough. All sites were weeded at two and five weeks after crop emergence. Dipterex (2.5% trichloroforn) was applied at five weeks after emergence to control maize stalk borer (Buseola fusca).



H = heap manure P = pit manure + = with straw - = without straw

L = straw alternated with manure in layers M = straw mixed with manure

Figure 6.1. Effect of method of incorporating straw in manure on total N concentration in second season validation trials at a).Mukudu farm. b). Muzavazi farm. c). Musegedi farm.

Harvesting of trials and N analysis of grain and stover

Maize grain yield was measured from a quadrant of 2m x 2m, which was randomly selected within the main plot. Five hundred grams of grain was collected from the measured grain for determination of moisture in the field using a moisture meter (Model G – 6C Delmhorst Instrument Company). The grain yield was adjusted to 12.5% moisture content using the formula:

D = B- (C – 12.5) X B/ 100 where:

B= Grain yield kg/ha

C= Grain moisture Content %

D= Grain yield kg/ha adjusted to 12.5% moisture content.

The 500g of grain were then packed in khaki bags. This was followed by collection of stover from 5 plants in the same quadrant. Grain and stover samples were dried prior to analysis and ground to pass through a 1-mm screen and analysed for total N concentration with the Kjeldahl method (Bremner and Mulvaney, 1982).

Recovery of manure N

The recovery of manure N from 3 years of maize grown following one application of manure in 1997/98 season was calculated by adding the recoveries from individual years. Apparent recovery of manure N was calculated as follows**:**

((N uptake from the manured plot – N uptake from the control plot) / the amount of total N applied) x 100

Statistical analysis

A t-test was done to determine overall treatment differences in the characteristic composition of the manures. A cross site analysis was performed to determine differences in grain yield and total N uptake from different quality manures using analysis of variance (one-way ANOVA procedures in Mstat). Data on second season verification trials was analysed using one-way ANOVA (randomised blocks) procedures in Genstat.

6.3 Results

Manure and soil chemical properties

The chemical composition of manures used in the study is presented in Tables 9, 10 and 11. The statistical treatment of data showed that there were significant differences ($P<0.05$) in the chemical composition of the manures. Anaerobically decomposed manures were always high in mineral N, lignin contents and carbon levels than aerobically decomposed manures. Non-volatile elements were usually higher in anaerobically composted manures than in aerobically decomposed manures. Calcium was found in highest concentrations in anaerobically decomposed manures. Table 12 shows soil chemical data for some trials sites used in the study. All trial sites were on a medium grain sandy soil with a pH value of 3.7 to 4.5.

Rainfall distribution

Rainfall distribution for the study area during the 1997/98, 1998/99 and 1999/00 seasons are shown in Fig. 6.2. Rainfall totals were 1115.00 mm, 1389.85 mm and 1104.02 mm for the three cropping seasons respectively.

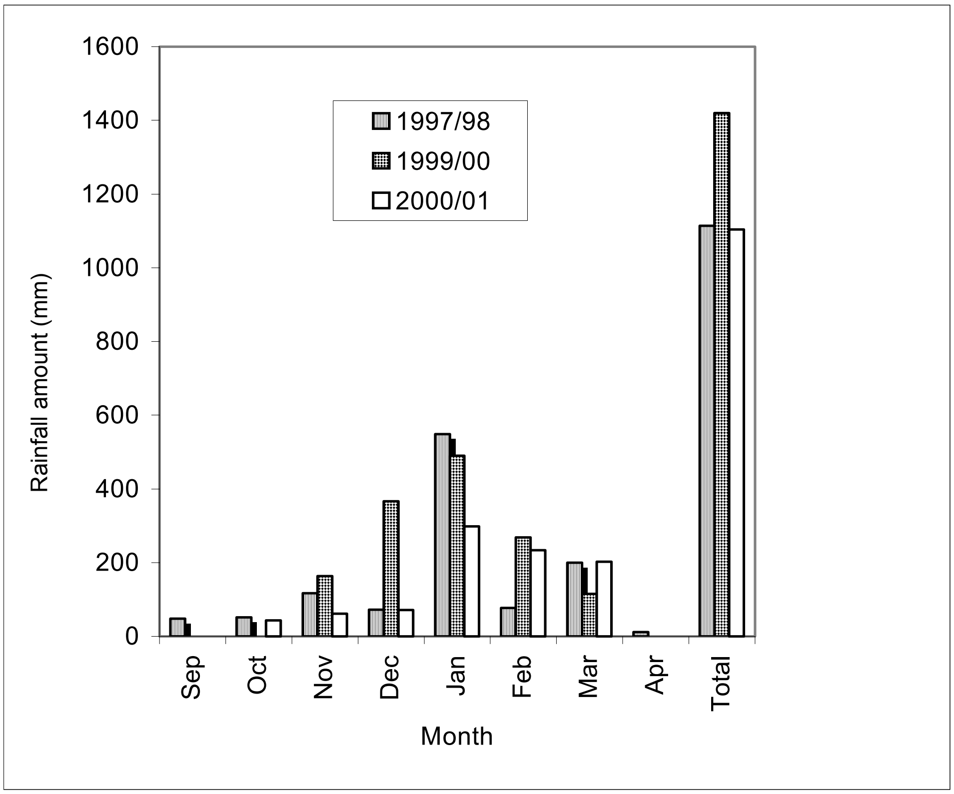


Figure 6.2. Mean monthly rainfall distribution at Musami (Mangwende) for the1997/98,1998/99 and 1999/00 cropping seasons.

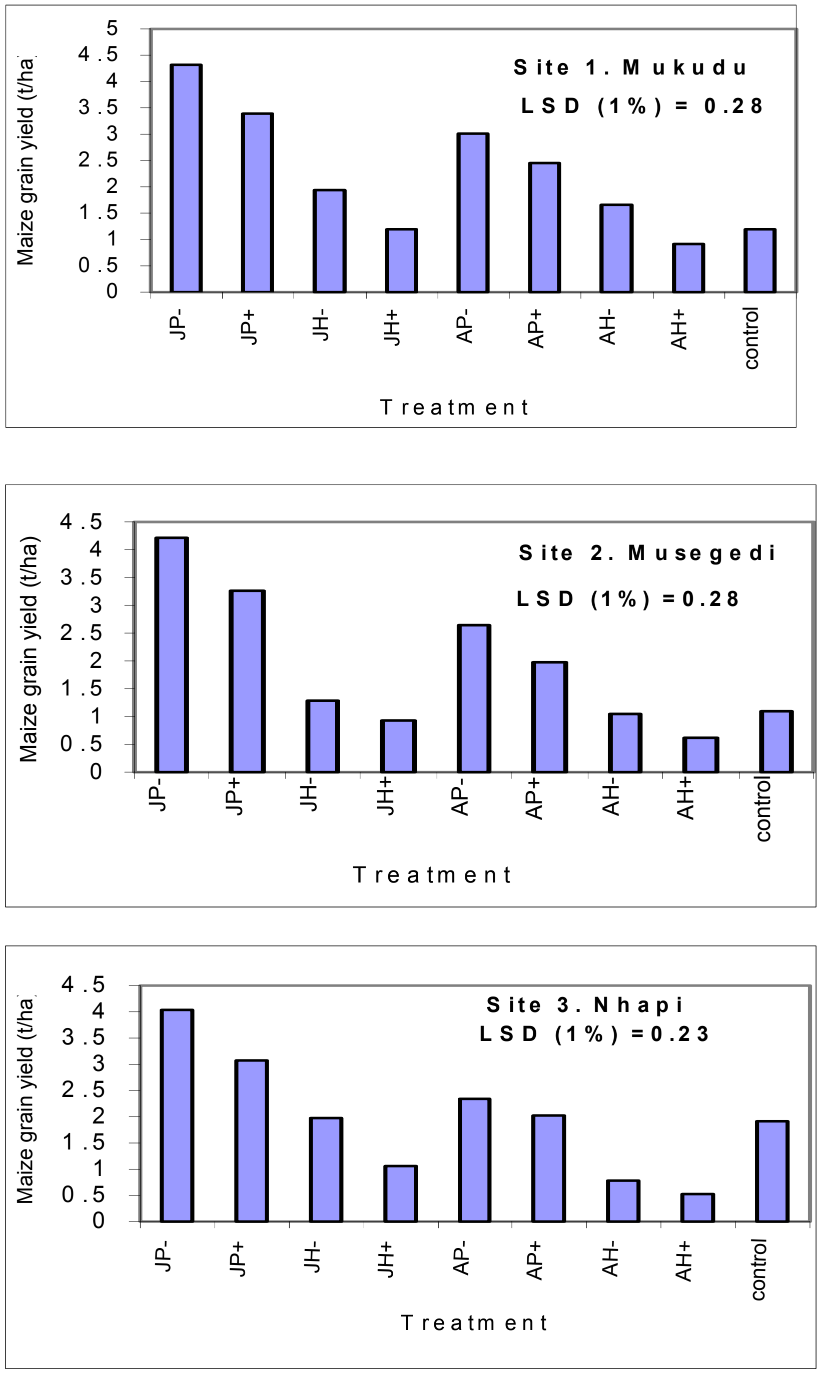
First season trials (1997/98 cropping season)

Yields from anaerobically decomposed manures Vs aerobically composted manures

Grain yield responses to manure from different storage systems are shown in Fig. 6.3 and 6.4. The treatment effects from applying manures from different storage systems were significant ($P<0.05$). In 1997/98 season, grain yield response was greatest with anaerobically decomposed manures and lowest with aerobically composted manures (Fig 6.3).

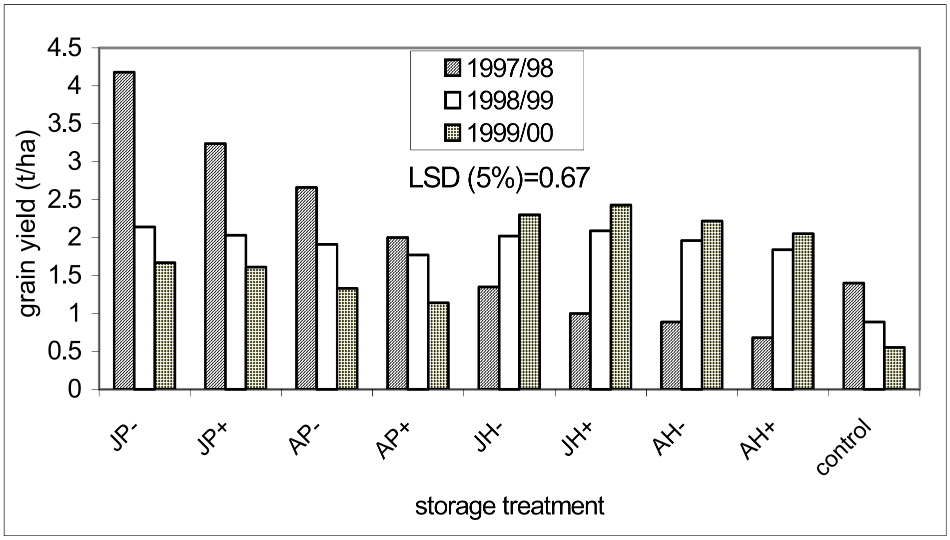
Cross site analysis of data collected from 3 sites (Fig 6.4) showed that anaerobically decomposed manures increased grain yields by almost twofold that of aerobically composted manures in the year of application ($P<0.05$). For instance, in 1997/98 season, grain yields from amending soil with JP- were 4.18 tha^{-1} compared to 1.35 tha^{-1} from JH-. In the same season, the application of JP+ yielded 3.24 tha^{-1} of grain compared to 1.00 tha^{-1} with JH-. Yields obtained from applying aerobically composted manures were always lower than the control in the year of application (Fig. 6.4).

In the residual years (1998/99 and 1999/00 seasons), grain yield responses with aerobically composted manures significantly increased ($P<0.05$) compared to that obtained in the year of application. The opposite was observed for grain yields from anaerobically decomposed manures which, were reduced with time ($P<0.05$). (Fig. 6.4).



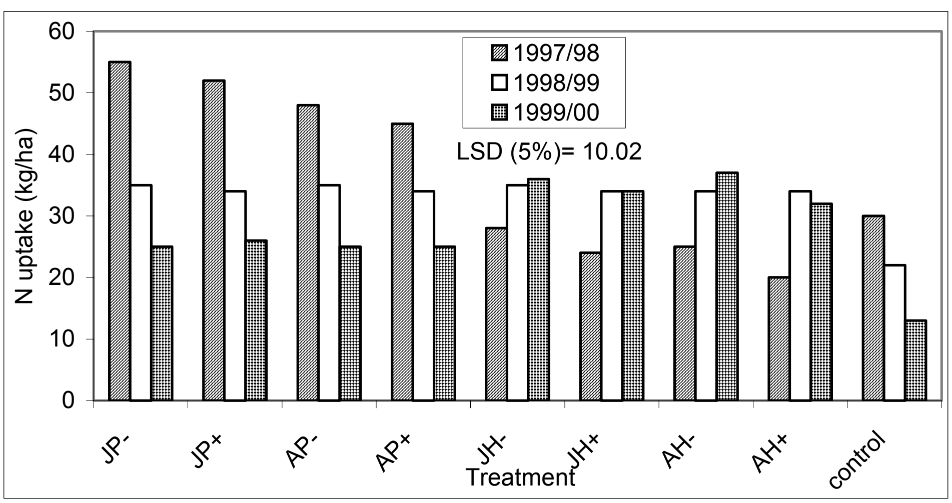
J = July storage + = with straw H = heap manure (aerobic)
A = April storage - = without straw P = pit manure (anaerobic

Figure 6.3. Effectiveness of manures from different storage systems on maize yield in the year of application (1997/98 season).



J = July storage + = with straw H = heap manure (aerobic)
A = April storage - = without straw P = pit manure (anaerobic)

Figure 6.4. Immediate and residual effects of applying manure from different storage conditions on maize grain yield (n = 3).



J = July storage + = with straw H = heap manure (aerobic)
A = April storage - = without straw P = pit manure (anaerobic)

Figure. 6.5. Immediate and residual effects of applying manure from different storage conditions on maize N uptake (n = 3).

Yields from treatments with straw (+) Vs no straw (-)

The effect of straw in storage systems was significant ($P<0.05$) in the year of application (19987/98 season) (Fig 6.3). There was a marginal yield decrease after amending soil with manures treated with straw. In the year of application, JP+, AP+, JH+ and AH+ depressed maize grain yield by 22.5%, 24.8% 31% and 23,6% respectively (Fig. 6.4).

Yields from April Vs July treated manures

There were significant differences due to applying manures of different age ($P<0.05$). Incremental benefits in terms of grain yield were greatest from treatments, which received manures treated in July. The percent increase in yield after applying manures without straw in 1997/98 were at least 45% across all treatments (Fig. 6.4).

N uptake from aerobic and anaerobically decomposed manures

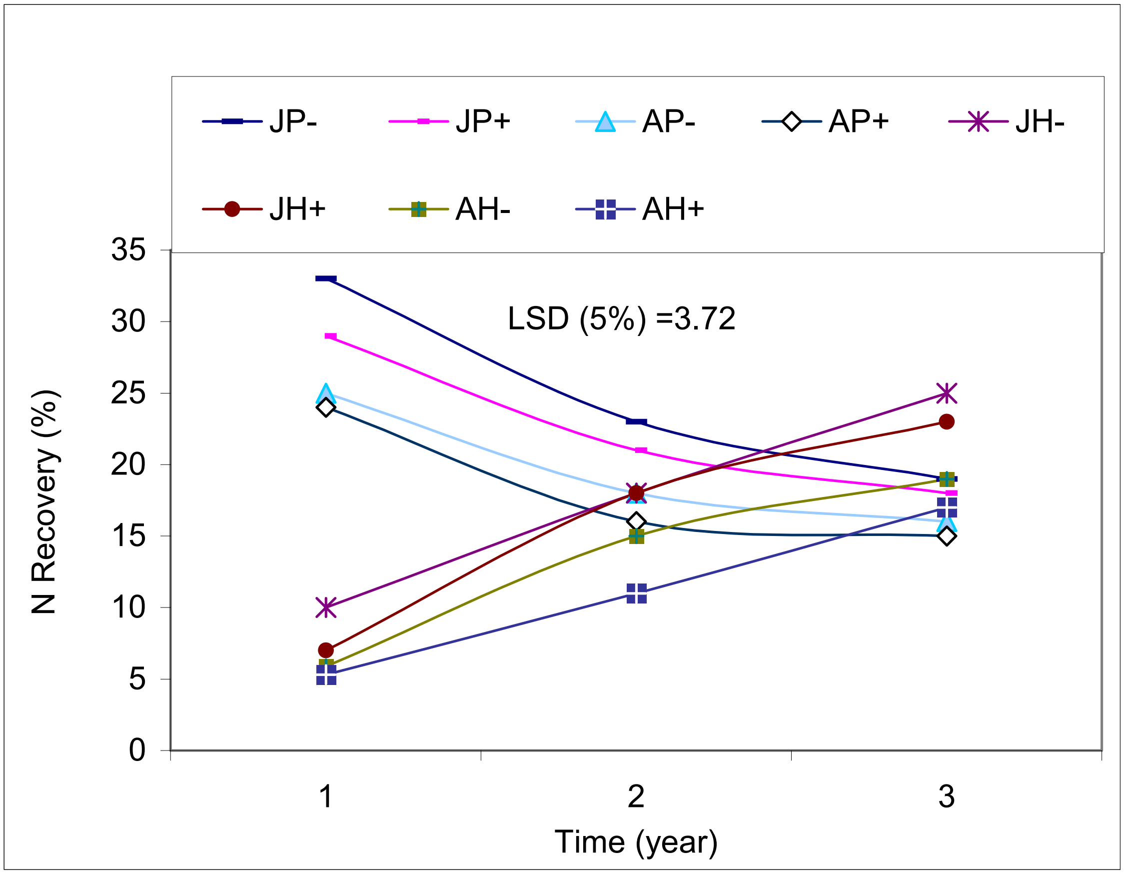
N uptake from different quality manures is shown in Fig. 6.5. In the 1997/98 season N uptake was significantly higher than the control for anaerobically decomposed manures ($P<0.05$). N uptake from the control was 35kg ha^{-1}. Aerobically composted manures exhibited N uptake of less than 28kg ha^{-1}. There was a significant increase in uptake of N in the residual years from aerobically composted manures ($P<0.05$). N uptake in the first and second year residuals was not significantly different for aerobically composted manures. But N uptake from anaerobically decomposed manures decreased significantly with time ($P<0.05$).

Recovery of N

Apparent N recoveries in this study were significant ($P<0.05$). (Figure 6.6). Apparent recoveries of applied N ranged between 5 and 25% for aerobically composted manures. The N recovery values from these manures were significantly lower ($P<0.05$) in the year of application than in the residual years. Treatments, which received anaerobically decomposed manures, exhibited high rates of N recovery in the year of application which, gradually decreased in the subsequent residual years. For instance the recovery of N from JP- was 33%, 23% and 19% in three successive seasons compared to 10%, 18% and 25% with JH-.

Relationship between maize grain yield and NH_4-N in treated manure.

A test was made to see whether the yield could be correlated to the NH_4-N present in the manures used in the current study. The NH_4-N in manure highly correlated with grain yield at the three sites (Fig. 6.7). Aerobically composted manures with their low contents of NH_4-N amounting to not more than 300 mg kg $^{-1}$ resulted in lower yields of less than 2.5t ha^{-1}. Anaerobically decomposed manures with their high NH_4-N of more than 400 mg kg $^{-1}$ resulted in better yields above 2.5t ha^{-1}.



J = July storage
A = April storage

+ = with straw
- = without straw

H = heap manure (aerobic)
P = pit manure (anaerobic)

Figure 6.6. Mean apparent N recoveries (%) by maize growth with manures from different storage systems at three sites (n=3).

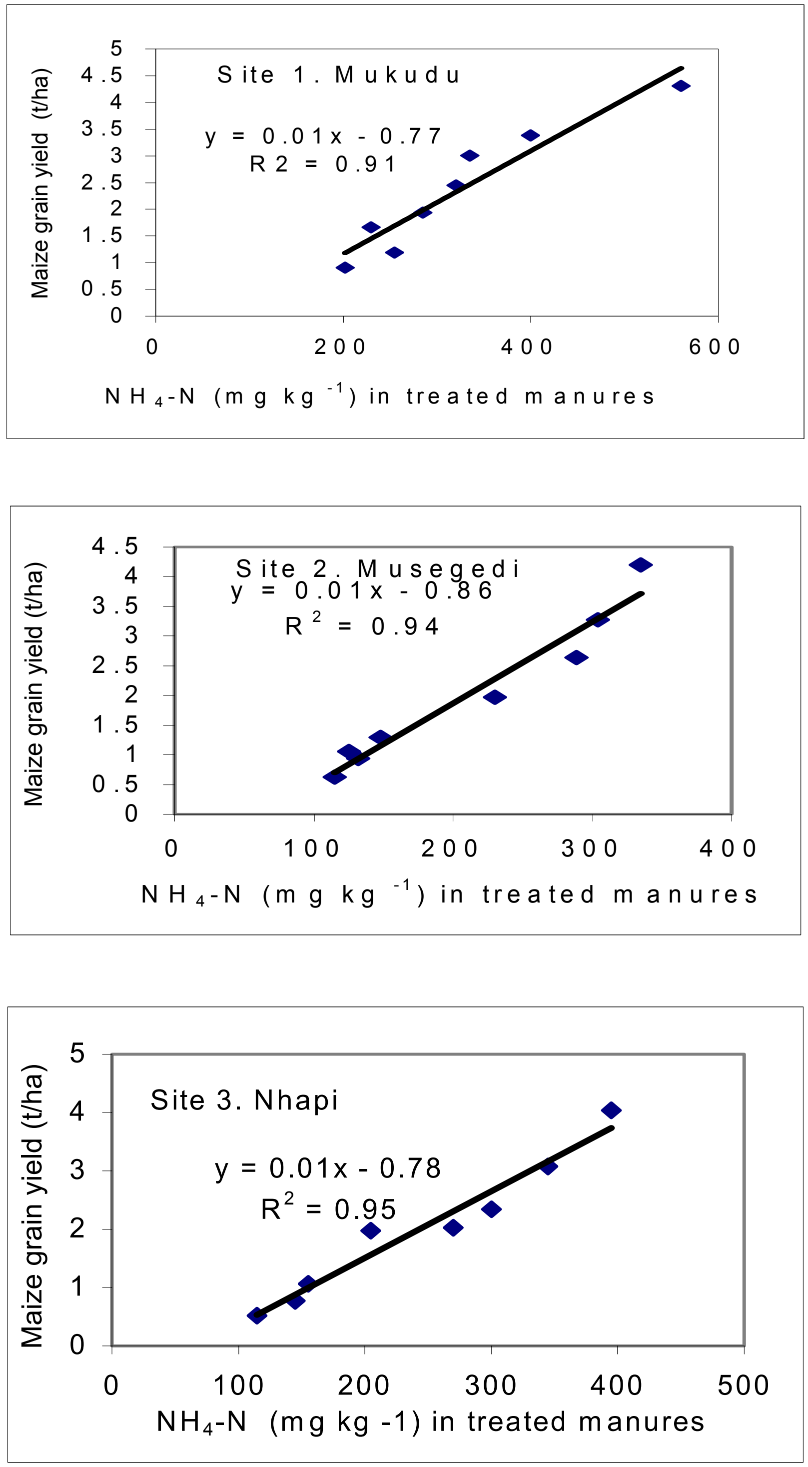


Figure 6.7. Relationship between maize grain yield and ammonia-N in manures of different quality.

Second season validation trials (1998/99 season)

The results did not show any significant differences in total N contents between the manure from mixed or layered straw at three sites ($P>0.05$). Figure 6.1. The results show indeed that the application of anaerobically decomposed manures without straw significantly gives higher yields than aerobically composted manures ($P<0.05$). Generally, there were no significant effects between methods of incorporating straw particularly in pits (Fig 6.8).

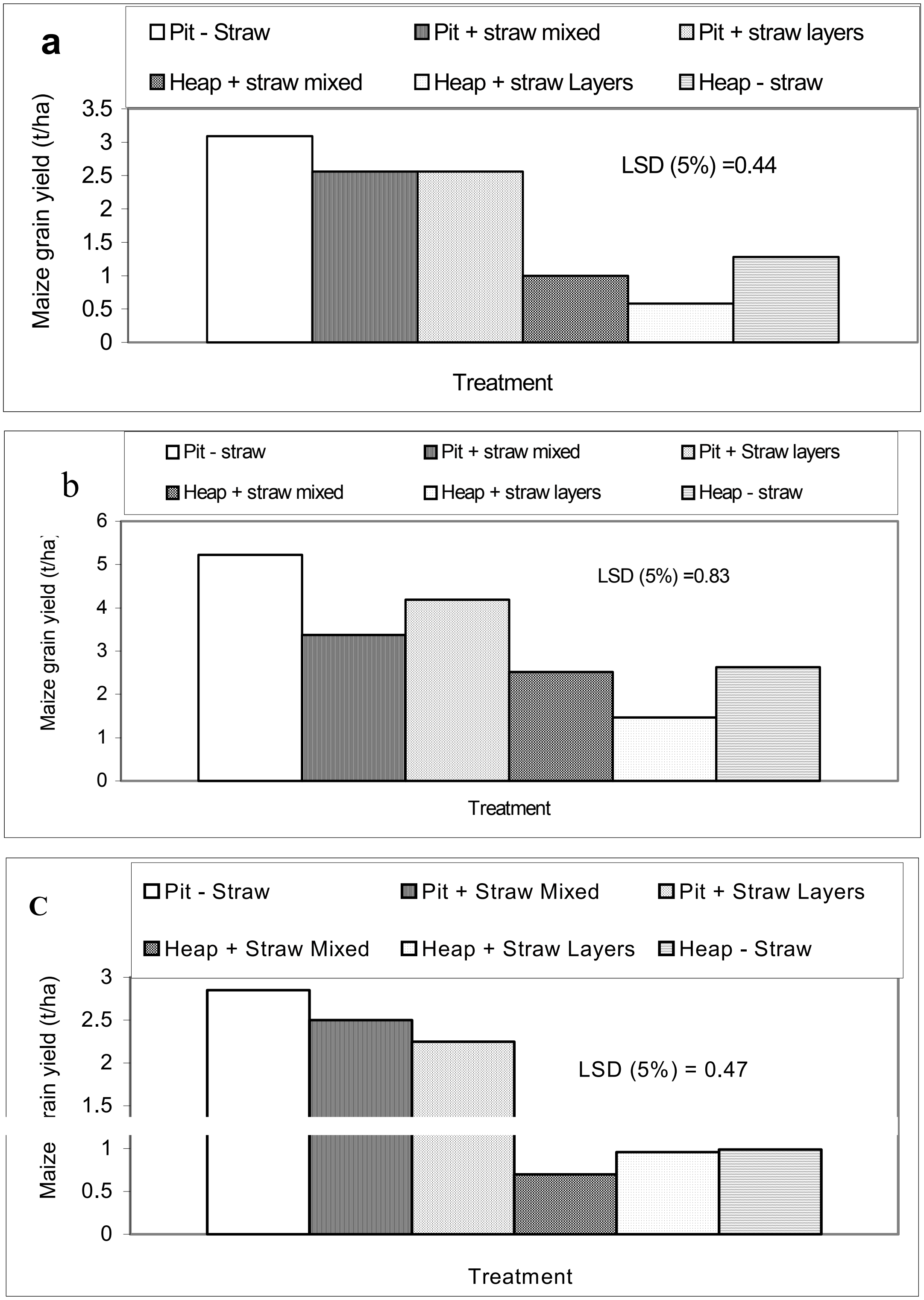


Figure 6.8. Effect of method of incorporating straw in manure on maize grain yield. a). Mukudu farm. b). Muzavazi farm. c). Musegedi farm. Second season validation trials. Manures were applied after 3 months storage.

6.4 Discussion

The manures used in this study varied significantly in their nutrient composition. Higher inorganic N levels in anaerobically decomposed manures than in aerobically composted manures were due to mineralisation of N under anaerobic storage conditions. Conditions were also favorable for the hydrolysis of organic N of the manure accounting for accumulation of NH_4-N in anaerobic manures.

The high grain yields obtained with anaerobically decomposed manures in the year of application were due to the substantial release of N in the form of NH_4^+-N, thus accounting for high N uptake and high N recoveries observed from these manures. The low yields from aerobic manures in the first year of application can be explained by the temporal N immobilisation, since only 28 kg of N was taken up in treatments with aerobic manures compared to 35 kg in the control treatment. Further, a greater proportion of the N in aerobic manures was organically bound (Chapter 4). The $N0_3$-N, which was the predominant form of the inorganic N in aerobic manures (Chapter 4), was possibly subjected to leaching, reducing the N use efficiency of the maize crop.

Therefore, the application of aerobic manures was asynchronous with maize crop requirement. These results are in agreement with data from incubation studies (Chapter 5) in which aerobically composted manures continuously immobilised and there was never a peak for mineralisation. The general tendency for manures with straw to reduce grain yields than manures without straw may have been caused by wide differences in C/N ratio resulting in temporal immobilisation as observed in Chapter 5. Other studies have also indicated depressed yields after amending soil with manures of high C/N ratio (Paul and Beauchamp, 1993, 1994).

Maize grain yields from applying manures composted in April were generally lower than those from July treated manures ($P<0.05$). April treated manures were often low in inorganic N due to prolonged storage/composting which resulted in high volatile N losses (Chapter 4), hence the manures were of poor fertiliser value to the maize crop. Other workers have reasoned that prolonged composting results in more readily decomposable organic N forms being converted to stable forms with little concentration of inorganic N available for crop uptake (Castellanos and Pratt, 1981, Chaney *et al,* 1992, Kirchmann, 1985).

High grain yield increases for the second and third maize crops with aerobically composted manures indicate significant residual N for crop uptake from this type of manure. This was also supported by data from N recoveries in which low N recoveries from aerobically composted manures in the year of application subsequently increased with time. High N uptake, recoveries and grain yields in the residual years, suggests that a large proportion of organic N in aerobically composted is mineralised and made available to the crop in the subsequent years. Results from this study are similar to those reported previously by other workers who found N release from dry aerobically composted manures to be slow and asynchronous with maize crop requirement at eight weeks after establishment (Murwira and Kirchmann, 1993; Paul and Beauchamp, 1993; 1994).

6.5 Conclusion

This study showed significant differences in maize crop responses to manure from different storage systems. Maize grain yields were higher when grown with anaerobic manures than with aerobic manures in the year of application. This reflects that anaerobic manures can supply available N for crop uptake the short term than aerobic manures. This conclusion suggests the initial and short-term differences in the readily decomposable fractions of aerobic and anaerobic manures.

Aerobic manures could be more beneficial in the residual years. This is the time when the organically bound N is mineralised and becomes available for crop uptake. The residual N benefits from aerobic manures also imply that for a cereal crop to be grown in the year of application, supplementation with inorganic fertiliser will be necessary to reduce the initial N deficit of aerobic manures.

The fertiliser effects of aerobic manures should not be undervalued as aerobic manures can contribute to soil quality in the long term. Aerobic manures being more stable than anaerobic manures may enhance soil organic matter build up which improves soil physical properties (i.e. improvement in soil structure, increases in water holding capacity and infiltration rates and reductions in bulk density). The improved conditions result in a more favorable moisture status of the soils, enhancing root growth and nutrient mobility. The great importance of soil physical properties for plant nutrition and for efficiency of applied nutrients needs to gain more attention.

CHAPTER 7

THE EFFECT OF PLACEMENT METHODS OF AEROBIC AND ANAEROBIC MANURES ON NH_3 LOSSES AND MAIZE GRAIN YIELD

7.0 Abstract

A study was conducted on sandy soils in Mangwende communal area in the 1999/2000 season to determine the effect of placement method (broadcasting, banding and on-station) of heap (aerobically composted) and pit (anaerobically decomposed) manures on NH_3 losses and subsequent maize grain yield. The volatilisation of ammonia in the field was measured for 14 days after application of pit and heap manure in banded and broadcasted treatments using the chamber technique. The rate of ammonia loss was significantly higher (P<0.01) on broadcast manure treatments. Losses from broadcast manure were 25kg N t^{-1} manure and 19.3kg N t^{-1} manure for pit and heap manure respectively compared with the control where losses amounted to 0.7kg N t^{-1} manure. Losses were reduced to 4.9kg N t^{-1} manure (80% decrease) when pit and heap manure was banded. Significant increases (P<0.01) in maize grain yields were obtained with banded and on-station placement compared to the broadcast treatments. Yields from banding ranged between 2.96 to 3.20 t ha^{-1} with pit manure in comparison with yields of 2.39 to 2.43 t ha^{-1} from broadcasting. Banded heap manure gave grain yields between 1.39 and 1.75 t ha^{-1} compared to 1.01 to 1.16 t ha^{-1} with broadcasting. There was no appreciable difference in yield between the band and on-station placement (P = 0.266). This means that band and on-station placement methods can enhance efficient utilisation of manure-N for both aerobically composted and anaerobically decomposed manures.

7.1 Introduction

Placement methods are among factors that influence the efficient utilisation of N from fertiliser sources after application to soil (Thompson, 1990; Nathan and Malzer, 1994; Peoples, Freney and Mosier, 1995). The crop recovers less than 50% of N from manure added to the soil. This is attributed to the variations in N transformation pathways with respect to different placement methods (Paul and Beauchamp, 1990; Zerbath *et al.,* 1996).

Several workers have demonstrated the potential of broadcasting placement method leading to NH_3 volatilisation with subsequent reductions in N availability for crop uptake (Jazen and McGinn, 1990; Sweeney, 1993; Peoples *et al.,* 1995). Between 15 and 50% of surface applied NH_4-N in manure was volatilised within 48 – 72 hours of application (Lauer *et al.,* 1976; Beauchamp, 1982).

In Zimbabwe, the most common placement method of manure in crop livestock system is broadcasting (Munguri, 1996; Mubonderi, 1999). As anaerobically decomposed manures contain high amounts of NH_4-N (Chapter 4) at the time of application, possible losses as NH_3 with broadcasting applications could reduce efficient utilisation of the manure.

It has been demonstrated that uptake of fertiliser N can be improved and total N losses reduced from levels achieved with surface broadcasting by various methods such as deep placement (Bolland 1990, Malhi and Nyborg, 1992, Schmitt, Sawyer and Hoeft 1992).

The purpose of this study was to investigate on-field manure management strategies.

The study was based upon the hypothesis that:

Banding and station placement of manure can increase manure N utilisation by the crop and subsequent maize yields by reducing NH_3 losses by volatilisation than broadcast incorporations.

The objectives of this study were to:

i. compare grain yields and nutrient uptake from anaerobically and aerobically decomposed manures under band, station and broadcast placement

ii. examine the extent and magnitude of NH_3 losses by volatilisation from banded and broadcasted manure.

7.2 Materials and methods

Experiment 1. Effect of banding and broadcast incorporations of manures of different quality on ammonia losses

A study was set up in the 1999/2000-cropping season to evaluate ammonia losses from aerobic and anaerobically decomposed manure applied in the field using banding and broadcasting methods. All manures were applied at 100 kg N ha^{-1} equivalent. The trial was a factorial experiment of manure storage method (heap and pit), placement method (broadcast and band), and control. The experiment was laid out in a randomised complete block design with 4 replications. The treatments were:

1. heaped manure broadcasted
2. heaped manure banded
3. pit manure broadcasted
4. pit manure banded
5. control

Ammonia losses were measured using the static chamber technique (Watson et al., 1962) and the Gastec Multi-stroke Gas Sampling Pump and the Gastec Detector Tube N0 3L, (Gastec Corporation, 6431 Fukaya, Ayase-City, 252, Japan). The static chambers consisted of a square transparent plastic box (10L by volume) with fixed lids and a hole at the center, which was opened and closed as required during sampling. Three chambers were randomly inserted in each plot (at a depth of 3-cm) on the first day and left in place till the time of sampling.

Measurements of ammonia losses started immediately after application. After sampling, chambers were re-positioned at different places till the next sampling day to avoid possible cumulative effects of the chambers on the microenvironment in plots (Vallis *et al.,* 1982). This procedure continued for 14 days when little or no losses could be detected.

Experiment 2. Effect of method of application and manure on maize grain yield.

The experiment was conducted in 1999/2000 cropping season at 3 sites on a medium grain sandy soil. Soil samples were analysed for pH ($CaCl_2$), CEC, available P and K. The soil chemical characteristics of the experimental sites is shown in Table 7.2. Four manures of different quality were applied using three methods – station placement, banding and broadcasting. The manures were applied at a rate of 100 kg N^{-1} ha equivalent based on total N concentrations of the manure. The treatments were laid out as a 4 x 3 factorial in a randomised complete block design with three replicates as follows:

Main plot (manures of different quality)

1. Heaped manure with straw
2. Heaped manure without straw
3. Pit manure with straw
4. Pit manure without straw

Subplot (placement methods)

1. Banding
2. Station
3. Broadcasting

These treatments were replicated at 3 sites at Mapira, Manyani and Muzavazi all within one village. Each plot was 6m long and 4.5m wide. The chemical composition of the manures is shown in Table 7.1. In treatments with broadcast incorporations, manure was uniformly spread on the soil surface using a spade and incorporated (to depths of 5 to 10 cm with a hoe) after spreading. The normal farmer practice is use of a plough for incorporation after spreading. For banding, furrows were opened using a plough whereas in station placement, planting holes were dug with a hoe. To facilitate uniform distribution of the manure in these two methods, a precallibrated container was used. Manure in bands and planting holoes was covered by a layer of soil (3cm) immediately after application. All treatments were set up on the day of planting.

An early maturing maize hybrid (SC 501) was planted at an in-row spacing of 0.3 m and row spacing of 0.9 m giving a plant population of 37 000 plants per hectare. All treatments received a uniform top-dressing (40 kg N ha^{-1}) of NH_4NO_3 at 4 and 8 weeks after crop emergence. Maize grain was harvested at maturity.

Analysis of experimental data.

Data from the study on NH_3 losses after application in the field was analysed as a two-way ANOVA in GENSTAT whilst data from effect of placement methods on crop responses was analysed as split plots with placement methods as main plots and manure treatments as sub-plots. The Duncan's multiple range test was performed on grain yield data to distinguish treatment effects from placement methods.

7.3 Results

Chemical characteristics of manures

The manure used in the study varied in their N concentrations owing to different storage conditions prior to application. (Table 7.1). Manures anaerobically decomposed in pits had higher proportions of available N in comparison to manures aerobically decomposed in heaps. The pH of anaerobically decomposed manures was less than 7. Alkaline pH regimes were typical for aerobically composted manures.

Table 7.1 Chemical characteristics of manures used in the study on effect of placement method (n = 3).

Manure	pH ($CaCl_2$)	Total N (%)	Organic carbon %	NH_4-N	$N0_3$-N
				--------mg kg^{-1}-------	
Experiment 1					
Heaped	7.8	0.9	11. 0	39	105
Pit stored	7.3	1.4	25.0	192	21
Experiment 2					
Heaped	8.4	1.2	10.0	27	147
Pit stored	6.9	1.6	28.5	215	18

Soil characteristics of trial sites

The soil characteristics of trial sites used in the study are shown in Table 7.2. The trials were conducted on medium grained sandy soils with pH regimes slightly acidic. Nitrogen levels were within the medium range whilst phosphorus was limiting at all sites.

Table 7.2. Soil characteristics at trial sites used in the effect of placement methods of manure study (n = 3).

Texture	pH ($CaCl_2$)	N	P	---------------------- CEC---------------------- (cmol kg^{-1})				
		…..(mg kg^{-1})…..		K	Ca	Mg	Na	TOT
Experiment 1								
MG/S	4.8	18	13	0.20	0.67	0.38	0.0	1.3
Experiment 2								
MG/S	4.5	21	9.0	0.25	0.53	0.30	0.0	1.1

MG/S = medium grain sandy soil
TOT = total exchangeable bases

Effect of banding and broadcast incorporations on NH_3 losses by volatilisation

Placement methods of aerobic and anaerobic manures had a significant effect on ammonia volatilisation ($P<0.01$). Cumulative data on ammonia volatilisation following treatment application are presented in Fig. 7.1. Nitrogen losses occurred immediately after application during the first 7 days and decreased constantly thereafter. Highest losses were observed under broadcast treatments. This was particularly amplified in treatments amended with anaerobic manure where N losses amounted to 25 kg N t^{-1} manure compared to 19.3 kg N t^{-1} manure from aerobic manure. ($P<0.01$). Cumulative ammonia losses from the control were found to be negligible. Banding placement method significantly reduced N losses by 80% from aerobic and anaerobic manures. ($P<0.01$). There was an interaction between placement x sampling ($P<0.01$).

Maize responses to banding, broadcasting and on-station placement of manure

Banding and station placement methods significantly increased maize grain yield ($P<0.01$) relative to broadcasting. Yields from banding ranged between 2.96 to 3.20 t ha^{-1} with pit manure in comparison with yields of 2.39 to 2.43 t ha^{-1} from broadcasting. Banded heap manure gave grain yields between 1.39 and 1.75 t ha^{-1} compared to 1.01 and 1.16 t ha^{-1} with broadcasting. There was no significant ($P>0.05$) difference between grain yields from banding and when manure was placed on station (Table 7.3).

Results also show that banding and station placements of heaped manure without straw increased maize grain yields by 51% and 37% over broadcasting respectively. The efficiency of heaped manure with straw was enhanced by 38% and 32% over broadcasting through banding and station placement respectively. Pit manure with straw increased yields over heaped manure without straw from 80% to 113%. Yield increases with pit manure with straw ranged from 105% to 128% over heaped manures with straw (Table 7.4).

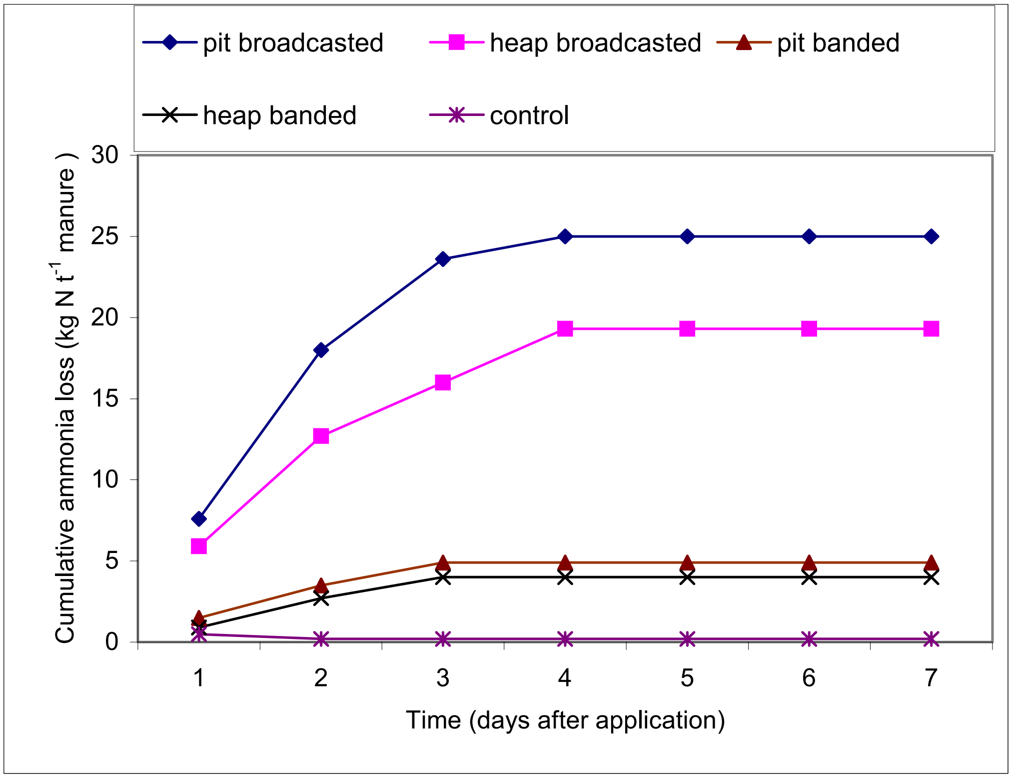


Figure 7.1. Cumulative NH_3 losses from anaerobic and aerobic manures as influenced by placement methods under field conditions.

Table 7.3. Effect of method of application and manure quality on maize grain yield.

Treatment	Banding	Station	Broadcasting
	Maize grain yield (t/ha)		
Heaped manure without straw	1.75c	1.59cd	1.16ef
Heaped manure with straw	1.39cde	1.33de	1.01f
Pit manure without straw	3.20a	3.26a	2.43b
Pit manure with straw	2.96a	3.04a	2.39b
Mean	2.14	2.31	1.75

LSD 5% = 0.37. lsd = least significant difference at 5%.
Means followed by the same letter are not significantly different (n = 3).

7.4 Discussion

Effect of banding and broadcast of manure on NH_3 losses by volatilisation

Higher losses were detected from broadcast applications. This is because much of the mineral N in manure is in the form of urea and surface application directly exposed it to the atmosphere where it was converted to gaseous NH_3 and lost by remaining on the soil surface. Exposure of the manure possibly reduced the partial pressure above the soil manure surface with consequential N losses, Vlek and Stumpe (1978). The length of time the manure remained on the surface before incorporation also contributed to the magnitude of N losses from broadcast applications. Ammonia losses could also have been influenced by the low CEC of soils from the study sites, which lead to poor adsorption of NH_4^+ ion onto the exchange complex of the soil, and NH_3 released was immediately lost to the environment. Similar findings on NH_3 volatilisation from broadcast applications have been reported by other researchers (Pain *et al,* 1989, Thompson *et al.,* 1990; Nathan and Malzer, 1994).

The higher NH_3 losses with broadcasted pit manure than heap manure indicate the significant differences in the concentrations of NH_4^+-N initially present in these manures. Pit manure contained higher NH_4^+-N concentrations than did heap manure resulting in greater NH_3 losses from pit manure compared with that from heap manure.

Maize responses to placement methods of aerobic and anaerobic manures

The significantly low grain yields from treatments under the broadcast applications suggest inefficient utilisation of manure-N relative to the application method. The time between application and incorporation of the manure under broadcast placements reduced the value of the manure as a fertiliser N, as major losses had occurred before incorporation of the manure into soil. Low yields were also possibly due to low nutrient use efficiency of the broadcasted manure-N as the latter was probably more susceptible to immobilisation by surface organic residues. Broadcasted manure is often inadequately mixed with soil for complete microbial decomposition resulting in slow decomposition of the manure, low nutrient use efficiency and depressed yields. These results are in agreement with those reported by Mailhi and Nyborg, (1991, 1992), who reported low nutrient use efficiency of N fertiliser with broadcast applications. This was attributed to increases in NH_3 volatilisation and nutrient immobilisation with broadcasted fertiliser N sources. Higher yields from band and station placement of heap and pit manures may have resulted from high nutrient concentrations placed in the root zone where they were more readily accessible for plant uptake. This combined with low volatile N losses associated with band placement may attribute for the increase grain yields.

7.5 Conclusion

The study demonstrated that field management of manure plays a critical role in improving the efficient untilisation of the manure. Results show that broadcast applications are susceptible to N losses by ammonia volatilisation thus reducing the potential fertiliser effects of the manure. With broadcasting treatments, application rates would need to be increased to compensate for reduced N levels due to N lost by volatilisation. In order to minimise losses from broadcast placements, farmers should incorporate manure immediately after spreading. However, N losses would still occur as spreading facilitates diffusion of NH_3 gas from the manure.

According to this study, there is greater scope in banding manure as it not only minimises volatile N losses but also concentrates nutrients in the root zone making them readily accessible for the plant. In anaerobically decomposed manure, NH_3 usually contributes a large proportion of the available N in the first year of application. The N from the manure could supply a larger area with banding.

CHAPTER 8

GENERAL DISCUSSION AND CONCLUSIONS

8.0 Synthesis of results from the study

Whilst the study has developed 'best bet' management technologies for improving quality and enhancing efficient utilisation of the fertiliser N value of cattle manure, there is need to develop a further understanding on how the results can be synthesised in the context of crop livestock systems. The following areas and questions form the crux of the synthesis.

Environmental impact of the study

i. There is need to determine to what extent information drawn from the present study influences nutrient cycling in crop livestock systems with specific reference to storage and handling of manure.

ii. In the present study, maize straw was found to be a viable strategy for immobilisation and absorption of urine during handling in cattle kraals. However, before the strategy can be adopted, it will be necessary to determine the benefits of providing bedding of cereal stover in cattle kraals over other competing uses of straw.

iii. Results from this study showed that biological processes can be manipulated during storage to reduce N losses through ammonia volatilisation and enhance nutrient retention in the system hence improve quality. However, attention must be drawn to side effects, which could probably be connected with N loss-reducing strategies.

That especially applies to the N loss reducing strategies during pit storage of manure, where benefits in addition to improved N availability and efficiency are expected from using the manure.

Impact of technology developed on farmers' investment returns in soil fertility.

The study indicates that one tonne of manure from conventional manure management practices is equivalent to 3kg fertiliser N. The fertiliser N value of this manure is too low to sustain crop requirements for high yielding crops like maize. The implications are that fertiliser N should be considered as an addition to meet plant requirements. Most farmers cannot afford the purchase of inorganic fertilisers required to remove the deficit in low quality manure due to high costs. Therefore pit storing manure can sustain crop production by meeting crop N requirements of the crop and reducing supplemental fertilizer N costs.

Labour implications

The economic benefits of improved manure management options should be investigated inorder to enhance farmers's decision making in implementing the technology. The way in which these questions are addressed should be able to show the extent to which knowledge obtained from the study can be applied in the context of crop-livestock systems. An attempt has been made to answer the questions and develop a systems interpretation of results from the present study.

8.1 Nutrient cycling in manure management systems

From the measurements made to quantify N leakage's through the process of ammonia volatilisation during the manure production cycle (from storage and handling of manure to application in the field), a unifying picture of N cycling in both conventional and improved management systems can be derived.

The capacity of crop-livestock systems to enhance quality of manure can be accounted for by N quantities that can be conserved through N loss-reducing strategies (during storage and handling of the manure and application in the field). On a field scale, exposed cattle kraals lose an average of 7kg N t^{-1} manure per LU per month to NH_3 volatilisation. The provision of straw in cattle kraals conserves N losses by 88%. This reduction in losses translates to about 3kg N t^{-1} manure.

The system shows that major losses occur during storage and are a function of storage method, duration of storage and incorporation of straw prior to composting. The conventional storage method of heaping (aerobic composting), accounts for highest N losses ranging from 22 kg t^{-1} to 40kg N t^{-1}. The system loses less than 5 kg N t^{-1} if the manure is stored in the pit under anaerobic conditions. When NH_4-N from storage was expressed as a percentage of total N, pit manure supplied between 7.5 and 31% of NH_4-N in comparison to a range between 1.4 and 9% of NH_4-N from heap manure in the year of application.

Management in the field reduced quantities of N from storage for recycling into the soil. When manure was broadcasted, 25kg N t-1 and 19.3 kgN t-1 from pit manure respectively were volatilised. Losses were reduced by 80% in both cases when manure was banded.

The high N recoveries for pit manure in the year of application, indicates a high synchrony of N availability and uptake by the crop. Therefore a high yielding crop like maize can be successfully grown in the year of application without applying a starter fertiliser.

The low and high N recoveries from aerobic manures in the year of application and subsequent seasons respectively, suggest that the manures could be advantageous in the long term, though overall cumulative yields are higher with anaerobic manures. Organic N from aerobic manures accumulates in soil and provides a reserve pool of nutrients which become available in the following seasons. Therefore fertiliser N should be considered as an addition to meet crop N requirements to enhance N release from aerobic manures.

8.2 Benefits of using straw in cattle kraals over other competing uses on-farm

During handling in cattle kraals, the first few hours are critical to prevent loss of N from fresh dung and urine to minimise initial loss through NH_3 volatilisation. From the study, it becomes apparent that quality of manure can be reduced during handling if it came from cattle kraals without bedding of straw.

Large quantities of straw would be required during handling to achieve a significant reduction in N loss of 88%. A proportion of 3 parts straw to 25 parts manure by weight (4.8 kg straw /t of manure) or simply providing a bedding mat of 3 cm straw (25kg straw per 3 LU/month) would be required to reduce losses by at least 50%. The straw amendments required are too large to be practicable under most farming systems, given a wide range of competing uses of straw (such as grazed by animals in the field, indirect animal feeding and or provision of bedding in cattle kraals, soil water conservation (e.g.mulching to control erosion and evaporation), direct incorporation to soil, burning) under these conditions.

The whole question of competing uses of crop residue on-farm should be resolved by considering the economics of residue use. Although returning all crop residues to the soil rather than feeding them to livestock results in greater crop yields (Gieger, Manu and Bationo, 1992; Bationo, Buerkert, Sedogo, Christiano and Mokwunye, 1995), this is not a viable strategy for many farmers. If crop residues are above a critical percentage composition in N (e.g. above 2% N for legumes) they may supply N to crops following their addition to the soil. But maize stover and cereal straws, which contain about 0.75% N or about 7.7 kg N per tonne of residues may require additional 10 –12.5 kg N per tonne to satisfy the needs of microbial organisms which effect decay. Besides the relatively low nutrient content, upon application to soil, crop residues often fail to maintain soil fertility and soil and water conservation because of the limited quantities produced on-farm (Powell and Unger, 1998).

In most cases, supplemental N fertilisation needed to compensate for net immobilisation and to hasten crop residue decomposition may be an uneconomic and unsustainable practice given the unavailability and high costs of inorganic fertilisers. Therefore solutions should rely on technologies and management resources within reach of the farmer.

Manure management in kraals and the utilisation of crop residues are intricately linked in several ways. The provision of crop residues in cattle kraals immobilise N from dung and urine, forming an important component in enhancing crop-livestock- crop interactions. The use of crop residues during handling, simultaneously allows them to be consumed by cattle in the kraal. This improves the condition of the animal at the end of the dry season, hence better draught power. The returns from crop residues fed to cattle are potentially high as cattle excrete 80% to 90% of the N, P and K they consume (Powell, Williams, 1993; Topps and Manson, 1967). Therefore the provision of straw to cattle pens to minimise N losses from dung and urine and as a stock feed could be a better alternative for crop residue management, enhancing nutrient cycling in crop-livestock systems.

8.3 Side effects connected with N loss reducing strategies

As a side effect of anaerobic decomposition of manure under pit storage system, mass balance studies suggested that the system looses 15 to 20% (DM) of its initial mass. Given the limited quantities of manure available on-farm, pit storage system could be an inefficient strategy as conservation of manure-N is accompanied by a reduction in quantities of manure. Application of manure in bulk quantities can result in accumulation of soil organic matter which improves soil physical properties such as structural aggregation, water holding capacities and infiltration rates. However, the loss in quantity associated with production of manure under anaerobic conditions can be compensated for, by high quality of the manure, which will influence quantities to be applied, if the application rate will be based upon total N concentrations of the manure. Accumulation of non-volatile elements such as P, K, Ca and Mg due to loss in dry matter under anaerobic storage conditions, can also benefit soil fertility in the long term by progressively increasing soil nutrient content.

The issue of enhancing efficient utilisation of limited quantities of pit manure can also be addressed by placement method. Apart from exposing manure–N to the atmosphere and subsequent N losses, broadcasting incorporations require large quantities of manure to amend a small portion of land, hence the latter would not be a viable strategy for maximising benefits from pit manure. Banding placement method can be an efficient method of not only concentrating nutrients from limited quantities of anaerobic manure, but also reduces N losses and improves grain yields by 80% and between 38% and 51% over broadcasting incorporations respectively. Another recommendation is to fertilise a small portion of land at a time, or better still to target specific niches.

8.4 Effect of improved manure management system on farmer's investment returns in soil fertility

Manure technologies developed in this study, make a significant contribution to the overall N budget of the farm. By increasing quality of manure by 0.1% N, anaerobic manure provides an extra 10kg N at application rates of 10t/ha or the equivalent of 30kg of ammonium nitrate (AN). The technology therefore enhances farmer's investment returns in soil fertility as it reduces fertiliser costs required to offset the N deficit in low quality manure from conventional storage and handling practices. The amount of mineral fertiliser applied per hectare of cultivated land in the smallholder sector is below the recommended rates in most farming systems due to high price (Chuma, Mombeshora, Murwira and Chikuvire, 2000), therefore improving quality of manure makes it more sustainable to use the low rates of supplementing fertiliser.

8.5 Labour implications

Whilst overall yield benefits from immediate and residual effects of applying anaerobic manure were found to be higher compared to the conventional heaped manure, labour implications might offset the net returns from the technologies resulting in uneconomic viability and poor adoption of the technology. In order to assess profitability of manure management technologies, further research will be required to determine the economic efficiency of the farm, taking in to account all private and social costs of inputs and outputs involved.

8.6 Suggested further research

The following strategic areas will require further research and possible refinement:

i. Development of more practical decision trees for predicting quality of manure

There is scope for development of decision tools for assessing manure quality. Further work is required to determine physical parameter categories of manures from different storage systems that are easily discernible. It will be important to correlate the physical parameter categories with chemical characteristics that can be linked to mineralisation and crop performance.

ii. **Economic assessment of pit storage manure vs. heaping**

i. A cost benefit analysis comparing heaped and pit stored manure technologies will be required to facilitate informed decisions on each storage system.

Manure storage and handling

i. to investigate, monitor and quantify potential downward movements of nutrients from storage and handling facilities.
ii. The effect of banding manure directly from the kraal in winter, versus application of anaerobically decomposed manure at the time of planting on crop growth and yield.

Application and use

i. With the presumably high labour costs for pit manure, there is need to determine to what extent net returns can be improved through targeting of application to crops/niches.
ii. To research and document long term implications of applying pit manure on a regular basis compared to heaped manure.
iii. To investigate the occurrence and significance of weed species from available manure management options.
iv. Socio-economic constraints to adoption of pit storage of manure.

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