THE UNIVERSITY OF ZAMBIA
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he effect of the nature and ratio of dry to green organic material
n decomposition and quality of Compost

BY

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ciences.

EDICATION

Dedicate this work to my late Mom and Dad and the rest of the family for all the support and ıcouragement during my long years spent at school.

Acknowledgments

The completion of this work would not have been possible without the assistance and encouragement provided by many who had a role. I thank, first my supervisor, Prof. O.I.Lungu for his support and time from his busy schedule as dean of the school of agricultural sciences, Mr. P.M Killeen, Organics general manager at AGRIFLORA for all the information and practical experience on composting, and Brother Paul Desmarais of Kasisi Agricultural Training Center for the use of library facilities. Lastly I thank all those who had a role one way or the other for the successful completion of this work.

TABLE OF CONTENTS

Appendices

List of Figures and Tables.

ABSTRACT.

This study investigated the effect of nature and ratio of grass to legume matter on decomposition and quality of compost. Composting is the process of breaking down organic materials of plants and animals to produce humus. The quality of compost varies depending on the nature of materials used and how the process is managed. One of the major limitations to composting is sourcing enough material of good quality to yield a consistent good quality end product. The requirements for composting are, organic matter, microorganisms, moisture, aeration, temperature control and labour. The hypothesis considered was that the nature of organic materials used would affect the decomposition rate, mineralisation rate and quality of the compost. In this study, the treatment materials used were the green materials sunhemp [*Crotalaria juncea*] and velvetbean [*Mucuna pruriens*]. These were composted in heaps in combination with dry grass and cattle manure at ratios of dry grass to green material of 1:1 and 2:1. The heaps were arranged in a Completely Randomised Design and replicated twice. A total of eight heaps were made and composted for twelve weeks. Decomposition rates were estimated by measuring change in volume of the heaps per week. Mineralisation rates were estimated by extracting nitrate-nitrogen (NO_3^-) and ammonium-nitrogen (NH_4^+) with potassium chloride (2M KCl) from samples taken at three-week intervals. The composts were tested for quality by estimating Cation Exchange Capacities (C.E.C) using the centrifugation method, carbon to nitrogen ratio(C/N ratio) calculated from values of total nitrogen determined by the Macro-Kjeldahl method and organic carbon by the Walkley & Black method. Available phosphorous and potassium were also determined using Bray 1 method and leaching with ammonium acetate respectively. The data were statistically analysed. The nature of organic material had no effect on the decomposition and mineralisation rates and quality of compost. This result suggests that velvet bean and sunnhemp used in combination with natural grass gives equally suitable compost. With the materials used in this study, maturity of the compost was achieved at six weeks of incubation. Varying the ratio of dry grass to fresh legume significantly ($p=0.05$) increased the decomposition and mineralization rates irrespective of the legume type. However, there was no effect on compost quality. Decomposition rate was fastest with 1:1 ratio, but there was greater reduction (65 %) in volume of the compost heap than the 2:1 ratio (48 %). In practice, this would mean that one needs a larger number of heaps in order to yield the same amount of compost. Therefore, composting at a 2:1 ratio would be desirable because of the greater yield of compost.

1.0 INTRODUCTION

One of the major limitations to increased crop production among most farmers in Zambia today is low or lack of fertilization, especially of major nutrients. Conventional farming methods rely heavily on the use of synthetic chemical fertilisers as nutrient sources. The ever-increasing cost of such fertiliser has caused problems of affordability especially to the resource–poor small scale and peasant farmers. Conventional farming methods practised extensively have also been seen to be a major contributor to the gradual loss of soil fertility to such levels that more fertilization is required if good yields are to be attained. This has resulted in low productivity; increased food costs ultimately threatening food security in the country.

The use of organic fertilisers is thus gaining importance as an alternative. Conservation methods are being encouraged as way of sustaining agricultural production. Organic farming methods are also gaining importance at commercial level due to the growth of the market for organic produce in European markets. Organic farming fits well into farmers' low input strategies and renders extra income if it can be sold as organic produce.

The challenge to the use of organic fertilisers is obtaining sufficient quantities of good quality materials. Manures and composts are the most widely used and are bulky in nature and laborious to handle and apply. Their quality and consistency also varies widely depending on a number of factors such as source, type, handling and management.

The term compost is derived from the verb decomposing which means breaking down or taking apart of organic matter. This is achieved by certain sets of organisms. A well made compost creates an environment in which decay–causing organisms can live and reproduce at an optimum rate to decompose and convert compost materials into humus, an important contributor to soil fertility. Well-made compost or natural humus contains all the elements needed by the plants.

It is important to produce and use as much compost as possible to maintain or improve fertility of soils through increased humus content of soils. The use of compost is one way of improving degraded, worn-out soils. Compost benefits plant growth by providing:

i. Sets of organisms that cycle nutrients into the right forms at the right rate to supply nutrients for healthy plant growth.
ii. Sets of inhibitory or antagonistic organisms that suppress pathogens.

iii. Better soil structure, texture, and aggregation improving moisture retention, drainage, reduced compacting for healthier root growth and less weed pressure.

iv. Sets of organisms that degrade toxic materials either in soils or compost.

v. Macro and micronutrients in addition to organic nitrogen, phosphorous and potassium; compost is an especially good supplier of trace minerals such as boron, cobalt, copper, iodine, manganese, molybdenum, zinc.

vi. Lower input costs, lower environmental costs.

The composting process uses 'waste' material to yield organic matter for use as fertiliser within several weeks depending on the ingredients used, management of the process and other factors.
The use of compost is still not widely adopted by most farmers in Zambia. This can be attributed mainly to unavailability of good quality materials to compost and the labour required to produce and apply compost. Large volumes of organic material are required to produce enough compost to apply to field crops.

The nature of organic materials used will have an effect on the quality of the compost and the time required for the composting process to be completed.
The composting process has to be carefully managed to optimise conditions for the decomposing organisms. Failure to manage the process carefully may result in slow decomposition rates, delaying the whole process and at times causing undesirable results such as putrefaction, which causes environmental pollution.

The effect of the nature of organic materials used on the composting process thus needs to be investigated in order to estimate the likely decomposition rate and quality of the compost. This will be important when making decisions on timing of operations so that the compost will be ready by the time its needed and also to determine the optimal application rates. The main objectives of this study were:

1. To determine the effect of the nature of organic materials used on the decomposition rate and mineralisation rate of compost.
2. To determine the effect of the ratio of dry grass material to fresh legume material on decomposition and mineralisation rates.

3. To investigate the effect of the nature of organic materials and the ratio of fresh to dry material on the quality of the end product (compost), in terms nitrogen, phosphorous and potassium, cation exchange capacity, and the carbon to nitrogen ratio(C/N ratio).

2.0 LITERATURE REVIEW

Composting is one way of providing plant nutrients through the natural nutrient recycling process. It is the process of breaking down organic materials to produce humus. Composting is the biological reorganization of the carbon content of organic matter, which exists in different forms, ranging from sugars to lignin. (Vukasin et.al.1995).

Composting attempts to recreate the conditions that would occur in undisturbed eco-systems where organic matter builds on the soil surface and is not regularly incorporated into the soil. Careful control of the conditions under which decomposition takes place allows the decay process to be optimised. (Lampkin, 1993). The composting process is basically centred on the nature of organic materials to be composted, the decomposition process and the composting process itself.

2.1 Nature of Organic Material

Organic matter for composting is any material that was once plant or animal. Inorganic materials such as plastics, glass, and crockery cannot be used. The presence or absence of nitrogen in any organic matter gives an indication of the likely rate of decomposition. The nitrogen content is expressed as a ratio between carbon and nitrogen(C/N ratio). The optimum C/N ratio for composting varies between 20/1 and 30/1. A higher ratio means less nitrogen and slower decomposition and a lower ratio means more nitrogen and the process may occur quickly. (Vukasin et.al.1995). The ideal C/N ratio can be obtained by using materials of different C/N ratios and thoroughly mixing them in suitable proportions. The C/N ratio and moisture content of the starting material will have a bearing on the success of the process. Table 1 shows the preferred range of C/N ratios in the starting material along with some characteristics of some likely ingredients (Organic farming, summer2001). A good C/N ratio may be obtained by using about half the volume of dry plant materials e.g. dry grass and the other half fresh materials and manure. Coarse materials such as maize stalks ideally should be chopped into pieces before adding to the compost in order to increase their surface area and speed up the decomposition process.

In addition to crop wastes, natural sources of green organic materials can be collected. Marginal, non-arable or fallow lands can be harvested regularly for weeds and other materials. Such marginal lands can also be used to cultivate good compost crops like pigweed (Amaranthus), sunnhemp, velvetbean, sesbania and other fast growing bulk species. These are good for compost due to their low C/N ratios and bulky biomass.

In this study, sunnhemp and velvet bean were selected on the basis of them being legumes, hence a lower C/N ratio (table 1). These can be grown as inter-crops with for example maize as demonstrated under conservation farming methods being promoted at the conservation farm unit by the Golden Valley Agricultural Research Trust (GART). This will have the added advantage in that the current crop will benefit from the nitrogen fixed by these legumes in the inter-crop. At the end of the season, the crop can be harvested and piled into compost heaps right in the fields where they will be spread next season before planting. This will reduce on labour, which would otherwise be required to move materials to the composting site and compost from the site to the field.

Table 1:Desired characteristics of mixed ingredients

Optimal / desired:
C/N 20/1 to 40/1
Moisture content 50-65% (60% preferred)

Material	**C/N ratio**	**Moisture %**
Vegetable waste	11:1 – 13:1	75
Cattle Manure	11:1 – 30:1	67-87
Horse Manure	22:1 – 50:1	59-79
Laying Hens	3:1 – 10:1	62-75
Grass Clippings	17:1	82
Hay	15:1 – 32:1	8-10
Straw	48:1 – 150:1	4-27
Saw Dust	200:1 – 750:1	19-65
Legume Hay	15:1 – 25:1	
Maize Stalks	60:1	

Source: Organic Farming: summer 2001 p31

2.2 Decomposition Process

The decomposition process involves the breakdown of the organic materials by macro and microorganisms to produce humus. Optimal moisture, aeration, and temperature are required for optimal functioning of decomposing organisms to optimise decomposition rate and to yield desired end products.

2.2.1 Micro and Macro Organisms

Macro and Micro organisms that are involved in the composting process range from bacteria, yeasts and moulds, algae and protozoa, visible fungi, mites, ants, termites, millipedes, beetles, earthworms. Some will survive extremely hot and cold temperatures but most thrive between 15-40°C (Walters, 1993). Larger organisms, such as ants, termites, and earthworms aid the process by reducing the size of the materials, which are then more readily broken down by smaller organisms, bacteria, fungi.

Microorganisms use organic matter, oxygen and moisture for growth and reproduction. They generate carbon dioxide, moisture and energy. The energy created is used for growth, movement and reproduction. Surplus energy is released as heat. The broken down materials provide yet more food for the organisms and the process is perpetuated until the organic matter or oxygen or moisture is depleted.

While many of these organisms may be present in the raw materials, addition of mature compost, soil or manure will accelerate decomposition by increasing numbers and diversity of organisms present in the heap. Some commercial compost inoculants can be used. If the right organisms are not present in the pile, nitrogen may be lost in form of ammonia or nitrogen gas, while carbon may escape in the form of carbon dioxide. A German scientist, Dr Ehrenfreid Pfeiffer published a small manual on composting which lists parent materials for composting and their possible combinations for good results (Acres, 1982). He was the first to use modern science to give the farmer compost starter preparations. Dr Pfeiffer began almost 60 years ago to investigate the process of composting (Walters, 1993). This led to the formulation of the biodynamic compost starter (BD) or the Pfeiffer process, composed of some 50 different organisms, most of which come from outstanding soils of the world and each with a particular mission in the pile and in the soil on which it will be placed. In addition, there are homeopathic quantities of vital trace elements, enzymes, vitamins and other growth substances, all of which play a significant role in the proper life functions of the soil. The starter has been used successfully throughout the world for several decades. However, such starter materials are expensive to obtain, as they have to be imported. For the purpose of this study, cattle manure and topsoil were used to provide microbial life to the compost heaps. These have a diverse population of microbial life, which is expected to increase with the optimised conditions in the compost heaps.

2.2.2 Moisture

It is important to regulate the moisture content to ensure optimum conditions for the organisms in the compost. The optimum moisture level is similar to that of a squeezed out sponge. Table 1 shows the preferred moisture range in the starting material. There are a number of ways to maintain a good moisture level in the heap (Foes of Famine, 1993).

Moisture can be added by providing raw materials with high moisture content like green matter mixed with drier materials. In tropical conditions, Green matter may be scarce for most of the year and when available may dry out quickly, hence moistening of the compost by adding water regularly is necessary. Moisture is also added at the time of construction of the compost and when turning the compost.

The heaps can be constructed in a sheltered position to reduce moisture loss. Protection from wind and rain also may be needed. Covering the compost with mulch, plastic sheet or a 5cm layer of soil will also reduce moisture loss. Different types of composting units can be constructed according to the season in order to accommodate the moisture levels e.g. in pits in the dry season and heaps in the rainy season.

In this study, the moisture content in the heaps was regulated by adding water once every other day for the whole period of composting. The heaps were also covered with a layer of soil, about 5 centimetres, to reduce moisture loss.

2.2.3 Aeration

This is the sustained supply of air that is essential for the microorganisms and for an effective composting process. Aeration is required to prevent the development of anaerobic conditions, which allows the growth of organisms that do not contribute positively to the process. If oxygen levels are too low, anaerobic organisms come into operation and the compost rots, rather than decays.

Methane gas (CH_4), rather than carbon dioxide (CO_2) is produced by these organisms and this may lead to a number of undesirable effects including low temperatures, slow decomposition, susceptibility to pathogen development, release of odorous compounds such as hydrogen sulphide, generation of plant toxins particularly alcohols. Turning and mixing the heap frequently, such as 1 to 2 times per week helps in aerating the heap. (Organic farming, 2001). In this study, the compost heaps were turned once per week for the whole period of composting to aerate them.

2.2.4 Temperature

Temperature control is critical to the process. The temperature of a properly constructed heap can rise to 65-70°C after a few days as the compost passes through a standard temperature–time curve of warming up and cooling down. The heat is generated as a result of microorganisms breaking down sugars, starches and fats. When these are depleted, temperature levels decrease and micro-fungi, and earthworms become active. The high temperatures are beneficial as weed seeds and pathogens are killed. However, if the heap over heats, moisture levels drop, beneficial organisms die and fungi take over halting the decomposition process.

If the temperature exceeds 65-70°C, then the heap must be broken apart, aerated, moistened and rebuilt with adequate air channels. If the temperature is too low, the heap should also be taken apart and more nitrogen (green material) added to increase microbial activity. In this study, temperature was regulated by turning and moistening the heaps when too high or adding known quantities of the green materials under investigation when too low.

3.0 COMPOSTING PROCESS

There are many ways to produce compost. Copying the natural process that occurs on the soil surface in, for example forests is known as sheet composting. A layer of organic matter is spread and maintained and the material will gradually decompose to form humus. This method is a lengthy process and can take several years to produce a healthy soil.

A more efficient and faster method is to reproduce the natural process in a concentrated way in a heap or pit. Constructing a compost heap/pit involves placing the organic materials in alternating layers to desired height (Vukasin et.al, 1995). The order may be as follows:

i. 30cm layer course material for aeration and drainage e.g. stems, stalks.
ii. 30cm moistened organic composting material e.g. dry grass, straw, hay and sawdust.
iii. 30cm green materials e.g. vegetable wastes, weeds, and in this study sunhemp and velvet bean were used.
iv. 5cm activator- mature compost, manure, soil or commercial inoculants
v. Mix thoroughly and repeat the steps until the desired height is reached, ideally 1.5 meters.
vi. Cover the heap with a layer of soil, mulch, plastic, sacks or tent to keep the heap warm and reduce moisture loss.

The minimum dimensions of an efficient heap are 1 to 1.5m width, 1.5m height, and at least 1.5m long. A narrower width or lower height prevents the heap heating up sufficiently. A wider and higher heap affects aeration in the heap. Pit composting is recommended where water is scarce as this method reduces the amount of water required. A pit can be 1m deep, 2m wide, 2m long. Fill the first 50cm of the pit with coarse material (prunings, stalks, branches) to ensure adequate drainage. Add the other materials until 1m above ground. The difficult with pit composting is the difficulty of turning the compost and labour in digging the compost pits. It is for this reason that composting was done in heaps for the purpose of this study.

The composting method used in most commercial composting operations is aerobic windrow composting. Aerobic windrow composting involves maintaining oxygen levels in the pile by regular turning, and the use of microbial starter preparations to inoculate the windrows. The process utilizes the heat produced during break down of organic matter to kill weed seeds, pathogens, and pests. Tractor pulled or self-propelled compost turners are used to keep the material aerobic in such operations. Thermal aerobic composting, as it is also called, enables producers to achieve high quality and high thorough put, with a turn over time from break down to build up into humus and maturing in just 7 to 8 weeks. There are various ways of aerobic composting (Organic farming, 2001), ranging from stock piling with occasional turning, to managed systems of windrow composting. A well-managed system ensures production of consistent, high quality compost.

Controlled microbial composting (C M C) concept is the most widely used by organic farmers worldwide. The Lubke family developed the concept in Austria over a long period of research. The method emphasises on maintaining aerobic conditions during composting by frequent turning and moistening of the windrows as a way of ensuring an optimum environment for microbial functioning. The main goal of the concept is to increase soil fertility through application of aerobically produced compost. Controlled build up of humus through humus management is possible with C M C, as a stable, homogeneous product, which is ideal for agricultural purposes, can be produced within 6 to 8 weeks. With CMC, harmful emissions or pollution of the environment through the composting process is avoided. There is no odour, no harmful gases, no leachate of any form and no ground water pollution (Hilderbrandt etal.2001). Controlled microbial composting aims at understanding natural cycles of decomposition for process control, monitoring and guidance (C M C concept). The basic principles of this method of composting are that composting is carried out in windrows and C MC starter culture (inoculant) is added to the windrow at the start of composting. Temperature and carbon dioxide levels are monitored regularly (daily), and windrows are turned when either of these measurements is too low or too high. Windrows are covered to prevent nutrient leaching, reduce gaseous emissions and reduce heat loss.

Ensuring the windrow is built in the most effective way helps develop a homogenous, well aerated and odour free heap. The actual design of the windrow will vary depending on the ingredients available, e.g.

a) $30m^3$ dry matter (hay, grass, weeds)
b) $20m^3$ manure
c) $10m^3$ finished compost
d) $15m^3$ pack house waste (vegetable)
e) $10m^3$ field waste
f) $10m^3$ clay to form the clay humus complex in the final product and a microbial inoculant to add to the diversity of microorganisms.

A small amount of soil can be added to add to the diversity of organisms .The windrow should not exceed 2.5 m width and 1.2 m in height and should be covered with a breathable cover e.g. Top Tex, polypropylene fabric. Toptex inhibits the formation of leachate, protects the compost from drying out, sheds off water like a tent but allows for the necessary gas exchange at all times. Another positive aspect of toptex is protection from harmful UV radiation thus allowing for optimum conditions for microbial function even at the very outside of the compost material.

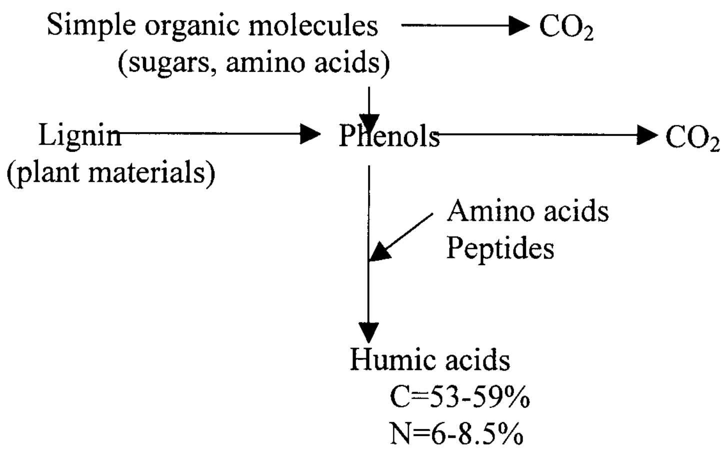
To try to answer questions about compost, Fletcher Sims, an American researcher on commercial composting wrote a short paper entitled "Composting on a Small Scale" where he pointed out that there was more to composting than just striking a good C/N ratio (Walters, 1993). Sims also noted that there is a shortage of people who know how to compost scientifically, exactly and precisely, to both accomplish the job and also to maintain a uniform product. Fletcher Sims emphasised on the role of the microorganisms in the composting process. Microorganisms ranging from bacteria, fungi, and actinomycetes break down organic materials. The organic wastes are broken down to smaller units of material such as phenols, amino acids, peptides and sugars (Linder, 1982).

Technology has now given farmers inoculants composed of many bacterial types, such as *actinomycetes, ascomycetes, yeast, moulds* and the *clostridium species*. These digest and excrete a finished product and finally contribute their bodies to the compost heap. The result is the formation of humus, which is stable, without odour, pathogens, or weed seeds. This will function in the soil as both a buffer and a source of nutrients.

The humus that results from the composting process can be of various compositions. It can be insoluble humins or humic acids ranging from low to high nitrogen content .The humus molecule is a long chain like affair with the capacity to bind plant nutrients such as phosphorous, nitrogen, amino acids, certain sugars and a host of trace minerals, becoming a veritable sponge of nutrients (Acres USA 1993). In the process developed by Sims, raw manure was prepared by sizing and proper moisture inserted. Material to be composted was placed in precise windrows, and Biodynamic starter produced by Dr. Pfeiffer introduced. The piles were turned periodically using a machine designed by Sims, which has a capacity to turn 600t/hr, and the compost was ready in about 1 month. Fletcher Sims' compost usually ran 2% nitrogen, 2% phosphorous and more than 2% potassium. Pfeiffer's biodynamic preparations were styled BD 500 to 508, each prepared in a different way. One example is BD 500 also called horn manure, which was made by packing fresh bovine manure (cattle) into a horn and inserting it in a fertile soil between late fall and spring (Pfeiffer, 1982).

Withal, composting remains more an art than a science. One who has made compost for sometime begins to get a grasp of quality, smell being one of the most revealing indicators, colour and feel coming in a close second (Sims, 1993). The best immediate indicator of compost quality is the humic acid content. There are different ways of characterising humus. It consists of humic acids and fulvic acids, as well as humin. The humic acid fraction is soluble in alkali, but insoluble in acid The fulvic acid fraction is soluble in acid as well as in alkali. The humin fraction is not soluble in either. Overall, the nitrogen content of humic acid does not go beyond 6% on a dry weight basis, of which 20 to 50% is in the form of amino acids, and 1 to10% in form of amino sugar nitrogen, (Linder, 1993).

FIGURE 1: Breakdown of Organic Matter



Source: Isotopes and Radiation in soil organic matter studies, congress Vienna, IAEA. Page 189 Haider K.M & Martin J.P (1968)

There are two processes thought to be involved in the formation of humic acids from lignin and other organic materials (Figure 2). The first is the break down process into phenols and other simple organic molecules and the second is the build up process from phenols and other factors to humic acids. (Haider and Martin, 1968). Fulvic acids tend to have more nitrogen than other humic acids. They also have more functional oxygen groups. This allows more chelating of nutrients such as nitrate, phosphate, and trace metals. Humic acid tests on Sims' "agri–formula" compost made with Petrik's CompoStar registered as high as 15% humic acids. CompoStar is an inoculant containing numerous growth regulators, cultures of bacteria, fungi and actinomycetes. It is produced by Petrik laboratories, of the USA. (Petrik, 1982).

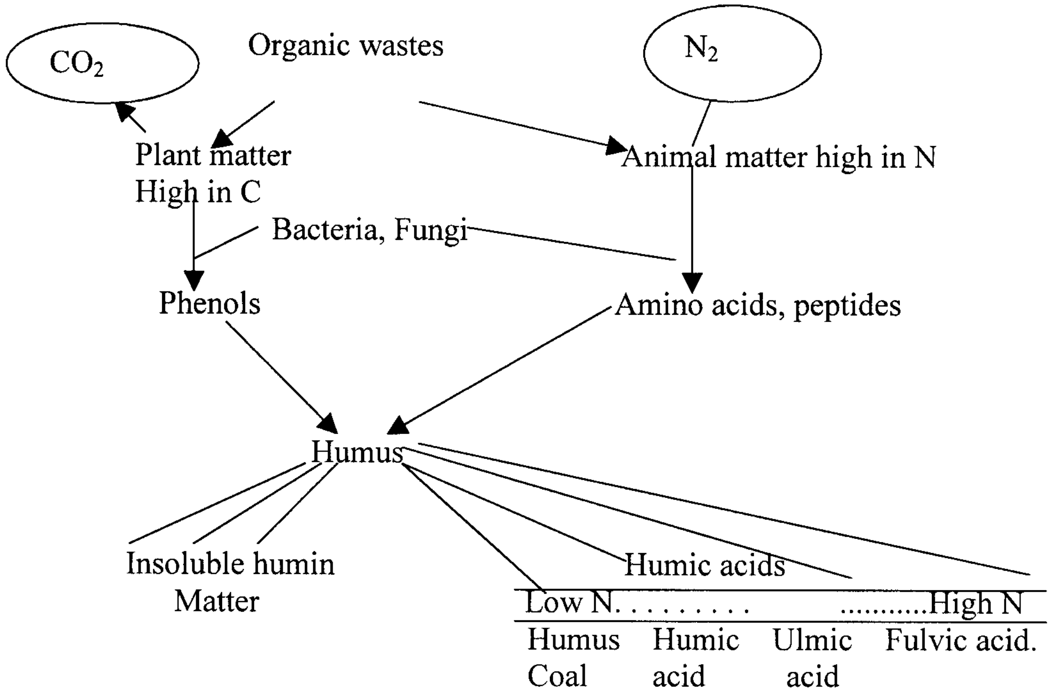
The composting option selected for the purpose of this study was based on the principles of controlled microbial composting. The method was *controlled* in that materials to be used and amounts to be used were carefully selected, *microbial* in that conditions in the heaps were monitored and controlled to favour growth and functioning of aerobic microbial life.

Labour is required for constructing, moistening and turning the heaps. To produce one tonne of compost a heap approximately 2m wide, 5m long and 2m high ($20m^3$) is required, varying depending on materials used (Lampkin, 1993). Composting is thus labour intensive and can be done during periods when labour is not required for other activities such as after harvest. To reduce labour cost, compost heaps can be sited for access to:

a) Sources of materials including animal manures.
b) Sources of water.
c) Site where compost is to be used
d) Sun in winter, shade in summer.

Building the pile next to animal enclosures will reduce the transport of manure and water but on the other hand it may increase the distance for transporting finished compost to the field. In this study, in order to make the heaps more manageable and to allow control of the process, the size of the heaps was minimised to 2 metres in length, 1.5 meters height and 0.5 meters wide. Several such heaps can be constructed instead of fewer, larger heaps, which may be difficult to manage with manual labour.

<u>Figure 2: Maria Linder's Blackboard Presentation</u>



Source: Fletcher Sims' compost. Charles Walters (1993).

4.0 MATERIALS AND METHODS

4.1 Design and Layout

Materials used for composting were grass (straw, weeds) for dry matter, and the treatment materials sunhemp and velvet bean for green matter. Cattle manure and soil were used as biological starter to inoculate the heaps. The sunhemp was grown, rain fed over the 2001/2002 rainy season. The velvet bean was grown inter cropped with maize as promoted in sustainable farming methods. In this study sunnhemp was grown broadcast as a rotation following horticultural crops grown organically. The velvet bean was grown as an intercrop with maize grown rain fed and picked as organic baby corn over the 2001/02 season. At the end of the season the sunnhemp and the velvet bean were slashed and piled into compost heaps at the edge of the fields in a completely randomised design.

The heaps were designed at two ratios of dry grass material to green legume material and these were 2 to 1, and 1 to 1, for each of the green materials sunnhemp and velvet bean. The procedure was replicated twice. Each heap was constructed in layers as follows:

i. 10 cm ($0.6m^3$) layer coarse materials, twigs of weeds.
ii. 30 cm ($0.6m^3$) moistened dry grass
iii. 15cm ($0.3m^3$) for the 2 to 1 ratio and 30cm ($0.6m^3$) for the 1 to 1 ratio of green material, sunnhemp or velvet bean respective to a heap.
iv. 5 cm ($0.1m^3$) cattle manure and a layer of soil.

This order was repeated until the heap was 1.5meters high, with a length of 2 meters and a width of 0.5 meters, giving an initial volume of 1.5 m^3. With two treatments, sunnhemp and velvet bean at two ratios with the dry grass material (1 to1 and 2 to 1), and two replications, a total of eight (8) heaps were constructed for the experiment. The heaps (experimental units) were arranged in a north-to-west direction in a straight line in order to have equal effect of the sun's rays on all the heaps as a way of reducing experimental error. The experimental design used was the Completely Randomised Design (CRD), which was set up by assigning treatments at random to a previously determined set of experimental units with little variability associated with identifiable sources. The treatments were assigned to the heaps at random using random numbers as outlined in Agricultural Experimentation, Design and Analysis (Little etal, 1985).

The heaps were labelled accordingly for ease of identification as:

i. S1a- Treated with sun hemp at 1 to 1 ratio of dry to fresh material.
ii. S1b- Treated with sun hemp at 2 to 1 ratio of dry to fresh material.
iii. S2a and S2b as replications of S1a and S1b respectively.
iv. V1a- Treated with velvet bean at 1 to 1 ratio of dry to fresh material.
v. V1b- Treated with velvet bean at 2 to 1 ratio of dry to fresh material.
vi. V2a and V2b as replications of V1a and V1b respectively.

Each heap was turned once a week and moistened every other day.

4.2 Observations and Measurements

4.2.1 Decomposition Rate

The decomposition rate was estimated by measuring the change in volume of each heap per week. Measurement of length, height and width was made once a week after turning the heaps to determine volume.

4.2.2 Mineralisation Rate

Samples were taken from each heap once every three weeks for analysis of mineralisation from each heap. Ten core samples per heap were taken randomly and composited after turning each heap. The samples were then sieved with a 2mm sieve to remove undecomposed material before being stored under refrigeration while awaiting analysis. Analysis was done in batches of samples taken every three weeks.

Mineralisation was estimated by extracting nitrate nitrogen in the samples using 2M KCl. For each of the samples 10 grams was weighed and put into a 250 ml conical flask. 100 ml of 2M KCl was then added to the sample and the flask was stoppered and placed on a reciprocating shaker for 30 minutes. The solution was then filtered to obtain a clear filtrate. 10 ml of the aliquot of the extract was placed into a distillation flask, to which 0.1 grams of magnesium oxide was added. The mixture was distilled for 3 minutes and the distillate collected into a 50 ml beaker containing 20 ml (excess) 2% Boric acid indicator solution. A spoonful of dervarda alloy was added to the residue in the distillation flask and distillation done for another 3 minutes. Nitrates were reduced to ammonium nitrogen.

The distillate was then titrated with 0.005M sulphuric acid ($H_2 SO_4$). A blank solution was also titrated with 0.005M sulphuric acid. The volume of titrant used was then determined for the sample and for the blank solution. Results were quoted as milligrams NO_3 - N per Kg air-dry compost.

4.2.3 <u>Cation Exchange Capacity</u>

The cation exchange capacity (C.E.C) of the end product of composting was determined for each heap after twelve weeks using the centrifugation method. Exactly one (1g) gram of compost was weighed and transferred into a 50 ml centrifuge tube. To this, 20 ml of 1 normal neutral ammonium acetate (NH_4Aoc) was added and the mixture mixed for 15 seconds in a vortex mixer. This was done for all the eight samples. The samples were allowed to stand for two hours, after which they were mixed and centrifuged for 5 minutes at 2500 rpm. The supernatant liquid was then decanted carefully without pouring out any compost. 20ml of 1N NH_4Aoc was added to each of the samples and the samples mixed for 15 seconds and centrifuged for 5 minutes once more. The supernatant liquid was then decanted carefully. The above two steps were repeated once more. 15ml of ethyl alcohol was then added to each of the samples and mixed for 15 seconds and the samples were then centrifuged for 5 minutes and the supernatant liquid decanted carefully. This was repeated two more times, after which 5ml acidified sodium chloride (NaCl) solution was then added to each of the samples and mixed.

The solutions were then transferred quantitatively into a steam distillation flask using pure water in a wash bottle. To this, six (6) drops of 10 N sodium hydroxide (NaOH) was added and the solution, and distilled into 20ml boric acid collecting about 30ml. The distillate was then titrated with standard acid, 0.1N sulphuric acid (H_2SO_4), to violet end point. A blank solution of 5ml NaCl in 10ml pure water was also distilled and titrated as above. The volume of acid used to titrate each sample and the volume used to titrate the blank were recorded.

The cation exchange capacity was then determined as:

$$C.E.C = [(ml_S - ml_B)* N* 100 / \text{sample weight}] \text{ meq per 100g}$$

Where: ml_S is the volume of acid used for the sample
ml_B is the volume of acid used for the blank
N is the normality of the acid.

4.2.4 Carbon to Nitrogen Ratio (C/N ratio)

The C/N ratio of the final product was determined by analysing for Total Nitrogen and Organic Matter in the sample. Organic matter was determined using the Walkley & Black method to give an indication of the carbon content in the samples. Exactly one gram of air-dry compost was weighed into a 250 cm^3 conical flask. To this, 10 cm^3 of 1N potassium dichromate ($K_2Cr_2O_7$) was added with a pipette. Then 20 cm^3 of concentrated sulphuric acid was rapidly added, directing the stream into the suspension. The suspension was then swirled gently until the compost and solution were mixed. Swirling was then done more vigorously for one minute and the suspension stored for half an hour (30 minutes) in a fume hood. After half an hour 150 cm^3 of distilled water and 10 cm^3 of concentrated phosphoric acid (H_3PO_4) were added to the suspension. The solution was then titrated with iron (2) sulphate ($FeSO_4$) solution using 10 drops (1cm^3) of diphenylamine indicator. In the beginning of titration the solution was yellow brown and progressively changed to blue and eventually violet. From then on the iron (2) sulphate solution was added very slowly until the colour abruptly changed to green. The volume of $FeSO_4$ added was then recorded. A blank titration without compost was carried out throughout the procedure to standardise the dichromate solution ($Cr_2O_7^{2-}$). The difference between the amount of $FeSO_4$ added to the blank solution and that added to the sample, or titration difference was determined. This is equivalent to the amount of dichromate reduced by organic carbon. Thus, the organic carbon content was then calculated as;

$$4 \times (a - b) / a = \%C,$$

taking the stoichiometric value of carbon to 4 instead of 3 since the oxidation process yields about 75% of the total organic carbon present. (a – b) is the titration difference, a being the amount of $FeSO_4$ added to the blank and b that added to the sample.

Total Nitrogen was determined using the Macro Kjeldahl method. The samples were sieved to 2mm mesh size to improve on accuracy. One gram was then weighed into a small beaker to which 4g of mixed catalyst was added. The mixture was then transferred into digestion tubes and 10ml concentrated sulphuric acid was added. The sample was then digested for one hour after which it was allowed to cool adequately. After cooling the sample was transferred into a 100ml volumetric flask and distilled water added quantitatively up to mark. 10ml of the distillate was then pipetted into a distillation unit to which 15ml of 10N sodium hydroxide was added. The digest was then steam distilled for 5 minutes trapping the distillate in 2% boric acid indicator solution, which changed colour from purple to green. The distillate was then titrated to purple end point with 0.01N hydrochloric acid. A blank was treated in similar manner and the total nitrogen content was determined as:

$$\% N = \frac{(a - b) \times 1.4 \times N \times 10}{\text{sample weight}}$$

Where a = cm^3 HCl used to titrate the sample

b = cm^3 HCl used to titrate the blank.

N = normality of the acid, 0.01N

The carbon to nitrogen ratio was then calculated by dividing the percent organic carbon by the percent total nitrogen.

4.2.5 Determination of Available Phosphorous.

Available phosphorous was determined in the final products using the Bray I method. About 3 grams of compost was weighed into a 500ml bottle. To this, 21ml Bray I solution was added, to have an extraction ratio of 1:7. The Bray I solution combines 0.025N HCl and 0.03N NH_4F at P^H 3.5. The mixture was then placed on a shaker for 1 minute. The solution was then filtered to obtain a clear filtrate. Five (5) ml of the filtrate was pippeted into a 25ml volumetric flask and 10ml of distilled water. To this, 4ml of reagent B was then added and the mixture made up to mark with distilled water. Shaking was then done to homogenise the mixture, after which it was allowed to stand for colour to develop. Working standards of 0 mgL^{-1}, 0.5 mgL^{-1}, and 1 mgL^{-1} were prepared from standard stock solution for use in calibrating the spectrophotometer. The concentration of phosphorous was then read on a spectrophotometer at 882nm in mgL^{-1} and the results converted to milli-gram per kg compost.

4.2.6 Determination of Exchangeable Potassium.

Exchangeable potassium was determined in the final product by extracting with 1N ammonium acetate (NH_4Aoc) buffered at pH 7. Ten grams of compost was weighed into a conical flask and to this, 50ml of 1N NH_4Aoc was added. The mixture was then placed on a shaker for 30 minutes after which it was filtered to obtain a clear filtrate. The filtrate was then analysed for potassium concentration using an Atomic Absorption Spectrometer (A.A.S).

5.0 RESULTS

5.1 Decomposition Rate

Table 5.1a Measured Volume of compost heaps Per Week (m^3).

Trt.	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8	Wk9	Wk10	Wk11	Wk12
S1a	**1.5**	1.50	1.46	1.30	1.12	1.00	0.87	0.65	0.52	0.48	0.42	**0.41**
V1a	**1.5**	1.46	1.33	1.15	1.10	1.00	0.84	0.61	0.44	0.42	0.39	**0.37**
S1b	**1.5**	1.50	1.48	1.46	1.43	1.33	1.20	1.12	0.85	0.62	0.54	**0.51**
V1b	**1.5**	1.46	1.38	1.37	1.24	1.12	0.84	0.72	0.54	0.48	0.46	**0.46**
S2a	**1.5**	1.50	1.44	1.30	1.25	1.10	0.96	0.77	0.62	0.58	0.54	**0.42**
V2a	**1.5**	1.48	1.41	1.39	1.28	1.15	0.98	0.78	0.59	0.54	0.48	**0.41**
S2b	**1.5**	1.50	1.43	1.42	1.38	1.24	1.12	1.80	0.79	0.58	0.52	**0.43**
V2b	**1.5**	1.48	1.39	1.34	1.20	1.14	0.86	0.71	0.58	0.46	0.42	**0.40**

The decomposition rate was calculated as:

$$OM_t = OM_o * e^{-kt} \quad \text{Where,}$$

OM_t is the volume of the heap at time t,
OM_o is the initial volume of the heap at time 0,
k is the decomposition rate and
t is the time in weeks.

Table 5.1 b Calculated Decomposition Rates of compost heaps (Per Week)

sample▶	**S1a**	**V1a**	**S1b**	**V1b**	**S2a**	**V2a**	**S2b**	**V2b**
OM_o ▶	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
time▼	**k**	**k**	**k**	**k**	**k**	**k**	**k**	**k**
1	0	0.027	0	0	0	0	0	0
2	0	0.027	0	0.007	0	0.007	0	0.007
3	0.005	0.040	0.005	0.007	0.014	0.025	0.016	0.021
4	0.007	0.066	0.007	0.021	0.029	0.028	0.014	0.019
5	0.029	0.062	0.010	0.018	0.036	0.045	0.017	0.032
6	0.049	0.068	0.040	0.032	0.052	0.046	0.032	0.044
7	0.058	0.083	0.032	0.049	0.064	0.079	0.042	0.061
8	0.068	0.112	0.049	0.083	0.083	0.094	0.051	0.082
9	0.093	0.136	0.063	0.083	0.098	0.106	0.071	0.102
10	0.106	0.127	0.088	0.093	0.095	0.118	0.095	0.102
11	0.104	0.122	0.093	0.104	0.116	0.116	0.096	0.104
12	0.104	0.122	0.093	0.104	0.116	0.110	0.104	0.108
Average	**0.052**	**0.083**	**0.04**	**0.050**	**0.059**	**0.065**	**0.045**	**0.057**

5.1.1 Statistical Analysis of Decomposition Rates

5.1.1a Decomposition Rate: Sunhemp Vs Velvetbean at 1:1 ratio

The complete statistical analysis and ANOVA Table are shown in Appendix 1a. The F value observed was 4.000, which is less than the required F value, 18.51 at 5% confidence level. This means that there was no significant difference in decomposition rate between heaps treated with sunhemp and those treated with velvetbean at 1:1 ratio.

5.1.1b Decomposition Rate: Sunhemp Vs Velvetbean at 2:1 ratio

The complete statistical analysis and ANOVA Table is shown in Appendix 1b. The F value observed was 2.000, which is less than the required F value, 18.51 at 5% confidence level. This means that there was no significant difference in decomposition rate between heaps treated with sunhemp and those treated with velvetbean at 2:1 ratio.

5.1.1c Decomposition Rate: Sunhemp at 1:1 ratio Vs. Sunhemp at 2:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 1c. The observed F value was 20.000, which is more than the required F value of 18.5 at 5% confidence level. This means that there was a significant difference in the decomposition rate between heaps treated with sunhemp at 1:1 and those treated at 2:1 ratio of dry to green material. L.S.D analysis indicated that the 1:1 treatment was superior.

5.3.3d Decomposition Rate Velvetbean at 1:1 Vs. Velvetbean at 2:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 1d. The F value observed was 21.3889, which is more than the required F value of 18.5 at 5% confidence level. This means that there was a significant difference in C/N decomposition rate between heaps treated with velvetbean at 1:1 and those treated at 2:1 ratio of dry to green material. L.S.D analysis indicated that the 1:1 treatment was superior.

5.2 Cation Exchange Capacity (C.E.C)

Table 5.2. Calculated C.E.C Values of Compost

Sample	Treatment	C.E.C $cmolkg^{-1}$ compost
S1a	Sunhemp, 1:1 ratio	46.5
V1a	Velvetbean, 1:1 ratio	18.5
S1b	Sunhemp, 2:1 ratio	17.5
V1b	Velvetbean 2:1 ratio	12.0
S2a	Sunhemp, 1:1 ratio	29.0
V2a	Velvetbean, 1:1 ratio	22.0
S2b	Sunhemp, 2:1 ratio	18.0
V2b	Velvetbean, 2:1 ratio	26.0

5.2.2 Statistical Analysis of C.E.C data

5.2.3a Sunhemp Vs. Velvetbean at 1:1 ratio

The complete statistical analysis and analysis of variance Table (ANOVA) are shown in Appendix 2a. From Appendix 2a, the observed F value was 12.75, which is less than the required F value 18.51 at 5% confidence level. This means there was a non significant difference in C.E.C between the heaps treated with sunhemp versus those treated with velvetbean at 1:1 ratio of dry to green material.

5.2.3b Sunhemp Vs. Velvetbean at 2:1 ratio

The complete statistical analysis and ANOVA Table are shown in Appendix 2b. The observed F value was 17.9, which is less than the required F value, 18.51 at 5% confidence level. This means there was a non significant difference in C.E.C between the heaps treated with sunhemp versus those treated with velvetbean at 2:1 ratio of dry to green material.

5.2.3c Sunhemp at 1:1 ratio Vs. Sunhemp at 2:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 2c. The observed F value was 13.3, which is less than the required F value, 18.51 at 5% confidence level. This means that there was a non significant difference in C.E.C between the heaps treated with sunhemp at 1:1 ratio and those treated with sunhemp at 2:1 ratio.

5.2.3d Velvetbean at 1:1 ratio Vs Velvetbean at 2:1 ratio

The complete statistical analysis and ANOVA Table are shown in Appendix 2d. The observed F value was 0.620, which is less than the required F value of 18.51 at 5% confidence. This means that there was no significant difference in C.E.C between the heaps treated with velvetbean at 1:1 and at 2:1 ratio of dry to fresh material.

5.3 Carbon to Nitrogen Ratio (C/N ratio)

5.3.1 Organic Carbon

Table 5.3.1 Organic Carbon content of compost

Sample	Treatment	Total organic carbon %
S1a	Sunhemp, 1:1 ratio	3.0
V1a	Velvetbean, 1:1 ratio	2.9
S1b	Sunhemp, 2:1 ratio	3.2
V1b	Velvetbean 2:1 ratio	2.7
S2a	Sunhemp, 1:1 ratio	3.0
V2a	Velvetbean, 1:1 ratio	2.9
S2b	Sunhemp, 2:1 ratio	3.2
V2b	Velvetbean, 2:1 ratio	2.8

5.3.2 Total Nitrogen and C/N ratios

Table 5.3.2 Total Nitrogen and C/N ratios of Compost

Sample	Treatment	% N	C/N
S1a	Sunhemp, 1:1 ratio	0.30	10:1
V1a	Velvetbean, 1:1 ratio	0.36	8:1
S1b	Sunhemp, 2:1 ratio	0.26	12:1
V1b	Velvetbean 2:1 ratio	0.30	9:1
S2a	Sunhemp, 1:1 ratio	0.30	10:1
V2a	Velvetbean, 1:1 ratio	0.29	10:1
S2b	Sunhemp, 2:1 ratio	0.26	12:1
V2b	Velvetbean, 2:1 ratio	0.28	10:1

5.3.3 Statistical Analysis of C/N Ratio

5.3.3a C/N ratio Sunhemp Vs C/N ratio Velvetbean at 1:1 ratio

The complete statistical analysis and ANOVA Table are shown in Appendix 3a. The F value observed was 0.211, which is less than the required F value, 18.51 at 5% confidence level. This means that there was no significant difference in C/N ratio between heaps treated with sunhemp and those treated with velvetbean at 1:1 ratio.

5.3.3b C/N ratio Sunhemp Vs C/n ratio Velvetbean at 2:1 ratio

The complete statistical analysis and ANOVA Table is shown in Appendix 3b. The F value observed was –0.08, which is less than the required F value, 18.51 at 5% confidence level. This means that there was no significant difference in C/N ratio between heaps treated with sunhemp and those treated with velvetbean at 2:1 ratio.

5.3.3c C/N ratio Sunhemp at 1:1 Vs. C/N ratio Sunhemp at 2:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 3c. The observed F value was 0, which is less than the required F value of 18.5 at 5% confidence level. This means that there was no significant difference in the C/N ratio between heaps treated with sunhemp at 1:1 and those treated at 2:1 ratio of dry to green material.

5.3.3d C/N ratio Velvetbean at 1:1 Vs. C/N ratio Velvetbean at 2:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 3d. The F value observed was 0.154, which is less than the required F value of 18.5 at 5% confidence level. This means that there was no significant difference in C/N ratio between heaps treated with velvetbean at 1:1 and those treated at 2:1 ratio of dry to green material.

5.4 Available Phosphorous

Table 5.4 Available Phosphorous in compost

Sample	Treatment	Available P $mgkg^{-1}$
S1a	Sunhemp, 1:1 ratio	18
V1a	Velvetbean, 1:1 ratio	21
S1b	Sunhemp, 2:1 ratio	17
V1b	Velvetbean 2:1 ratio	19
S2a	Sunhemp, 1:1 ratio	19
V2a	Velvetbean, 1:1 ratio	22
S2b	Sunhemp, 2:1 ratio	19
V2b	Velvetbean, 2:1 ratio	17

5.4.1 Statistical Analysis of Available Phosphorous.

5.4.1a Available P Sunhemp Vs. available P Velvetbean at 1:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 4a. The observed F value was 1.00, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in available phosphorous between heaps treated with sunhemp and those treated with velvetbean at 1:1 ratio of dry to fresh material.

5.4.1b Available P Sunhemp Vs. Available P Velvetbean at 2:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 4b. The observed F value was 0.00, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in available phosphorous between heaps treated with sunhemp and those treated with velvetbean at 2:1 ratio of dry to fresh material.

5.4.1c Available P Sunhemp at 1:1 Vs. Available P Sunhemp at 2:1

The complete statistical analysis and ANOVA Table are shown in Appendix 4c. The observed F value was 0.182, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in available phosphorous between heaps treated with sunhemp at1: 1 ratio and those treated with sunhemp at 2:1 ratio of dry to fresh material.

5.4.1d Available P Velvetbean at 1:1 Vs. Available P Velvetbean at 2:1

The complete statistical analysis and ANOVA Table are shown in Appendix 4d. The observed F value was 8.182, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in available phosphorous between heaps treated with velvetbean at1: 1 ratio and those treated with velvetbean at 2:1 ratio of dry to fresh material.

5.5 Exchangeable Potassium

Table 5.5 Available Potassium in compost

Sample	Available K		
	AAS reading, $mgkg^{-1}$	$cmolkg^{-1}$ compost	% C.E.C
S1a	125	3.205	10.6
V1a	110	2.821	15.2
S1b	105	2.692	15.4
V1b	103	2.641	13.2
S2a	121	3.103	10.7
V2a	115	2.949	13.4
S2b	100	2.564	14.2
V2b	98	2.513	9.7

5.5.1 Statistical Analysis of Exchangeable Potassium

5.5.1a Exchangeable K Sunhemp Vs. Exchangeable K Velvetbean at 1:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 5a. The observed F value was 10.286, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in exchangeable potassium between heaps treated with sunhemp and those treated with velvetbean at 1:1 ratio of dry to fresh material.

5.5.1b Exchangeable K Sunhemp Vs. Exchangeable K Velvetbean at 2:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 5b. The observed F value was 0.375, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in exchangeable potassium between heaps treated with sunhemp and those treated with velvetbean at 2:1 ratio of dry to fresh material.

5.5.1c Exchangeable K Sunhemp at 1:1 Vs. Exchangeable K Sunhemp at 2:1

The complete statistical analysis and ANOVA Table are shown in Appendix 5c. The observed F value was 39.429, which is more than the required F value of 18.51 at 5% confidence level. This shows that there was a significant difference in exchangeable potassium between heaps treated with sunhemp at 1:1 ratio and those treated with sunhemp at 2:1 ratio of dry to fresh material. Mean separation using L.S.D gave a value of 0.189, which is less than the difference between the means, 0.526. This means that the difference between the means is not significant however.

5.5.1d Exchangeable K Velvetbean at 1:1 Vs. Exchangeable K Velvetbean at 2:1

The complete statistical analysis and ANOVA Table are shown in Appendix 5d. The observed F value was 11.875, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in exchangeable potassium between heaps treated with velvetbean at 1:1 and those treated with velvetbean at 2:1 ratio of dry to fresh material.

5.6 Mineralisation Rate: Available Nitrogen, NH_4^+ and NO_3-

Table 5.6.1 Ammonium and Nitrate nitrogen content ($mgkg^{-1}$)

Week	1		3		6		9		12	
sample	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-
S1a	14	28	98	119	147	168	154	175	161	203
V1a	7	21	77	98	154	175	154	175	70	105
S1b	7	21	77	105	133	154	154	154	112	140
V1b	0	18	70	84	140	147	147	154	84	133
S2a	21	28	105	98	126	147	154	168	140	189
V2a	7	28	77	98	147	154	154	175	91	119
S2b	0	18	91	105	140	154	147	154	91	140
V2b	0	0	77	98	112	154	154	154	98	126

N.B

$$mgkg^{-1} = \frac{(cm^3 sample - cm^3 blank) * 0.35}{g\ compost * \frac{10^{-3}Kg}{g}}$$

5.6.2 Mineralisation Rates

Mineralisation rate k, is given as

$$N_{min} = N_o\,[1-e^{-kt}]$$

Where: Nmin is the mineralised nitrogen or NO_3- N,
No is the potentially mineralisable nitrogen or total nitrogen in the original material,
The mineralisation rate is k and
The time period is t in weeks.

Table 5.6.2 Mineralisation Rates of compost heaps (per week)

sample▶	S1a	V1a	S1b	V1b	S2a	V2a	S2b	V2b
N_o ▶	30	24	24	20	30	24	24	20
time▼	**k**	**k**	**k**	**k**	**k**	**k**	**k**	**k**
1	0.66	0.63	0.63	0.64	0.66	0.63	0.56	0.62
3	0.53	0.54	0.56	0.55	0.50	0.54	0.56	0.59
6	0.31	0.35	0.33	0.35	0.30	0.33	0.31	0.36
9	0.21	0.24	0.22	0.24	0.21	0.24	0.22	0.24
12	0.16	0.18	0.16	0.18	0.16	0.18	0.17	0.18
Average	**0.37**	**0.39**	**0.38**	**0.39**	**0.37**	**0.38**	**0.36**	**0.40**

5.6.3 Statistical Analysis of Mineralisation Rates

5.6.3.1a Mineralisation rates; Sunhemp Vs. Velvetbean at 1:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 6a. The observed F value was 0.00, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in mineralisation rate between heaps treated with sunhemp at 1:1 and those treated with velvetbean at 1:1 ratio of dry to fresh material.

5.6.3.1b Mineralisation rates; Sunhemp Vs. Velvetbean at 2:1 ratio.

The complete statistical analysis and ANOVA Table are shown in Appendix 6b. The observed F value was 7.00, which is less than the required F value of 18.51 at 5% confidence level. This shows that there was no significant difference in mineralisation rate between heaps treated with sunhemp at 2:1 and those treated with velvetbean at 2:1 ratio of dry to fresh material.

5.6.3.1c Mineralisation rates; Sunhemp at 1:1 Vs. Sunhemp at 2:1

The complete statistical analysis and ANOVA Table are shown in Appendix 6c. The observed F value was 20.00, which is more than the required F value of 18.51 at 5% confidence level. This shows that there was a significant difference in mineralisation rate between heaps treated with sunhemp at 1:1 and those treated with sunhemp at 2:1 ratio of dry to fresh material. Analysis of L.S.D indicated that the mean for 1:1 ratio was superior.

5.6.3.1d Mineralisation rates; Velvetbean at 1:1 Vs. Velvetbean at 2:1

The complete statistical analysis and ANOVA Table are shown in Appendix 6d. The observed F value was 20.00, which is more than the required F value of 18.51 at 5% confidence level. This shows that there was a significant difference in mineralisation rate between heaps treated with velvetbean at 1:1 and those treated with velvetbean at 2:1 ratio of dry to fresh material. L.S.D analysis indicated that the mean for the 1:1 ratio was superior.

6.0 DISCUSSION

A summary of the results of the study is shown in Appendix 9. The effect of the nature of organic material on decomposition and mineralisation rates is shown in Table 9.1. From the table it can be seen that the nature of organic material had no effect on decomposition and mineralisation rates at the given level of confidence. This can be attributed to the fact that treatment materials, sunhemp and velvetbean are both legumes, hence have similar C/N ratio and nutrition for the microorganisms.

However, as shown in Table 9.2, the effect of the ratio of dry to fresh material indicated that there was a significant difference in decomposition and mineralisation rates. Heaps treated at 1:1 ratio had higher rates of decomposition and mineralisation than those treated at 2:1 ratio. Charts of decomposition versus time and mineralisation versus time are shown in Appendices 7 and 8 respectively. Generally it can be observed from these graphs that decomposition was faster in heaps treated at 1:1 ratio than those at 2:1 ratio. Similarly, the heaps treated at 1:1 ratio had higher mineralisation rates with nitrate accumulation reaching a constant (maximum) value at or just after the sixth week of composting. The higher rates in 1:1 ratio heaps was due to the fact that these heaps contained more green material indicating a high nitrogen content than those heaps treated at 2:1 ratio.

Decomposition and mineralisation were slow during the first three weeks. This could be attributed to the low temperature prevailing at the time (last week of May and early June). Microorganisms require certain optimum temperature for optimum function usually 20 to 35^{o} C (Lampkin, 1993). Atmospheric conditions in this case had direct influence as the heaps were covered with a layer of soil, which may not have been very effective in keeping the heaps warm during the cold periods. Advanced composting methods suggest that heaps are covered with materials such as plastic, toptex covers but these may make the composting exercise costly and unaffordable for resource poor small scale and peasant farmers.

Mineralisation and decomposition started reaching a near constant value after week 6 (Appendix 7) as the material depleted (decomposed), until a final rate was assumed after 12 weeks (table 9.2). Final heap volumes as indicated in table 5.1 show that heaps treated at 1:1 ratio reduced more than those treated at 2:1, hence the high amount of green material caused a high reduction in volume. Organic matter represents nitrogen on the move. In finished compost it is in a more static condition and less is given off. The rate of nitrogen movement depends on the C/N ratio of organic matter, if it is high the movement will be slow, as in the heaps treated at 2:1, while if its low, the movement will be fast as in heaps treated at 1:1 ratio. In the finished product despite the C/N ratio being low there is resistance to rapid decomposition and the movement is slower and will take place over a longer period of time.

The effect of the nature of organic material on compost quality is summarised in table 9.3a. Average results indicate that there were no significant differences in compost quality with regards to the nature of organic material at the given level of confidence. In terms of C.E.C, there was no effect on C.E.C values at the given level of significance. The final product of the composting process is decomposed material or humus, which does not differ significantly in quality regardless of the nature of the original material. Humus is the end product of the decomposition and re-composition of organic matter by microorganisms (Organic farming, 2001).

Total nitrogen values obtained in the final product also show that there was no effect on nitrogen content, since the materials are both legumes. There was not much difference in phosphorous levels statistically but the trend in results shows that heaps treated with sunhemp had less phosphorous concentration than those treated with velvetbean. Also heaps with 1: 1 ratio of dry to fresh material had higher P values than those at 2:1. Generally, sunhemp and velvetbean have about equal concentration of phosphorous, 0.2% (Agrodok 8,1999). Values obtained ranged from 17 mg/kg to 22mg/kg, which is moderate in terms of plant requirement (Albrecht, 973). Generally there was no effect on potassium concentration at the given level of confidence, but the trend in results is that heaps treated with sunhemp gave higher values than those treated with velvetbean and so were those treated at 1: 1 ratio over 2: 1 ratio of dry to fresh material. Values ranged from 98 mg/kg to 125 mg/kg, which is low to moderate since interpretation of results (Albrecht, 1973) is such that below 70 mg/kg is very low.

The carbon to nitrogen (C/N) ratios obtained ranged from 8 to 10 and generally there was no statistical difference in C/N ratios. However, the trend in results shows that samples treated with sunhemp had slightly higher ratios than those with velvetbean and the same holds for those treated at 1:1 as opposed to those at 2:1. There was thus more decomposition in heaps treated with velvetbean and those at 1:1 ratio of dry to fresh materials. Humus averages about 10:1 in C/N ratio (Miller 2000). The C/N ratio of the starting material was not determined in the laboratory but from literature, using green manure (12/1), straw (80/1) and farmyard manure 20/1) in a heap gives estimated average C/N ratios of 40/1 for heaps made with 1:1 ratio of straw to green manure and about 60/1 for heaps made at 2:1 ratio (Agrodok 8, 1999). This shows a reduction in C/N ratio of about 75% to 60% following composting.

From these results, it can be seen that using either velvetbean or sunhemp will not have much effect on decomposition and mineralisation rates of compost and also on compost quality. However, the ratio of dry grass to fresh legume material will have an effect on decomposition and mineralisation, with heaps having high amounts of green material decomposing and mineralising at faster rates than heaps with more dry material. However, heaps treated with more green material resulted in high reduction in volume (65%), which has implications on the volume of compost that is required to meet field requirements. Since there is a non significant effect on quality, for the purpose of reducing on the number of heaps or volume of material to compost it would be ideal to use 2:1 ratio of dry to fresh material though the process would take more time to complete.

7.0 CONCLUSSION AND RECOMMENDATIONS

The results of this study have shown that the nature of organic material used in composting has no effect on decomposition and mineralisation rates at the given level of confidence. The materials tested are both leguminous in nature, hence there is need to investigate other materials, which can equally and economically be used for compost. The study results indicated that the ratio of dry grass to fresh legume material will have a significant effect on decomposition and mineralisation rates but has no effect on compost quality. Having more nitrogen in the heap made the process faster but the high reduction in volume means more materials will need to be composted to meet field application requirements. Compost is an organic fertilizer and as can be seen from the quality results, the nutrients are not as concentrated as in chemical fertilizers hence large volumes are required if adequate supply is to be met. Since there is no difference in the quality of the end product, using a high ratio of dry to fresh material will be advantageous in that there will be less reduction, requiring less heaps to produce a given volume of compost. The materials investigated in this study are good compost materials in that they are legumes, hence have a low C/N ratio and also they produce a bulky biomass. The materials can also be grown by the farmer at little cost on marginal land or as intercrops with field crops like maize.

Composting is very laborious and requires dedication and hard work to be successful if large volumes to meet field requirements are to be produced. There is thus need for further research on reducing labour requirements for composting, such as designing affordable turning and watering machines since the ones currently on the market are too expensive even for commercial farmers. There is also need for further research on optimisation of the composting process to reduce on time required for the process to be complete whilst maintaining, if not improving on compost quality.

Composting requires specific sets of microorganisms, without which the organic matter will not be transformed into humus, but merely decomposed to a consistency that is merely decomposed waste. The process should thus in all angles favour microbial growth and function if results are to be optimised. The nature of organic material should be of high quality (nitrogen and carbon balance), the conditions in the heap should be aerobic, with sufficient heat and optimised moisture level. Ploughing under organic matter requires that conditions in the soil are ideal for the proper functioning of microorganisms to be able to decompose these materials. This may not be guaranteed especially in degraded, acidic soils with low organic matter, which is common on lands extensively fertilized using chemical fertilizers as is common on most soils in Zambia today. Legumes may also fail to fix atmospheric nitrogen in acidic conditions where the activity of the symbiotic bacteria responsible for fixation is reduced, making the rotation or inter crop ineffective or costly to the current crop. Composting guarantees decomposition and also adds life to the soil, which is important for many soil reactions involving plant nutrients. To make the best compost, the microorganisms must be able to function optimally and this can be achieved if the mentioned factors are combined to the best advantage.

Compost is used as an organic fertilizer, which can be added to the soil, or as a foliar spray. Compost benefits plant growth by providing nitrogen, phosphorous and potassium, which were found to be in sufficient amounts in this study. In addition compost contains micronutrients, not investigated in this study as well as sets of organisms that aid in decomposition of soil organic matter and in transforming plant minerals into available forms. Compost "teas" have also been found to be helpful in control of fungal and other diseases such as fusarium on several crops (Martens, 2001).

The composting method used in this study employed smaller heap sizes as a way of optimising the process. Large amounts of compost are required for field crops e.g. $20m^3$/ha (Agrodok 8, 1999), making compost fertilizer unattractive for use on field crops. Several small heaps can be made in a field after harvesting the crop grown as intercrop with either velvetbean or sunhemp. Water can be supplied by placing 210 litre drums at the end of each field. From observations made in this study, the 8 heaps required about 10 litres of water per heap every week, bringing total requirement to 960 litres for the 12 weeks of composting. The final total volume was approximately $3.4m^3$ for the 8 heaps; hence for an application rate of $20m^3$, about 47 heaps would be needed requiring about 5640 litres of water. Further the advantage of having the heaps made in the field is that it makes application easier as the material is already in the field, especially for farmers opting to adopt the potholing method. Compost will also make efficient use of fertilizer added as it prevents leaching by acting as a sponge for the nutrients, due to the high C.E.C values as observed in this study.

APPENDIX 1: **Statistical Analysis of Decomposition Rates**

Treatment	**Replication**		**Total Yi.**	**Mean Yi.**
	1	**2**		
	Yij	Yij		
	Yij	Yij		
			Y.. =	**Y.. =**

KEY

1.Correction Factor, $\mathbf{C} = \frac{(Y..)^2}{r\,n}$ where, r is the replications and n the number of treatments

2.Sums of Square Treatment **(SST)** = $\frac{(\sum Yi.)^2}{r} - C$

3.Mean Square Treatment **(MST)** = $\frac{SST,}{DfT}$ where d.ft is the degrees of freedom for treatments.

4.Total Sums of Square **(TSS)** = $\sum Yij^2 - C$

5.Sums of Square Error **(SSE)** = **TSS -SST**

6. Mean Square Error **(MSE)** = $\frac{SSE,}{d.fE}$ where d.fE is the degrees of freedom error.

7. Observed F value,(**Fo**) = $\frac{MST}{MSE}$

8.Ft is the F value obtained from tables at 5% level of confidence.

9. Least Significant Difference **(LSD)** = $t_{0.05} * \sqrt{2s^2/r}$

N.B

The key indicated above was used for all the statistical analyses indicated in appendices 1 to 6.

Appendix 1a: ANOVA Tables

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0006			
Treatment	1	0.0004	0.0004	4.000	18.51
Error	2	0.0002	0.0001		

Appendix 1b

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0002			
Treatment	1	0.0001	0.0001	2.000	18.51
Error	2	0.0001	0.00005		

Appendix 1c

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0002			
Treatment	1	0.0002	0.0002	20.000	18.51
Error	2	0.0000	0.0000		

Appendix 1d

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0007			
Treatment	1	0.0043	0.0043	21.3889	18.51
Error	2	0.0036	0.0018		

APPENDIX 2: **Statistical Analysis of Cation Exchange Capacities (ANOVA Tables)**

Appendix 2a

Source	d.f	SS	MS	Fo	Ft
Total	3	92.2			
Treatment	1	85.5	85.5	12.7	18.51
Error	2	6.7	3.9		

Appendix 2b

Source	d.f	SS	MS	Fo	Ft
Total	3	45.7			
Treatment	1	27.5	27.5	17.9	18.51
Error	2	18.2	6.1		

Appendix 2c

Source	d.f	SS	MS	Fo	Ft
Total	3	138.7			
Treatment	1	138	138	13.3	18.51
Error	2	0.7	0.35		

Appendix 2d

Source	d.f	SS	MS	Fo	Ft
Total	3	31.7			
Treatment	1	7.5	7.5	0.620	18.51
Error	2	24.2	12.1		

APPENDIX 3: **<u>Statistical Analysis of C/N ratios</u>**

Appendix 3a

Source	d.f	SS	MS	Fo	Ft
Total	3	24			
Treatment	1	16	16	0.211	18.51
Error	2	152	76		

Appendix 3b

Source	d.f	SS	MS	Fo	Ft
Total	3	96			
Treatment	1	4.0	4.0	0.08	18.51
Error	2	100	50		

Appendix 3c

Source	d.f	SS	MS	Fo	Ft
Total	3	4.0			
Treatment	1	4.0	4.0	0.00	18.51
Error	2	0	0		

Appendix 3d

Source	d.f	SS	MS	Fo	Ft
Total	3	2.7			
Treatment	1	0.2	0.2	0.154	18.51
Error	2	2.5	1.3		

APPENDIX 4: Statistical Analysis of Available Phosphorous

Appendix 4a

Source	d.f	SS	MS	Fo	Ft
Total	3	0.01			
Treatment	1	0.01	0.01	1.00	18.51
Error	2	0.02	0.01		

Appendix 4b

Source	d.f	SS	MS	Fo	Ft
Total	3	0.01			
Treatment	1	0.00	0.00	0.00	18.51
Error	2	0.01	0.005		

Appendix 4c

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0024			
Treatment	1	0.0002	0.0002	0.1819	18.51
Error	2	0.0022	0.0011		

Appendix 4d

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0112			
Treatment	1	0.009	0.009	8.1819	18.51
Error	2	0.0022	0.0011		

APPENDIX 5: **Statistical Analysis of Exchangeable Potassium**

Appendix 5a

Source	d.f	SS	MS	Fo	Ft
Total	3	0.085			
Treatment	1	0.072	0.072	10.286	18.51
Error	2	0.013	0.007		

Appendix 5b

Source	d.f	SS	MS	Fo	Ft
Total	3	0.019			
Treatment	1	0.003	0.003	0.375	18.51
Error	2	0.016	0.008		

Appendix 5c

Source	d.f	SS	MS	Fo	Ft
Total	3	0.290			
Treatment	1	0.276	0.276	39.429	18.51
Error	2	0.014	0.007		

Appendix 5d

Source	d.f	SS	MS	Fo	Ft
Total	3	0.112			
Treatment	1	0.095	0.095	11.875	18.51
Error	2	0.017	0.008		

APPENDIX 6: **Statistical Analysis of Mineralisation Rates**

Appendix 6a

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0003			
Treatment	1	0.0003	0.0003	0.0000	18.51
Error	2	0.0000	0.0000		

Appendix 6b

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0009			
Treatment	1	0.0007	0.0007	7.00	18.51
Error	2	0.0002	0.0001		

Appendix 6c

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0002			
Treatment	1	0.0000	0.0000	20.0000	18.51
Error	2	0.0002	0.0001		

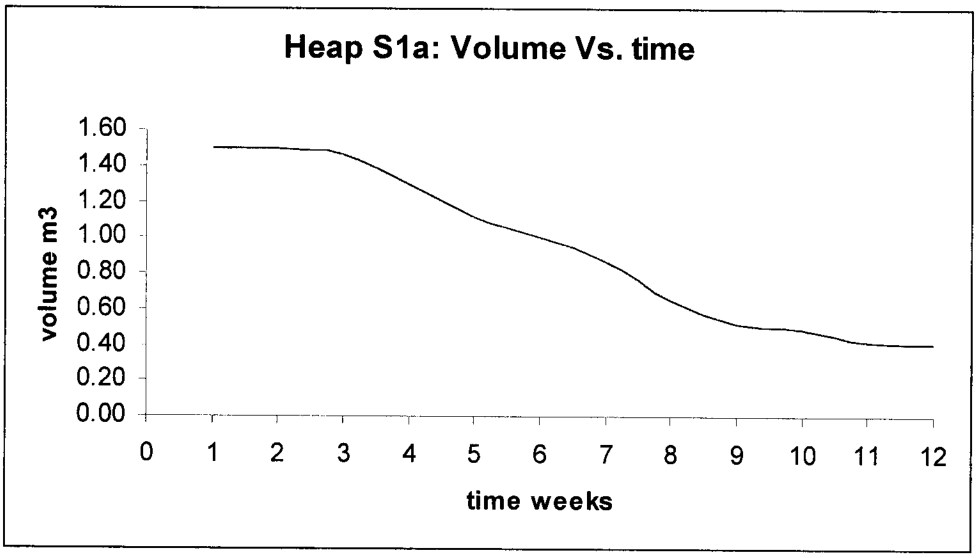
Appendix 6d

Source	d.f	SS	MS	Fo	Ft
Total	3	0.0002			
Treatment	1	0.0001	0.0001	20.00	18.51
Error	2	0.0001	0.00005		

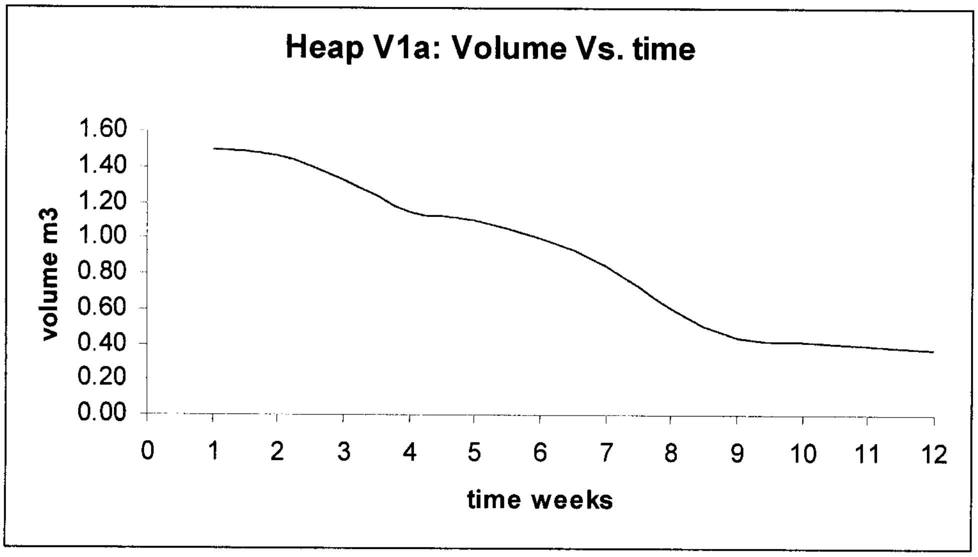
APPENDIX 7

Appendix 7a : **Charts of Volume Change Versus Time**

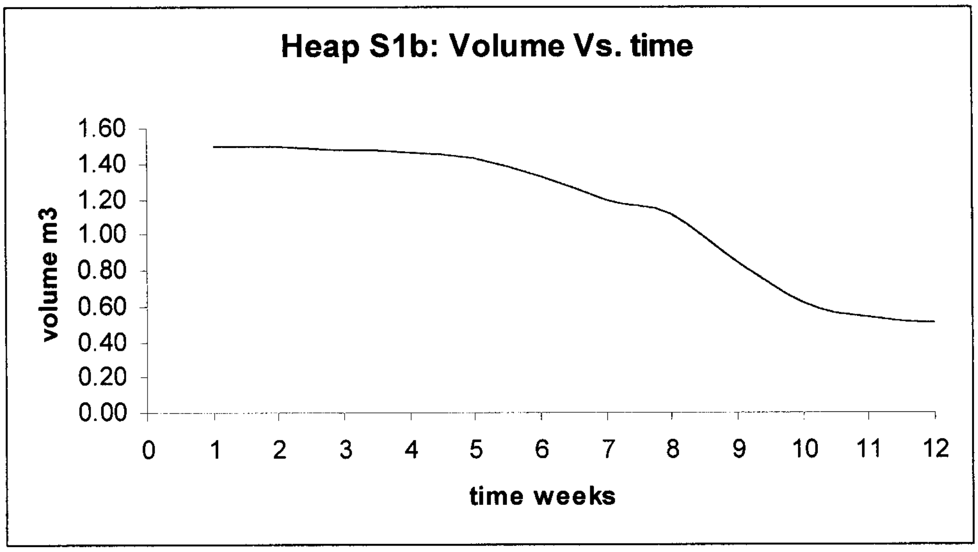
Heap S1a



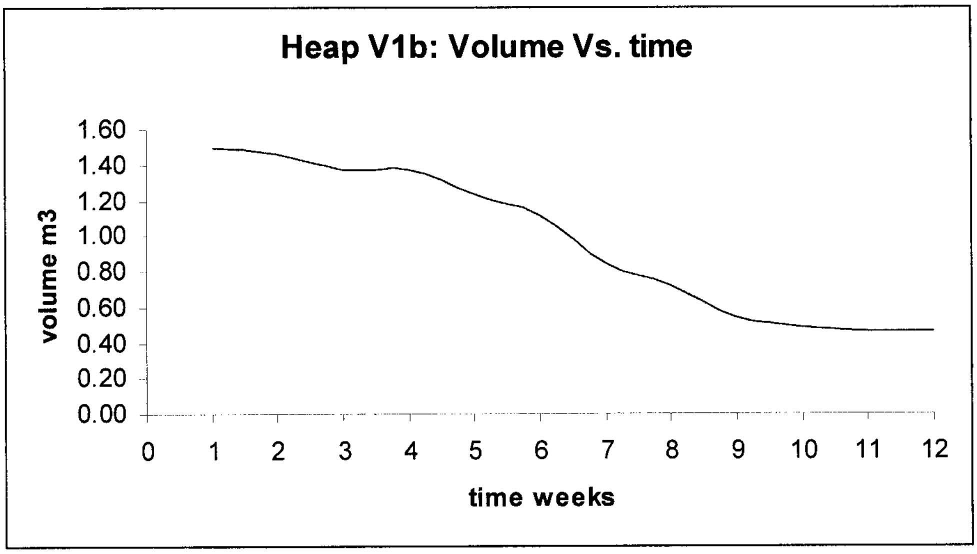
Heap V1a



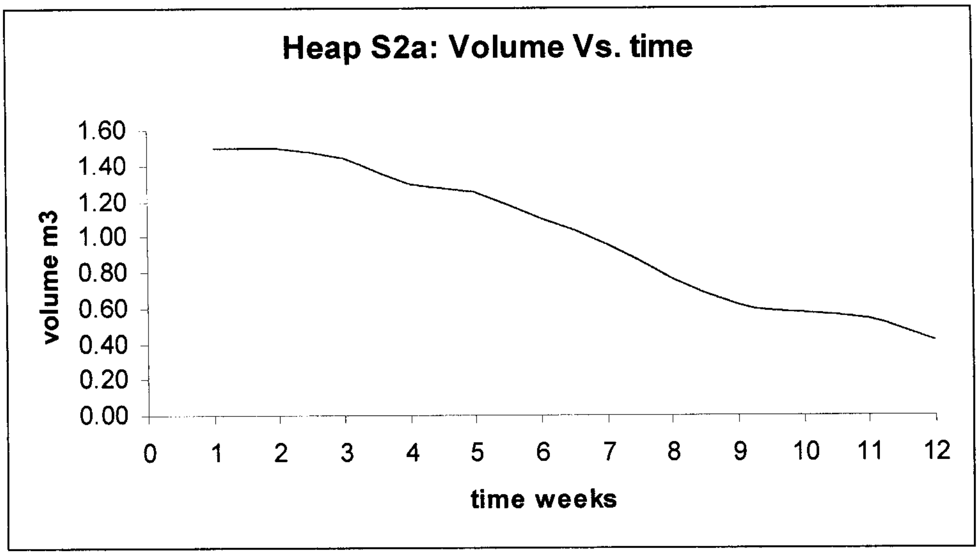
Heap S1b



Heap V1b



Heap S2a



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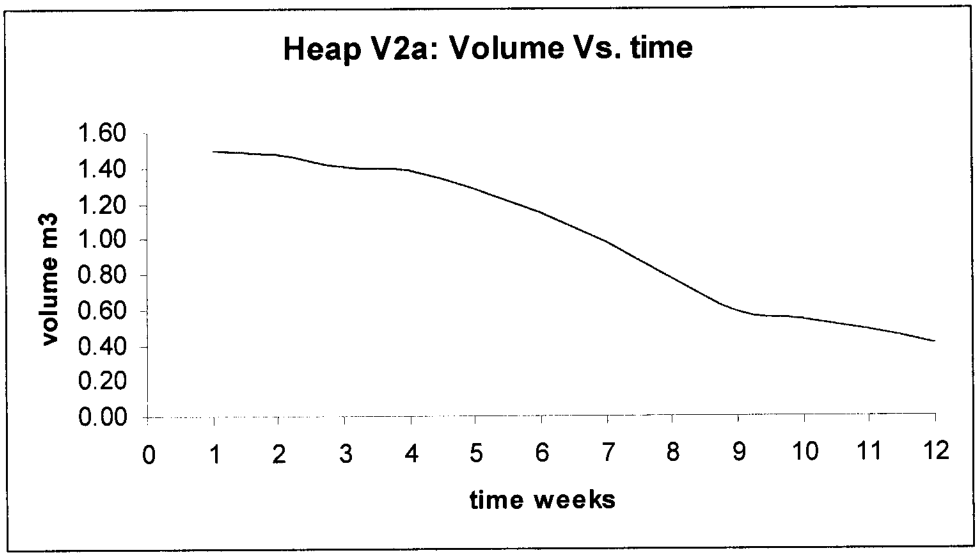

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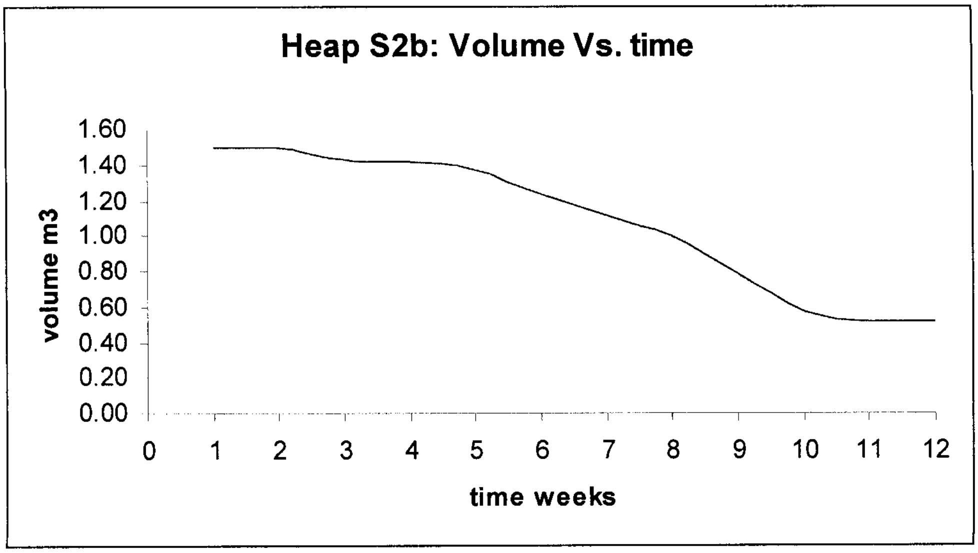

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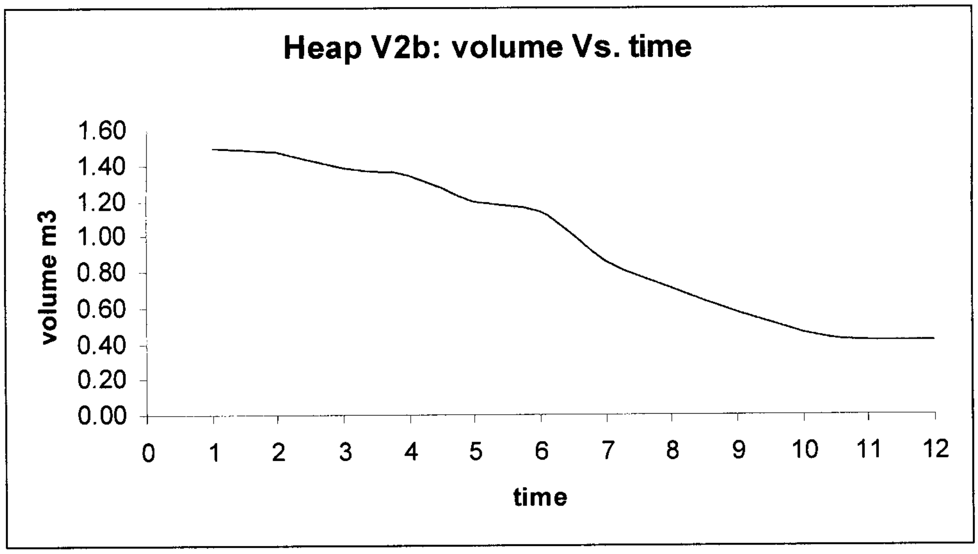
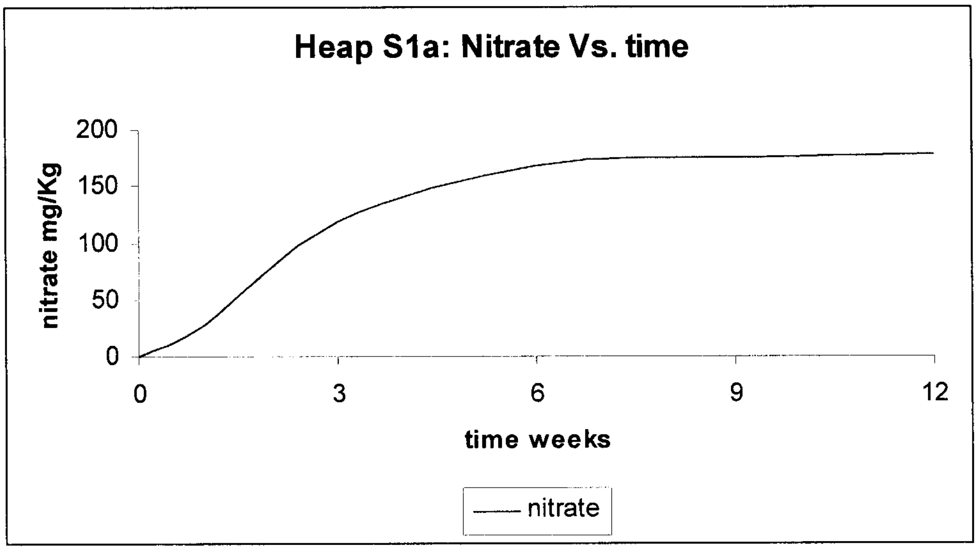


Appendix 7b : **Charts of Nitrate Concentration Versus Time**

Heap S1a



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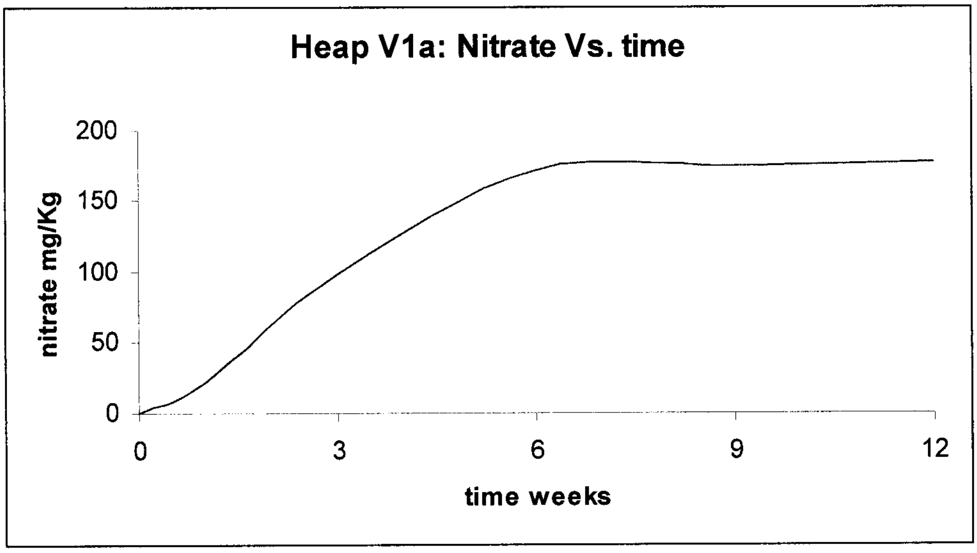
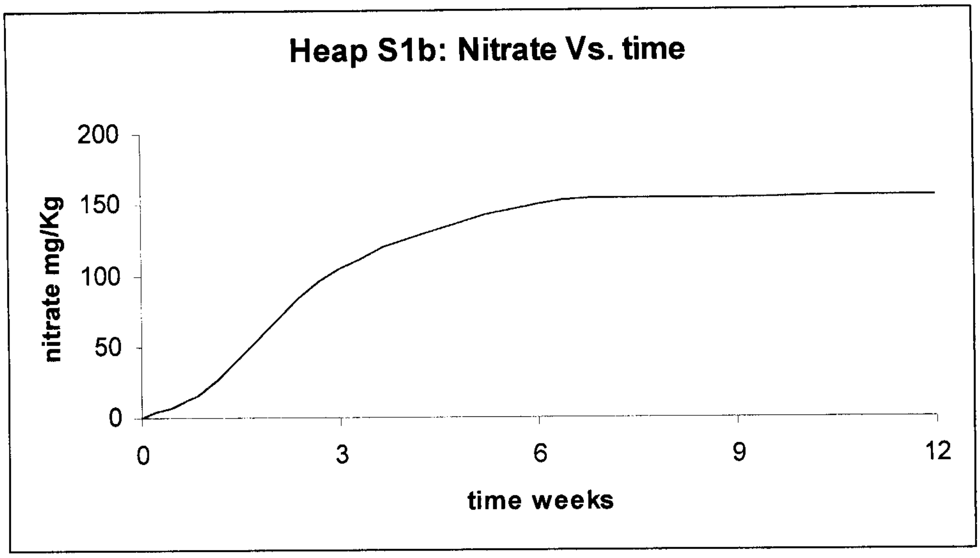


Heap S1b



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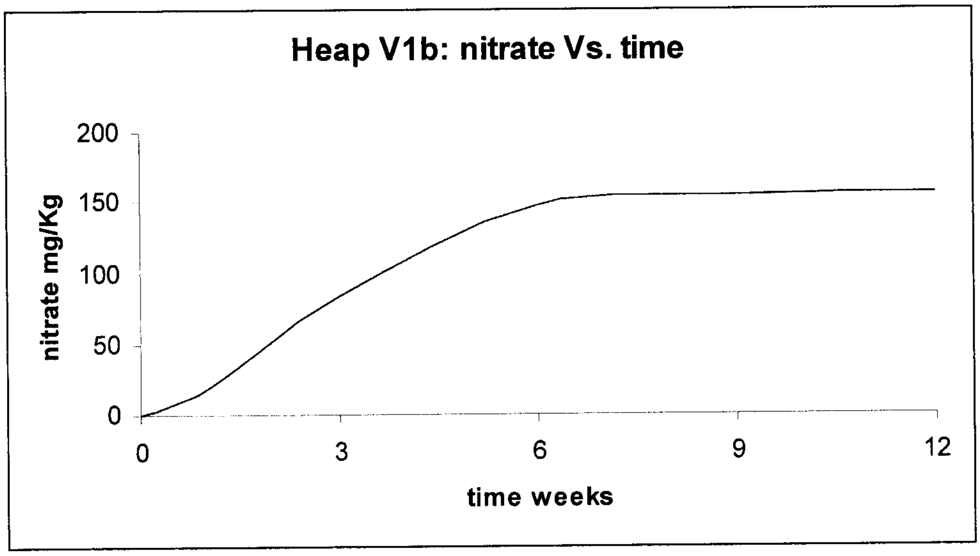

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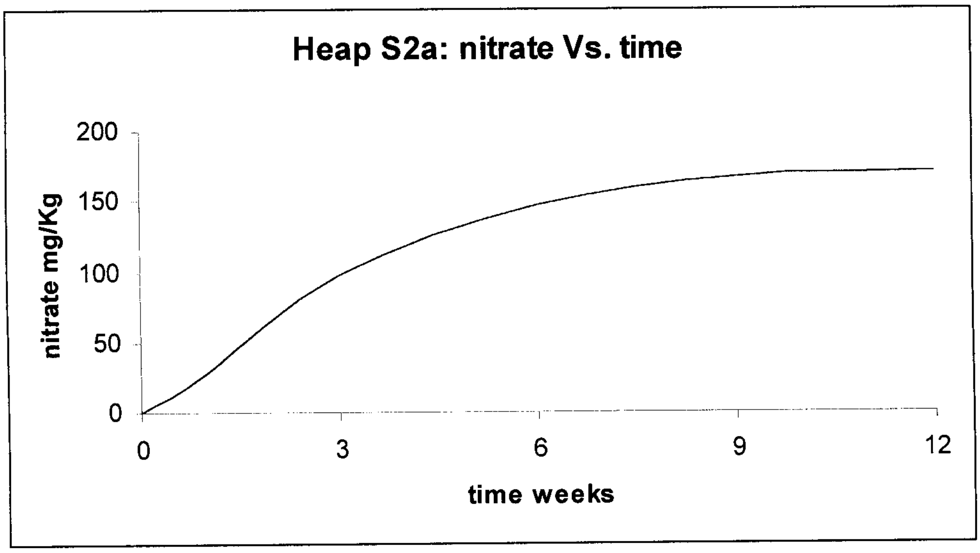

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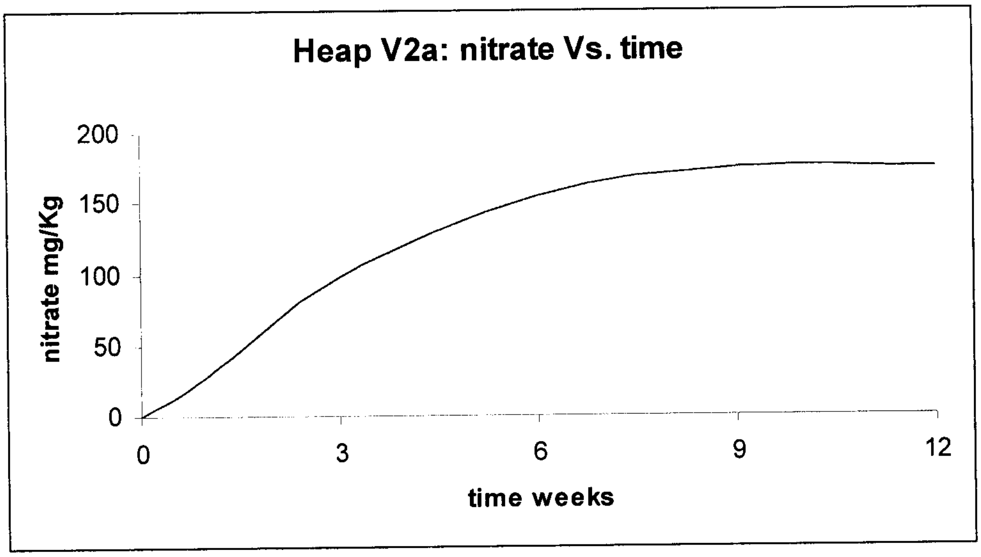

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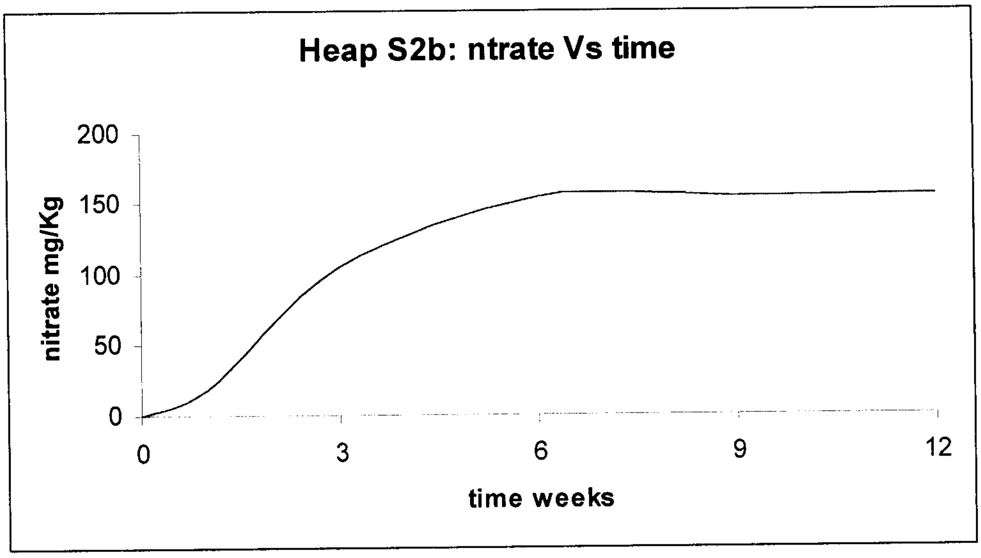

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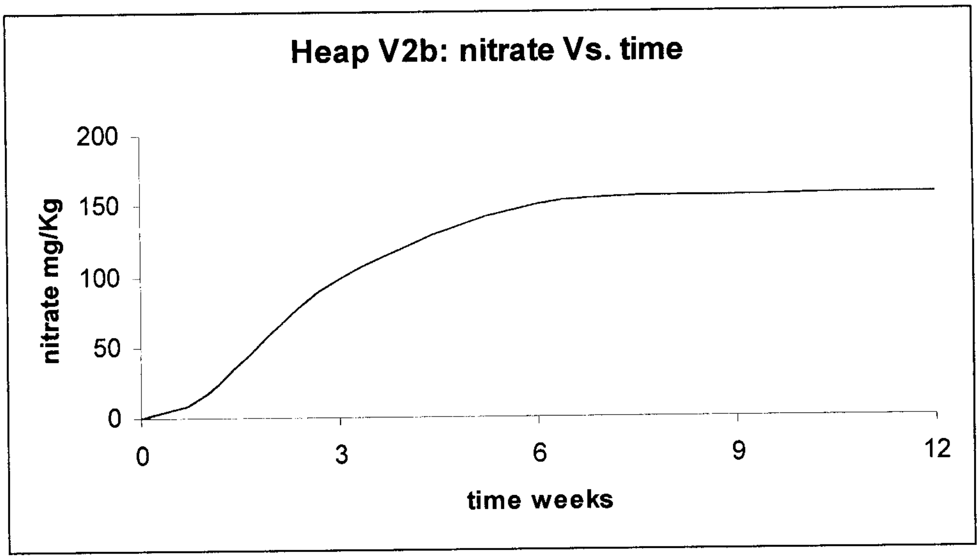
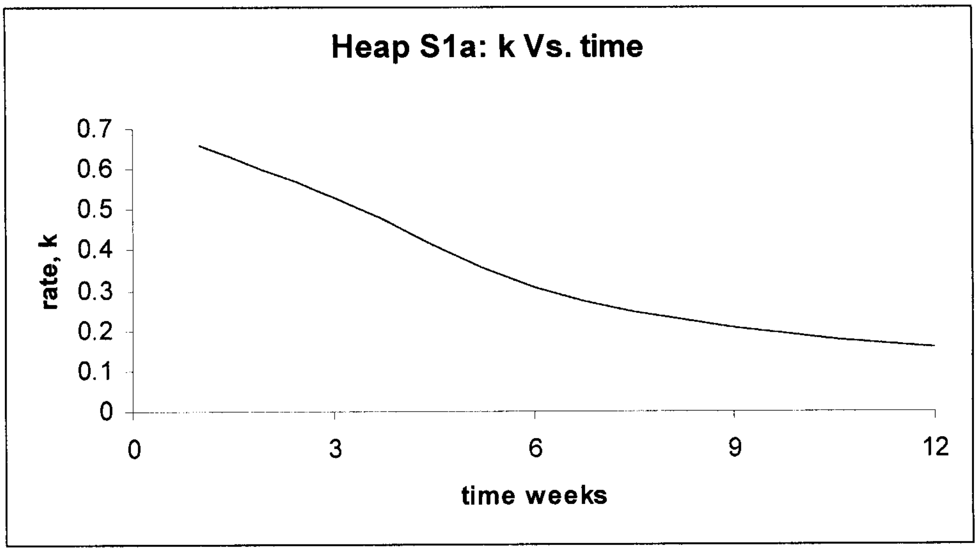


APPENDIX 8

Charts of Mineralisation Rates Versus Time

Heap S1a



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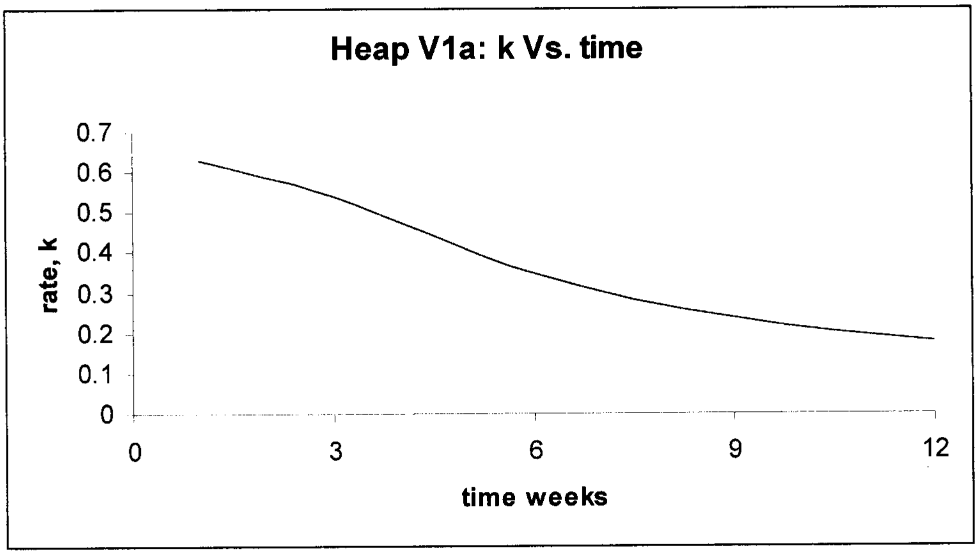
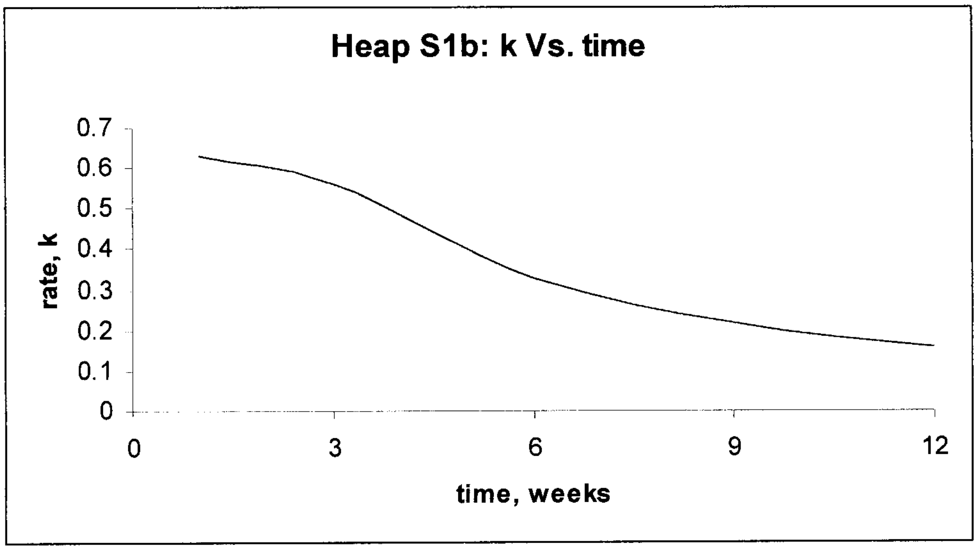
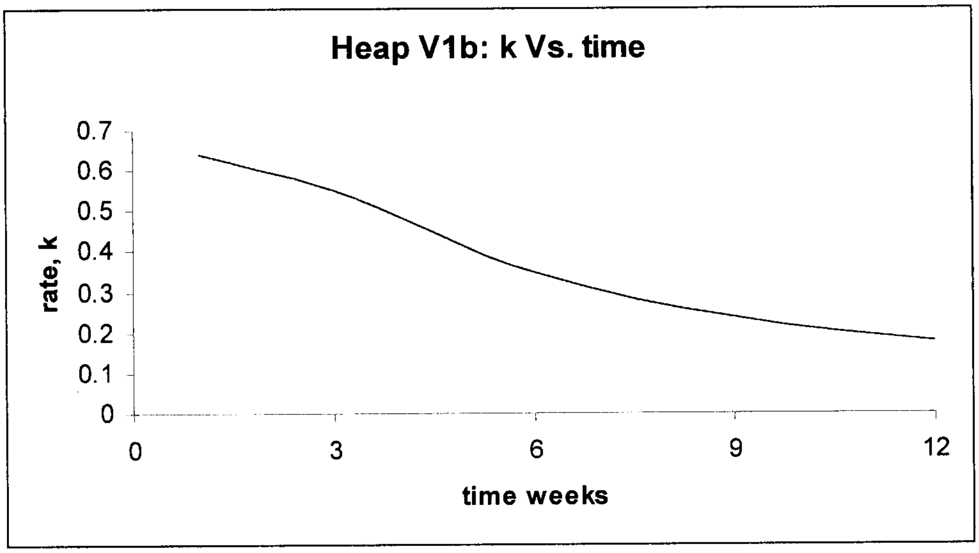


Heap S1b



Heap V1b



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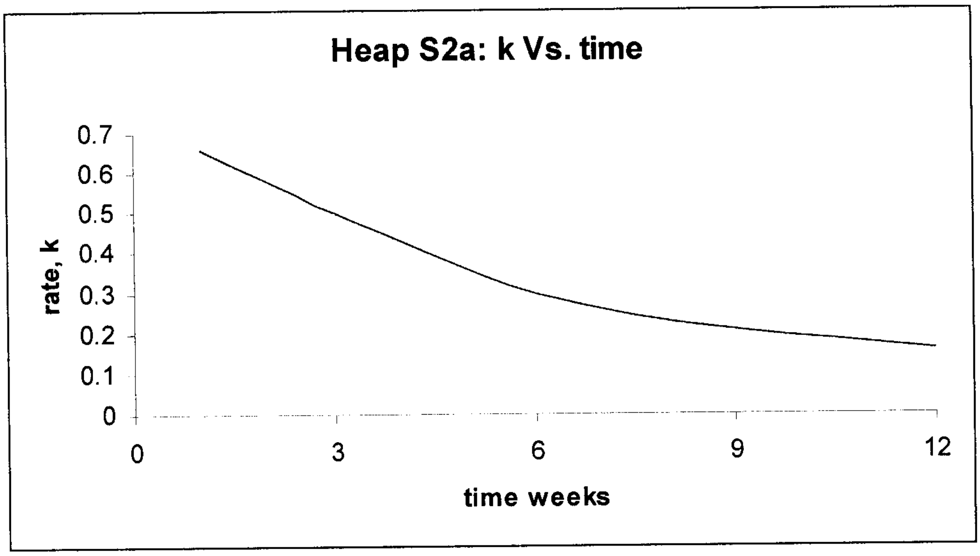

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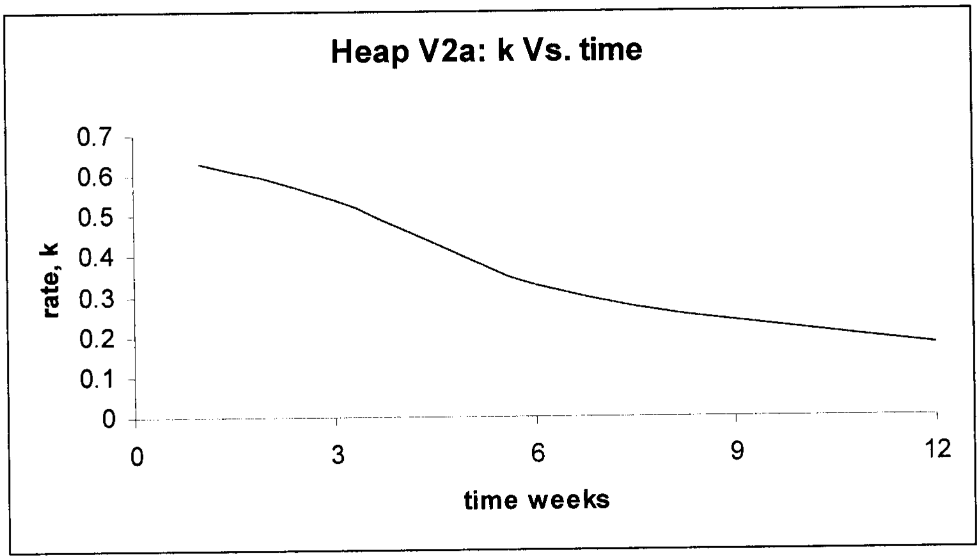

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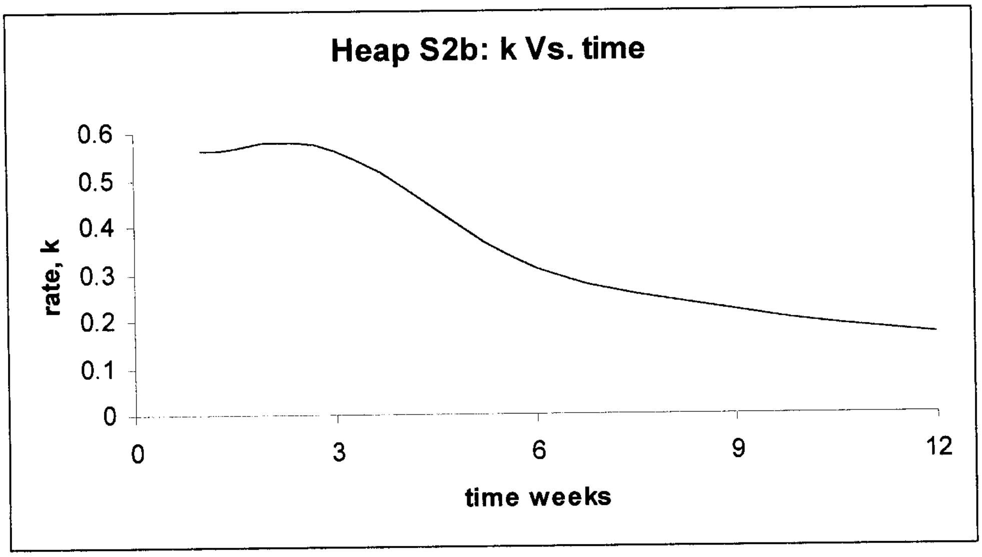

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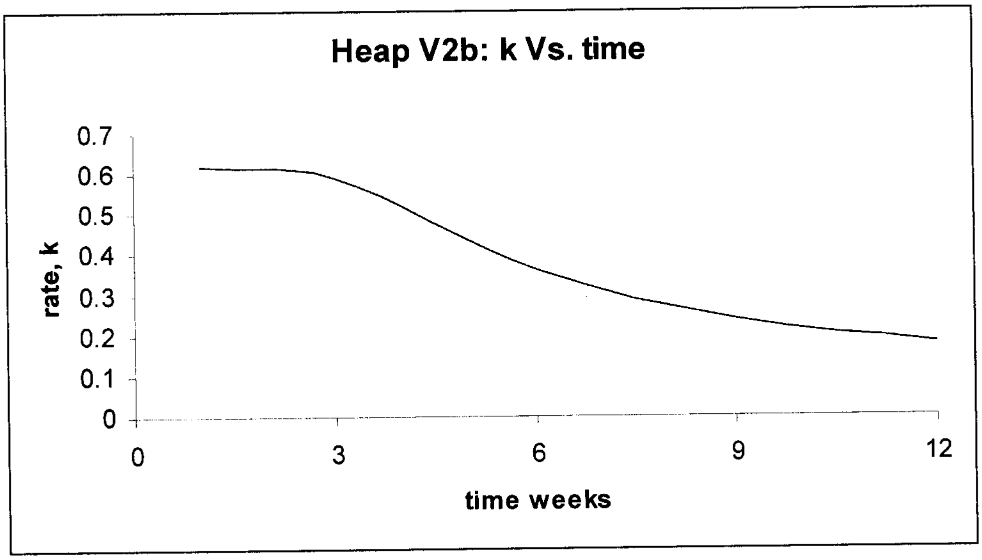

APPENDIX 9 SUMMARY OF RESULTS

Objective 1

Table 9.1 Effect of organic material on decomposition and mineralisation rates

Sample	Treatment/organic material	Decomposition rate $Week^{-1}$	Mineralisation rate $Week^{-1}$
S1a / S2a	Sunhemp	0.05 [b]	0.17 [a]
V1a / V2a	velvetbean	0.07 [a]	0.14 [b]

DMRT Separation of means: a = superior, while b = inferior

Objective 2

Table 9.2 Effect of the ratio of dry to fresh material in compost heap on decomposition and mineralisation rates.

Sample	Treatment/organic material	Decomposition rate $Week^{-1}$	Mineralisation rate $Week^{-1}$
S1a / S2a	Sunhemp, 1:1	0.05 [a]	0.17 [a]
	Sunhemp, 2:1	0.04 [b]	0.16 [b]
V1a / V2a	Velvetbean, 1:1	0.07 [a]	0.14 [a]
	Velvetbean, 2:1	0.05 [b]	0.12 [b]

Objective 3

Table 9.3a Effect of Nature of organic material on compost quality.

sample	Nature of material	Compost quality parameter				
		%N	mgP/kg	mgk/kg	C.E.C, cmol/kg	C/N ratio
S1a/S2a	Sunhemp	0.3	18.5	123	29.5	10
V1a/V2a	velvetbean	0.32	21.5	112.5	20.3	9

Appendix 9 continued....

Objective 3

Table 3b Effect of ratio of dry to fresh organic matter on quality of compost

		Compost quality parameter				
sample	**Treatment/ratio**	**%N**	**mgP/kg**	**mgk/kg**	**C.E.C, cmol/kg**	**C/N ratio**
S1a/S2a	**Sunhemp, 1:1**	0.3	18.5	123	29.5	10
S1b/S2b	**Sunhemp, 2:1**	0.26	18	102.5	17.8	12
V1a/V2a	**Velvetbean, 1:1**	0.32	21.5	112.5	20.3	9
V1b/V2b	**Velvetbean, 2:1**	0.29	18	110.5	19	9.5

APPENDIX 10: Determination of Ammonium and Nitrate Nitrogen

Available N: Extract $\rightarrow NH_4+$ and NO_3-

Distil : $NH_4^+ + OH- \rightarrow NH_3 + H_2O$

Trap in boric acid: $NH_3 + H_3BO_3 \rightarrow NH_4\ H_2BO_3$

Distil: $NO_3- + OH- +$ Devarda alloy $\rightarrow NH_4\ H_2BO_3$

Titration: $NH_4^+ + H_2BO_3^- + H^+ \rightarrow H_3BO_3 + NH_4^+$

14g N ≡ **1 mole** H^+ (or concentration of acid * volume)

1cm3 of 0.0025M H_2SO_4 = **0.35mg** N

Calculation: **ppm** NO_3- and **ppm** NH_4^+

$$\frac{\text{cm3 standard acid} * 0.35}{\text{g soil} * 10^{-3}\ \frac{\text{kg}}{\text{g}}}$$

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