AGRICULTURAL AND
FOOD ENGINEERING
WORKING DOCUMENT

6

Waste management opportunities for rural communities

Composting as an effective waste management strategy for farm households and others

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by

Romeela Mohee

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2007

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Contents

List of figures

List of plates

List of tables

List of boxes

Acknowledgements

I would like to thank Dr Peter Steele, Senior Technical Officer (Agricultural Industries) of the Agricultural and Food Engineering Technologies Service (AGST) of the Food and Agriculture Organization of the United Nations (FAO) for inviting me to undertake the work required for the preparation of this paper, and of providing the resources with which to do so.

I thank Mr Gavin Wall, Chief, Agricultural and Food Engineering Technologies Service for his help to complete the project. The support of Mr Goolam Oodally, Agricultural Engineer, AGST, Ms Larissa D'Aquilio (AGST) for the desktop publishing, and the staff of AGST have been appreciated.

Many thanks to members of the Regional Compost Network, especially Dr Herbert Murwira from the Tropical Soil Biology and Fertility programme, University of Zimbabwe, Zimbabwe; Dr John Njoroge, Director of the Kenya Institute of Organic Farming (KIOF), Nairobi, Kenya; Dr Emmy Reinten, Senior Agricultural Scientist, Agricultural Research Council (ARC-Roodeplat), South Africa; for sharing with me the results of their composting experiments.

Also, I would like to thank the National Federation of Young Farmers, Les Mariannes Cooperative Society, the Rose Belle Sugar Estate in Mauritius and the Agricultural Community of Riviere Banane in Rodrigues for their willingness to initiate composting projects.

I would like to express my gratitude to the University of Mauritius, the technical staff of the Chemical Engineering laboratory, the research students, especially Mr A. Ramajthan and Miss J. Eustasie for their help and to all those who have helped me in some way.
Finally, I thank my parents and children whose love and support are indescribable. A special word of thanks is due to my husband Kem, for his unflinching support throughout the whole project.

Foreword

This working document has been prepared to guide individuals or groups who may wish to transform organic wastes into compost for their own use or for sale. Composting can play an important role in reducing environmental threats linked with improper organic waste management in rural and peri-urban situations.

Natural composting is a process that always has been a part of the global ecosystem; it is responsible for the breakdown or decomposition of organic material. Modern composting harnesses these natural processes in such a way that organic wastes can be transformed to a useful product, namely compost.

This working document describes simple, cost-effective approaches to composting. In particular, it provides a brief scientific overview of the composting process and then gives details for planning and siting a compost facility, monitoring of the performance of the composting process, and guidance on use of the compost. To conclude, a small number of case studies describe applications of composting in rural communities in Mauritius, Rodrigues, Kenya, South Africa, and Zimbabwe.

Gavin Wall
Chief
Agricultural and Food Engineering Technologies Service
Food and Agriculture Organization of the United Nations

Preface

This paper was written to help farm households in rural communities in the African region to manage effectively the huge amount of wastes generated. Farm households and rural communities in their daily activities are major generators of organic wastes, in the form of manure, crop residues or mixed solid wastes.

The main problem in most parts of Africa is inadequate nutrient returns to compensate for losses when crops are harvested and residues taken elsewhere or because of leaching and erosion. If insufficient inputs are applied to compensate for these losses soil fertility will decline. One study in the African continent estimated average annual losses of nitrogen at 22 kg, phosphorous at 2.5 kg and potassium at 15 kg for each hectare of arable land. (Hilhorst, *et al.*, 2003).

Composting can play an important role in farm households by reducing environmental threats linked to improper organic waste management as well as improving soil fertility, which will have immediate impact upon food productivity. Natural composting is a very old process that has always been a part of the global ecosystem and which continuously takes place, as all organic material will eventually decompose. However, a more recent approach has arisen in response to the need for a continuous controlled and hygienic disposal process to deal with large amounts of organic wastes.

This paper will serve as a useful tool when planning a farm or rural community composting facility. It employs scientific knowledge to find technically simple, cost effective solutions that can be implemented by farmers and rural people. Underlying principles are explained first so that the rationale behind composting technologies may be understood. In this way, the composting operation may be adapted to meet site-specific needs.

Additionally, this paper will help rural communities and farmers to establish and operate composting facilities and their use of the compost. Also, it is a useful resource for institutions and researchers involved in organic waste management, Non Governmental Organizations' (NGOs) and Community Based Organizations (CBOs) and technicians from the public and private sectors. Information on low-cost composting methods, planning and siting a compost facility, monitoring of parameters, compost use and development of a compost-marketing plan is provided. The last section of the paper describes the potential of composting in small island states in the Indian Ocean region as well as in some African countries.

PAPER OUTLINE

Section 1 describes the opportunities to recycle organic wastes at the farmer level and the role of composting.

Section 2 provides a brief scientific overview of the composting process. It discusses physical, chemical and biological factors that influence composting. Also, it describes the composting phases and the evaluation of compost stability.

Section 3 gives a detailed discussion of parameters involved in determining compost quality as well as major compost quality standards. It outlines the benefits of compost and provides guidelines for compost application.

Section 4 describes small-scale and large-scale composting technology as well as pre-processing and post-processing equipment. It summarizes typical elements of composting agricultural wastes and livestock manure for farm households.

Section 5 describes the issues to be examined by farm households and rural communities when planning a compost facility. Criteria for siting and constructing a composting facility are discussed and a breakdown of capital and operation costs of a typical composting facility is given.

Section 6 discusses the importance of community involvement and education in farm household composting projects and focuses on how to prevent or minimize the potential environmental impacts associated with composting. Safety and health risks of composting facilities are described also.

Section 7 describes applications of composting in rural communities in the Sub-Saharan African regions of Mauritius, Rodrigues, Kenya, South Africa and Zimbabwe.

Executive summary

Organic wastes can represent a large proportion of the solid waste stream in any rural community. Furthermore, farm households generate large amounts of manure that can pose a threat to the environment, especially watercourses, if not well managed because of nutrient overloading. Much concern about air, water and soil quality has been expressed in the past about the direct application of raw manure to agricultural land. Animal producers are being increasingly pressed upon to move towards environmental sustainability in managing the nutrients in the manure.

Composting the organic portion of solid wastes has multiple benefits, such as a reduction in the quantity of wastes to be disposed, a reduction in environmental impacts resulting from manure storage and production of a material safe to use in agriculture. Advantages of composting also include killing of pathogens, fly larvae and weed seeds and improving the handling of manure and other residues by reducing their volume and weight.

The need to increase soil organic matter in certain countries, such as those in the African continent, is an important reason for recycling organic waste in view of returning the nutrients to the soil. Composting plays an important role in organic farming practices as well as in improving soil fertility. Among other benefits, the use of compost can improve access to food in rural communities with higher yields of vegetables and fruit obtained from a more fertile soil.

Farm households have many reasons for joining a composting programme, as they possess almost all the basic requirements for composting. Feedstocks, air, water, land and labour are present already on the farm although the scale of composting would be an important determinant of the resources available. The resulting composting product is a resource for the farmer and can be an additional source of revenue. The compost produced can be used on farm or sold to other farmers and community members. Like any product, compost must be marketed adequately and issues about producing a high quality material need to be addressed if the farmer expects to get revenue from the composting operation.

The installation and management of an organic system requires careful planning and technological considerations. When planning for a composting facility, technical, social and economic issues have to be considered. Proper siting of a facility can be done only after examining site factors and designing all components of the composting system, such as active composting technologies, curing processes and pre-processing and post-processing equipment. Good process control and system management are needed to ensure that the composting facility continues to meet the objectives of the users. Proper project management involves monitoring compost parameters and maintenance to ensure that potential negative impacts associated with poor management in the form of leachate and odour or through the attraction of pests and vermin are minimized.

The benefits of using compost in farm applications and ways of producing compost are not always well known in farm households. Continuing efforts are needed to establish confidence in the quality of waste demanded for compost. There is an urgent need for more education and training aimed at various groups including composting facility operators, regulators, farmers and general public. Topics needing to be addressed are proper composting site management, the benefits of using compost in agriculture, and the public perception of the importance of composting in the context of a sustainable waste management strategy. Successful case studies and pilot projects conducted on composting in the African region are a valuable tool to demonstrate that composting has worked and can work successfully for farmers and rural communities.

This paper aims to provide information on all aspects of compost production and use for farm households. It is applicable also to rural communities where similar types of wastes are generated but on a larger scale. For farmers generating low amounts of wastes, a centralized composting facility using the various on-farm wastes can be set up within the

rural community, using composting principles similar to those for individual on-farm composting. It is hoped that readers of this paper will be better informed of the opportunities of composting on-farm wastes in rural communities so as to avoid the disposal of valuable organic materials by incineration or in landfills.

Chapter 1
Organic wastes as a resource for farm households

MANAGING SOLID WASTES AS A RESOURCE FOR FARM HOUSEHOLDS

Farm households in rural communities generate solid organic wastes such as manure, tree trimmings, grass clippings and crop residues. Organic wastes can amount up to 80 percent of the total solid wastes generated in any farm household (Brown & Root, 1997). Also, livestock generate large amounts of wastes. Manure production can amount up to 5.27 kg/day/1000 kg live weight, on a wet weight basis (Overcash, 1983).

The organic wastes, especially manure generated by animals, if improperly managed or left untreated can result in significant degradation of soil, water and air quality. Stagnant wastes provide a medium in which flies breed and diseases are transmitted. Uncontrolled decomposition of organic wastes produces odorous gases as well as ammonia volatilization, leading to acid rain. Odours generated at production and manure storage facilities are the most frequent source of complaints against animal producers (Wright, 1998). Because of the intensification of animal production on a small area of land, there are increasing concerns about:

- water quality resulting from higher nitrogen and phosphorous loadings;
- pathogens and antimicrobial compounds in the manure;
- foul odours and air quality from ammonia, methane and nitrous oxide emissions;
- soil quality because of potassium and phosphorous loading (Fabian, *et al*, 1993).

Farmers and gardeners have long recognized the importance of replacing nutrients and organic matter that are depleted under continuous cropping. They have been applying directly raw or partially treated wastes to the fields. Potential problems related to nutrient management, such as nutrient overloading, nutrient losses and high salt levels have been associated with the direct application of manure (Porter, 2000). In addition, manure has to be stored to enable it to be incorporated in the soil at scheduled times and some farmers may not have available cropland to effectively incorporate the volumes generated day after day. Also, some farmers may not have an adequate area of land to use in a sustainable manner all the nutrients in manure.

Organic wastes can be converted easily to a resource for farm households through composting. Composting agricultural and other types of wastes can be a useful process for recycling nutrients and maintaining or restoring levels of organic matter in the soil (Solano, et al., 2001). Composting can be an attractive, low-cost technology for farmers. Because composted waste is treated, it is more stable than untreated or partially treated wastes.

The composting fundamentals for individual on-farm projects are similar to rural community composting projects. Farmers generating low amounts of wastes can join together to compost larger amounts of wastes in bigger community facilities creating a more efficient way of generating income.

COMPOSTING STRATEGIES FOR FARM HOUSEHOLDS

Farmers and rural communities have several strategies for managing the large amount of organic wastes generated. These include grass cycling, backyard composting, mixed wastes composting and agricultural wastes composting.

Grass cycling

Grass cycling is the natural recycling of grass clippings by leaving them on the lawn after mowing: the rationale being that grass clippings will quickly decompose and release nutrients for the lawn. Often, grass clippings are more than 50 percent of on-farm wastes. The main advantages of grass cycling are:

- a reduction in labour necessary for collecting and bagging wastes;
- a reduction in the application of chemical fertilizers;
- the prevention of weed growth.

Grass cycling can reduce lawn maintenance by 38 percent (Billingsley, 2005).

Backyard composting

Backyard composting is the transformation of small amounts of organic wastes generated by households. In farm households, more than 60 percent of the residential waste is of an organic nature. Appropriate materials for backyard composting are kitchen wastes, green wastes such as leaves, branches and grass clippings and paper. The advantages of backyard composting are:

- lower collection, transport and disposal costs of wastes;
- a reduced need for chemical fertilizers and/or soil amendments;
- an improved soil structure and promotion of healthy plant growth.

Flyers, brochures, video, training programmes as well as subsidies for purchasing composting bins are means of encouraging backyard composting by farm households. However, farmers must be made aware of potential odour and pest problems linked to backyard composting mismanagement.

Mixed waste composting

Mixed waste composting refers to a centralized processing system that accepts mixed solid waste and separates materials into components for composting, recycling and disposal. Thus, all the organic portion of the mixed farm waste is captured. Savings at a community level can be achieved because of the collecting, transporting and disposing of on-farm wastes.

Composting technologies range from simple windrows to capital-intensive digester drums. Mixed waste composting facilities have high operating and machinery costs and the final compost can contain a high level of contaminants. Also, compacted food scraps and grass clippings can generate odours and leachate.

Agricultural waste composting

Agricultural waste composting is a method of aerobically digesting the solids portion of cattle, horse and other livestock manure. Manure contains organic matter and nutrients such as nitrogen, phosphorous and potassium. It can be a good source of fertilizer (Table 1).

The main objectives are to reduce threats to the environment, for instance the discharge of excessive nutrients, odours and leachate that can lead to groundwater contamination, and to produce a stable material that can be used on the farm or sold to the community.

TABLE 1
Characteristics of manure

Parameter	Pork pigs	Laying hens	Feedlot beef	Feedlot sheep	Dairy cattle
Wet waste (% total live weight per day)	5.1	6.6	4.6	3.6	9.4
Total nitrogen (% total solids)	5.6	5.9	7.8	4.0	4.0
Phosphate (% total solids)	2.5	4.6	1.2	1.4	1.1
Potash (% total solids)	1.4	2.1	1.8	2.9	1.7

(Source: Polprasert, 1996)

Technologies commonly used for manure composting are holding units for small-scale composting and windrows for larger amounts of wastes. Together with the farmer's experience in dealing with manure most composting requirements such as land, water and feedstocks usually are available on the farm. If the compost is to be marketed, a number of issues such as the scale of operation and equipment costs must be considered.

COMPOSTING AS A SUSTAINABLE TECHNOLOGY FOR FARM HOUSEHOLDS

Composting is a self-heating microbiological process in which the decomposition of organic materials is carried out by the growth and activity of a mixed population of micro-organisms.

There is a renewed interest in agricultural composting because of three main factors: environmental constraints on traditional manure management options, increased understanding of agronomic benefits of compost use and rising disposal costs for wastes generated on the farm (Fabian, Richard, Allee, *et al.*, 1993). Farmers already produce and market products. Given their experience with biological processes, and managing soil and wet and high nitrogen manures, they would have little difficulty composting.

Composting at the farm level has several advantages:

- All materials necessary for composting, such as feedstock, bulking agents, water, space, air and time are already on the farm.
- Disposal of raw manure such as poultry waste has a negative impact on the environment. Composting reduces the weight, moisture content, odour and vector attracting qualities of manure and other farm generated wastes leading to a lower risk of pollution.
- Compost can be applied at convenient times of the year because it provides the farmer with greater scheduling flexibility. While an untreated waste must be applied and incorporated promptly to prevent nitrogen loss and nuisance conditions, compost is stable and can be stored safely.
- Compost is an excellent soil conditioner. When applied to cropland compost adds organic matter improving moisture retention and soil structure, and reduces fertilizer requirements and the potential for soil erosion.
- Both compost and raw manure are good conditioners with some fertiliser value. Composting, however, converts the nitrogen contained in the manure into a more stable form. The nitrogen in compost is less susceptible to leaching and further ammonia losses.
- Highly bedded manure can have a high carbon to nitrogen (C/N) ratio. When applying this manure directly to land the high carbon causes the nitrogen in the soil to become unavailable to the crop. Composting reduces the C/N ratio to levels that are beneficial to plants.
- Composting, if done properly, is an effective method of destroying pathogens. Properly prepared compost has been found to reduce soil borne plant diseases. The heat generated by the composting process reduces the number of weed seeds contained in the manure, resulting in a significant reduction of weeds over several years of application.

- The high cation exchange capacity (CEC) of compost leads to increased efficiency of chemical fertilizers by reducing nutrient leaching.
- Composting reduces the amount of on-farm organic waste that would have gone for disposal, thus decreasing waste collection, transport and disposal costs.
- Compost is a safe and effective bedding material for livestock. Zehnder *et al.*, (1998) reported benefits of using compost as bedding material in cattle feedlots.
- Organic waste can generate an income by selling the compost. Good markets can be found for high quality compost and there are a many uses for lower grade compost.
- Composting is one of the few methods available for quickly creating a soil-like material on eroded land. Soil erosion has a direct financial impact on food production and the economy. Furthermore, eroded lands can lead to the pollution of surface water because of agricultural runoff from croplands.

INCOME GENERATION AT THE FARM LEVEL

The primary financial advantages of composting, such as generating revenue by charging waste 'tipping ' fees and through compost sales, appear to offer new income opportunities for farmers. With the growing prominence of environmental concerns and a crisis in waste disposal, a major new economic incentive to compost is emerging. Composting offers a benign way to divert a significant portion of the solid waste stream out of costly landfill and incinerators without considering the huge collection and transport costs. It is for this reason that an increasing number of rural communities are promoting composting as the most sensible and economic way to manage large volumes of organic waste.

On-farm composting can be a win-win situation for farmers who have to deal with environmental problems such as poor water quality, odours and nuisances created by handling, storing and applying agricultural wastes to land. Also, use of the finished product on the farm can help the farmer avoid some of the costs associated with the purchase of organic matter, fertilizer and soil conditioners.

Farmers have many of the prerequisites for composting. Most of the raw materials needed for composting are already on the farm. Also, farmers can take advantage of off-farm organic wastes such as garden wastes from households and get paid for their disposal.

Like most products, the price that can be charged for a given compost or compost mix depends on its consistency, overall quality and associated services. Farmers will have to allocate space, labour and equipment, have special manure handling schedules and also consider items such as transport costs of bulky compost and the presence of readily available substitute products.

Each farmer must look at his/her farm and financial resources to determine which method of composting to use. A study done on 15 farms to evaluate the costs/benefits of five composting approaches ranging from static pile to in-vessel composting, showed that the static pile approach and the loader turned windrow methods would be the most appropriate for farmers having suitable available land and reasonably small volumes of materials suitable for making compost (Fabian, Richard, Allee, *et al.*, 1993).

Most farm compost systems could produce small to moderate quantities of low value bulk compost without significant new costs. Farmers may consider the on-farm value of applying compost exceeds the net profit to be made by marketing low-value compost. A study in Australia ((Nolan-ITU, 2002) showed that use of compost in viticulture and horticulture was estimated to increase typical yields by about 12 percent. It was estimated that the combined gross crop productivity benefit for compost use within these industries was about US$102/tonne of organic product applied.

Marketing packaged compost is likely to be an economic option only for large producers of high quality compost. Handling large volumes of wastes and producing high quality compost requires an increasingly substantial investment of land, labour and capital. However, producers of high quality composts would have little trouble finding acceptance of their product among a wide variety of soil amendments, mulches and fertilizers with other farmers, the community and the public at large. Income generated by the sale of high quality compost would then offset the initial costs required to produce that grade of compost.

Farmers within a community can join together to adopt larger scale centralized facilities to enable them to realise economies of scale. This will be a more efficient way of generating income from composting, especially for those farmers having small amounts of on-farm wastes.

Chapter 2
The composting process

INTRODUCTION

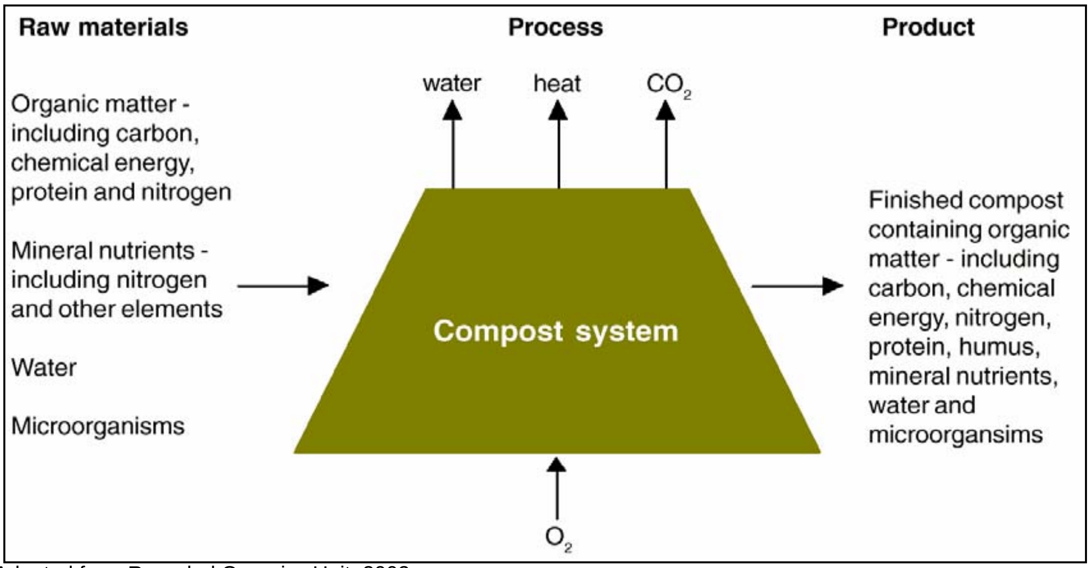
Composting refers to the bio-oxidation process of transforming wastes into a stabilized form and compost refers to the resulting product: stabilized organic matter. A complete definition of composting as stated by many authors (Gray, Sherman and Biddlestone, 1971; De Bertoldi, Vallini and Pera, 1983; Diaz, Savage, Eggerth, *et al.*, 1993) is: "*the controlled exothermic bioxidative decomposition of organic materials by indigenous micro-organisms in a moist warm aerobic environment, leading to the production of carbon dioxide, water and a stabilized organic matter, defined as compost*".

Composting has been occurring naturally with the decomposition of organic matter in the global ecosystem for centuries. This practice has been employed by farmers for a very long time and can be traced to Marcus Cato, a farmer and scientist who lived in Rome 2000 years ago. There are Roman and biblical references to composting as well as numerous accounts of farmer composting practices in subsequent millennia (Rynk, Van de Kamp, Wilson, *et al.*, 1992).

Much research has been carried out over the years on several aspects of the composting process, for instance feedstock, the role of micro-organisms, key parameters and technologies. Today a variety of composting processes exist that can be adapted for any scale of organic waste management. Systems range from simple to sophisticated technology. Passive piles, windrows, aerated static piles and in-vessel composting systems are being used world wide to treat different types of organic waste. Currently, there is more emphasis on compost maturity, quality and sustainability, which are key traits in the acceptance and use of the final product.

Compost feedstock is a complex mix of organic material, ranging from simple sugars and starches to more complex or resistant molecules such as cellulose and lignin. The composting process is shown in Figure 1.

FIGURE 1
The composting process



Adapted from Recycled Organics Unit, 2002a

KEY PARAMETERS

A diverse population of predominantly aerobic micro-organisms that decompose organic material carries out the composting process. The activity of the micro-organisms is encouraged through the management of the C/N ratio, oxygen supply, moisture content, temperature, particle size and pH of the compost pile.

The role of micro-organisms

Micro-organisms, such as bacteria, fungi and actinomycetes play an active role in decomposing the organic material. Different micro-organisms prefer different types of organic material. When the organic molecules a particular micro-organism requires are no longer available, they become dormant or die. In this process, the end products resulting from the metabolic activity of one type of micro-organism may be used as food or an energy source by another type of micro-organism. This chain of succession of different types of microbes continues until there is little organic matter remaining.

Micro-organisms are the key in the composting process. If conditions are ideal for a given microbial population to perform at its maximum, the composting process occurs rapidly.

Bacteria

Bacteria are small, single celled organisms usually spheroid but occasionally appearing as sheets, chains or branched filaments. Mostly they break down sugars and starches and are responsible for most of the decomposition and heat generation in compost. Bacteria have different temperature optima and are grouped accordingly; psychrophiles for temperatures less than 25^{o}C, mesophiles between 25^{o}C and 45^{o}C and thermophiles greater than 45^{o}C.

Fungi

Fungi include moulds and yeasts and are responsible for the decomposition of many complex plant polymers in soil and compost. They can attack organic wastes that are dry, acidic or low in nitrogen for internal decomposition. Fungal species are predominately mesophilic. When temperatures are high, most are confined to the outer layers of compost.

Actinomycetes

Actinomycetes are a kind of bacteria that form chains or filaments. In composting, actinomycetes play an important role in degrading complex organic molecules such as cellulose, lignin and proteins.

Physical parameters

Physical parameters include pH, temperature, moisture content and particle size. Analysis of these parameters is detailed in Annex 1.

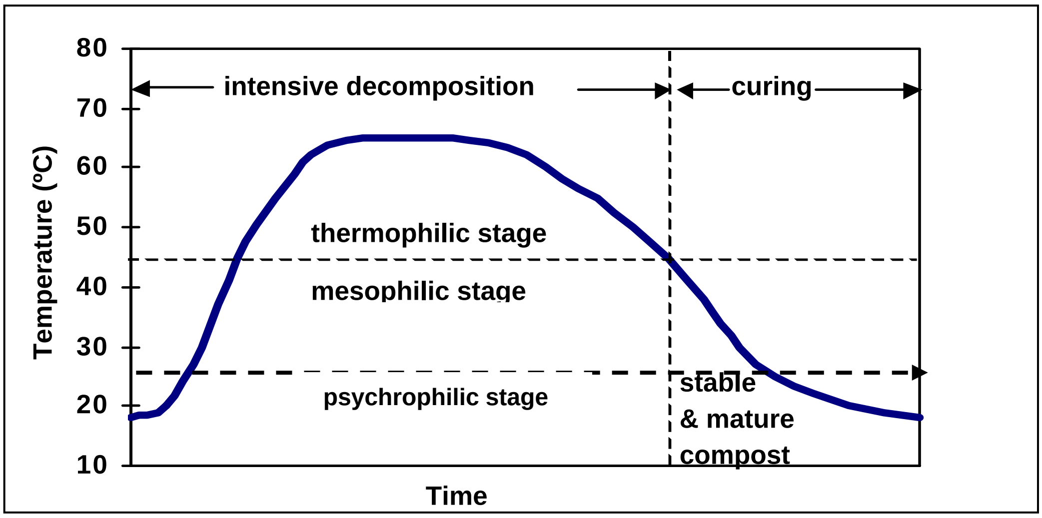
pH

The ideal range for microbial pH activity is between 6.5 and 8.0. It is very important with raw materials that have a high percentage of nitrogen, such as manure and bio-solids. A pH above 8.5 encourages the conversion of nitrogen compounds into ammonia gas, resulting in nitrogen losses from the compost. The pH levels vary in response to the raw material used in the original compost mix and the production of various intermediate products over the composting period. Over time, the pH drops to levels between 4 and 5 because of the formation of organic acids and usually approaches neutral during the maturation stage.

Temperature

The composting pile passes through a wide range of temperature over the course of the active composting period. As the temperature varies, conditions become unsuitable for some micro-organisms while at the same time becoming ideal for others. The active composting period has three temperatures ranges, which are defined by the types of micro-organisms that dominate the pile during rising temperatures: psychrophilic (< 25^{o}C), mesophilic (25 – 45^{o}C) and thermophilic (> 45^{o}C). The different phases of composting are represented in Figure 2.

FIGURE 2
Temperature profile



Adapted from Recycled Organics Unit, 2002b

Particle size

The particle size of the material being composted is critical. Smaller particles have more surface area per unit of weight and therefore facilitate microbial activity on their surfaces, leading to rapid decomposition. However, if all the particles are ground up, they pack closely together and allow few open surfaces for air to circulate. The optimum particle size has enough surface area for rapid microbial activity but also enough void spaces to allow air to circulate for microbial respiration. A range of 10 to 50 mm is adequate for effective gaseous exchange in the compost heap (FAO 1987).

Particle size is closely related to the porosity, texture and structure of the waste material.

Porosity

Porosity is a measure of the airspace within the compost mix and influences the resistance of airflow through the pile. A more uniform mixture of material that provides continuity of air space and larger particles to increase pore size and surface area improves porosity.

Texture

Texture is the relative portion of various particle sizes of a material and is descriptive of the amount of surface area available for micro-organisms. The finer the texture, the greater the surface area exposed to microbial activity.

Structure

Structure refers to the ability of particles to resist compaction and setting. It is important in establishing and maintaining porosity during the composting process. The ideal particle size of compost material must be a compromise between maximizing porosity, surface area and increasing structure.

Carbon to nitrogen (C/N) ratio

When combining organic materials to make compost, the C/N ratio is important. Carbon and nitrogen are the most important elements in the composting process. Carbonaceous materials serve mainly as an energy source for the composting microbes and nitrogen is critical for microbial population growth.

Micro-organisms in compost digest carbon as an energy source and ingest nitrogen for protein synthesis. A C/N ratio within the range of 25:1 to 40:1 results in an efficient process while a C/N ratio of 30 is optimal (Starbuck, 1998). Inadequate nitrogen (a high C/N ratio) results in limited microbial biomass and slow feedstock decomposition. Excess nitrogen (a low C/N ratio) is likely to produce a loss of ammonia gas or nitrate.

Oxygen

Composting is an aerobic process; that is the micro-organisms require oxygen to break down the waste materials. The compost pile should have enough void space to allow free movement of air so that oxygen from the atmosphere can enter the pile and carbon dioxide and other gases are removed. A 10 to 15 percent oxygen concentration is adequate. Higher concentrations of oxygen indicate that an excess amount of air is circulating, possibly causing excess heat removal. If the average oxygen concentration falls below five percent regions of anaerobic conditions develop within the pile (Dickson, Richard and Kozlowski 1991).

Moisture

Micro-organisms can digest only organic wastes containing the proper amount of moisture. Fifty to sixty percent moisture content is recommended as this provides a thin film of moisture around the waste material, while still allowing free air movement. At less than 40 percent moisture bacterial action is slowed by a lack of water. At a moisture level greater than 60 percent there is not enough air for aerobic decomposition.

COMMON RAW MATERIALS

On-farm materials

The predominant raw material available in rural communities is manure. Other materials are those not posing a management problem in terms of handling, cost or safety. These include green waste, crop residues, branches, leaves and household organic wastes. Table 2 shows C/N ratio and moisture content ranges for some composting materials.

TABLE 2

Characteristics of common composting substrates

Material	Moisture content (% dry weight)	C/N ratio	Structure
Manure			
Swine manure	65-90	9-19	Poor
Cattle manure	67-87	11-30	Poor
Poultry manure	22-46	12-15	Poor
Horse manure	52-60	29-56	Average
Crop residues			
Fruit wastes	62-88	20-45	Average
Vegetable waste	80-95	11-13	Poor
Municipal solid waste (MSW)			
Food waste	70	14-16	Average
Mixed msw	40-60	34-80	Good
Yard wastes	38	40-82	Good
Grass clippings	82	17	Average
Other materials			
Straw	-	100-150	Good
Sawdust	12	80	
Paper	19-65	200-750	Poor
Cardboard	8	563	Good
Seaweed	53	17	Poor

Source: Rynk, Van de Kamp, Wilson, *et al.*, 1992; Haug, 1993

Manure
Manure as excreted, is a nitrogen rich material with poor structure. A carbonaceous amendment has to be provided when composting manure, although when collected from a barn together with the bedding it does not require much additional material.

Cattle manure
Cattle manure is a nitrogen rich, wet material. The moisture content and C/N ratio depend on the amount of bedding used, the management practices and climate. Normally it requires a large amount of dry high carbon amendment.

Poultry manure
Poultry manure is a moderately moist material with between 30 and 45 percent moisture content. It has high nitrogen content and therefore needs a high carbon amendment. However, poultry manure with sawdust or woody shavings is well suited to composting.

Because of the high nitrogen content of poultry manure, while composting nitrogen loss and odour from ammonia are potential problems.

Horse manure
Horse manure usually contains a large amount of bedding material and therefore is dry with a high C/N ratio. It can compost well on its own, decomposing quickly. The composting process has a low odour potential.

Swine manure
Swine manure is a wet material rich in nitrogen with a strong potential for odours. It needs the addition of a dry, high carbonaceous material to compost properly.

Crop residues
Crop residues have variable characteristics depending upon the material, but normally have moderate to high moisture content and a high C/N ratio. Generally, older vegetation is drier and contains less nitrogen.

Other materials

Wood wastes
Wood wastes are a good carbon source, have the ability to absorb moisture and odours and are good bulking agents. Adding carbonaceous materials such as sawdust, wood shavings or wood chips, helps when composting high nitrogen materials such as manure.

Yard wastes
Yard wastes are vegetative matter resulting from gardening, horticulture and landscaping. It includes materials such as tree and shrub trimmings, plant remains, grass clippings and chipped trees. They are usually high in carbon and consist of several particle sizes. Yard wastes are useful as a carbon source or bulking agent in the initial compost blend.

Newspaper/cardboard
Paper has high carbon content and is moderately degradable. It has the ability to absorb moisture well but has poor porosity and structure. Cardboard also is a high carbon source with good degradability properties. Its structure provides for good moisture absorption.

Fruit and vegetable wastes
Food by-products commonly composted include damaged fruit and vegetables, eggshells, coffee grounds and meal remains. There is a high potential for putrefaction and odours. Compost from food wastes is rich in plant nutrients but may have elevated salinity levels.

Sewage sludge (bio-solids)
Bio-solids are organic solid residues derived from residential, commercial or pre-treated industrial wastewater processing. Compost produced from sewage solids is rich in plant nutrients but contains contaminants. Because of pathogens, caution must be exercised when using bio-solids as feedstock.

Finished compost

Finished compost has a low C/N ratio (around 10:1) and low moisture content (< 30 percent). Unscreened compost consists of different sizes of materials. When screened, the coarse particles can be used as a source of micro-organisms or insulating material in fresh compost mixes.

Materials not to be composted

Materials not to be composted

Materials should not be composted if they promote diseases, cause odours, attract pests or create other nuisances. These include fish, meat, poultry, dairy products, weeds with seeds, difficult weeds and infected plants.

Materials to be avoided

Materials that should be composted in limited amounts include wood ash (source of lime), sawdust (requires extra nitrogen) and plants treated with herbicides and pesticides.

The compost mix

Composting aims to maximize the rate of natural decomposition. Thus, to achieve a higher rate of microbial activity the compost mix must be designed to optimize the conditions within the pile in terms of nutrition, oxygen, moisture content and pH (Table 3).

Components of the compost mix

Most materials available for composting do not fit the optimal conditions for composting. Therefore, different materials have to be blended. Mixing materials of different sizes and textures helps to provide a structurally stable and well-drained compost pile as well as maintaining the right C/N ratio and moisture content.

The three basic components to a compost mix are:

- ***The primary substrate*** is generally the main material that requires treatment.
- ***The amendment*** is any material that can be mixed with the primary substrate to balance the C/N ratio, modify the pH and achieve the proper moisture content.
- ***A bulking agent*** is a decay resistant material whose main purpose is to provide structure and porosity in the pile. However, an amendment can be a bulking agent also. When selecting bulking agents, factors such as economics, particle size and the availability of carbon must be considered.

Additives

Inoculants, activators and lime are compost pile additives. Inoculants are dormant micro-organisms, activators contain sugars or a nitrogen source and lime increases the pH of the compost pile. Inoculants are rarely needed since kitchen scraps, leaves, and finished compost already contain ample bacteria that can work readily on their own.

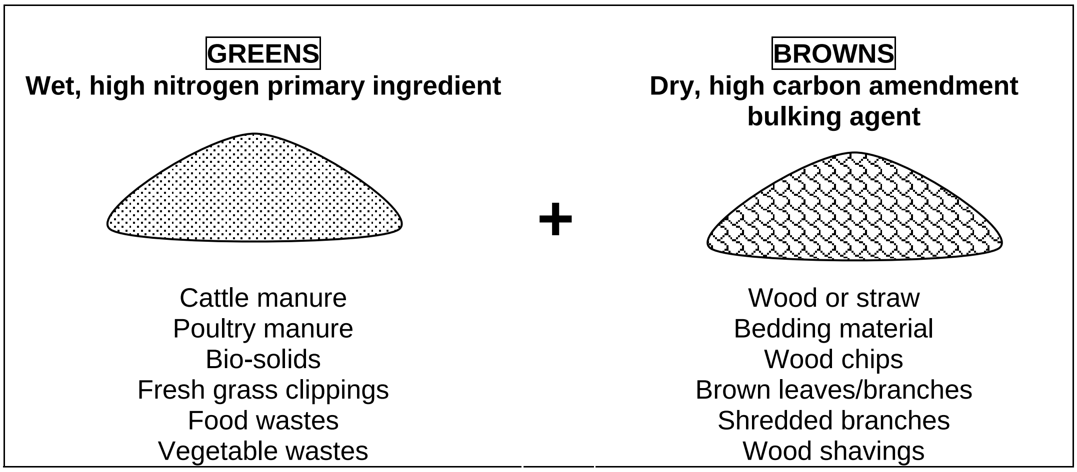
TABLE 3

Recommended conditions for rapid composting

Parameter	Range of values	Preferred range
Temperature (^{0}C)	45 - 65	55 - 60
Oxygen concentration (%)	> 5	> 12
Moisture content (% ww)	40 - 65	50 - 60
C/N ratio	20:1 –35:1	25:1
Particle size (mm)	3-13	-
PH	5.5-9.0	6.5-8.0

Source: Recycled Organics Unit, 2002c

FIGURE 3
Combinations of greens and browns



Typical composting mixtures

When forming a compost mixture, the physical and nutritional characteristics of the raw materials are manipulated to achieve ideal conditions for microbial activity. In general, the two main characteristics taken into account are the C/N ratio and the moisture content. Calculations can be made to correct proportions so that a compost mixture has the correct C/N ratio and moisture content. However, proper balance of the C/N ratio and moisture content using the available waste materials, is not always possible. In this case the mixture should be designed so that either the C/N ratio or moisture content is within the recommended range. Usually it is best to develop an initial composting mix ratio based on the C/N content and then adjust the moisture as necessary.

Raw materials normally should be blended to approximately a 30:1 C/N ratio. In rural communities or in farm situations, a compost recipe is not determined using calculations but developed by adding a carbon and a nitrogen source together to achieve a pile of good structure that composts well.

A simple way for farmers to achieve that balance is by combining greens and browns in layers. Generally, all composting ingredients fall under one of two categories: ‘Browns’ for high carbon materials or ‘Greens’ for high nitrogen materials. Browns are dry materials such as woodchips, dried leaves, branches, paper and cardboard. Greens are fresh, moist, high nitrogen materials such as food scraps, manure and grass clippings.

A quick and easy way for farmers to obtain the proper C/N ratio is to mix adequately “Greens” and “Browns” (Figure 3).

The ideal compost recipe allows for rapid microbial breakdown of the organic fraction, whilst minimizing impacts on the environment. The formulation of a good compost recipe is essential so that a composting operation can maximize the revenue generated from the sale of products. To achieve the shortest possible composting period, parameters such as sufficient moisture, adequate C/N ratio and good aeration are required. An indication of the duration of composting for some composting mixes is shown in Table 4.

TABLE 4
Typical composting times for selected mixtures

Method	Materials	Range (weeks)	Typical (weeks)	Curing (weeks)
Windrow frequently turned	Garden organic+ manure	26 - 52	36	18
Passively aerated windrow	Manure+ bedding	10 -12	-	4-8
ASP	Bio-solids + woodchips	3 - 5	4	4-8

Source: Recycled Organics Unit, 2002c

STAGES IN THE COMPOSTING PROCESS

The composting process has three main phases:

- Pre-processing - consists of removing contaminants, reducing the particle size of materials and mixing with bulking agents.
- Active composting - the period of vigorous microbial activity during which readily degradable material is decomposed as well as some of the more decay resistant material such as cellulose.
- Curing - follows active composting and is characterized by a lower level of microbial activity and the further decomposition of the products of the active composting stage.

Pre-processing

Pre-processing or preparation of feedstock usually is necessary to create suitable conditions for bacterial action. It consists of three separate types of operation:

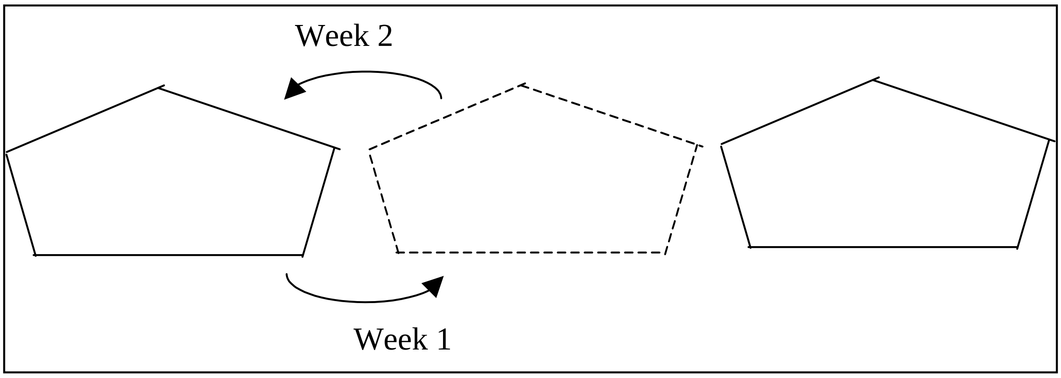
- separation or removal of oversize and dangerous materials and materials that cannot be composted;
- size reduction through chipping, grinding or shredding to create small particles;
- blending to adjust the carbon/nitrogen ratio, moisture content or structure of the materials to be composted.

Active composting

Active composting begins as soon as appropriate materials are piled together. Heat is given off, the temperature rises and other groups of micro-organisms develop. Some composting systems can more effectively deal with specific types of organic materials. For example, highly odorous material such as food organics are more easily processed in systems with forced aeration. The most common form of composting is the turned windrow system. This system is adequate for a large range of organics but requires more maintenance and a higher degree of process control.

For windrows and aerated piles, maintenance of the pile involves turning the pile and adding water to maintain conditions conducive to the composting process. After about a week, the windrow should be opened to the air and any compacted material loosened. Then the pile should be reconstructed; material previously on the top and sides of the pile should be moved to the centre (Figure 4). At each turning, the relatively un-decomposed outer layer can be scraped off and turned back to the centre of the pile. The centre material should be spread over the outer layer of the reconstructed pile. The turning frequency depends on the feedstock, temperature of the compost pile and aeration requirements.

FIGURE 4
Turning of windrows



Moisture should be checked regularly. Simple carbohydrates and proteins provide most of the energy for the initial rapid stages of decomposition. The activity in the pile will slow down when the more resistant materials, such as lignin and cellulose, become the main food source. The compost will be finished when the pile cools off and decreases to about one third of its original volume.

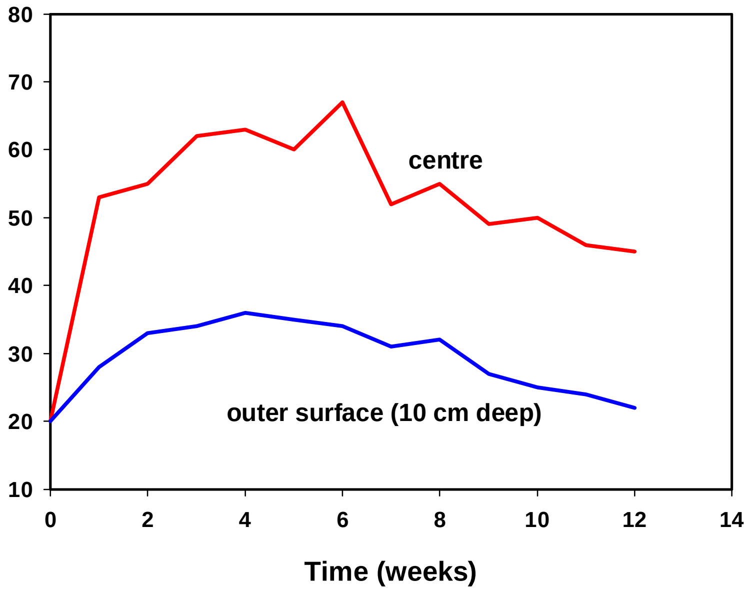
The process is monitored by observing temperature, odours, moisture, oxygen, and carbon dioxide. A troubleshooting guide is included in Annex 2.

Temperature

Temperature is an indicator of microbial activity. The temperature should begin to rise steadily as the microbial population begins to develop. A typical temperature profile for turned windrows is shown in Figure 5. A saw tooth is observed as the temperature at the core of the pile drops each time the pile is turned and picks up again due to microbial action. A lack of heating indicates that aerobic decomposition is not established. This can be caused by factors such as lack of aeration and an inadequate nitrogen or carbon source. Also, the pile may fail to heat because of excessive heat losses. Another possible reason for the failure of the compost pile to heat is that the initial mix is sterile or lacks a large microbial population.

A pile that begins to cool after achieving thermophilic temperatures is nearing the end of the composting process. However, a lack of moisture or aeration can be the cause. A loss of aeration can occur during composting as a result of a loss of structure and porosity as the material decomposes and the pile begins to collapse. Aerobic conditions can be re-established by turning or mixing the pile to rebuild porosity. A composting pile does not heat uniformly but has a temperature gradient from the inner core to the cooler outer surface (Figure 5). Temperatures on the outside of a windrow are much cooler than the centre of the pile (Stentiford and Mara, 1996). The initial compost temperature should be determined by measuring the temperature occurring at 240 to 360 mm inside the compost pile. Readings have to be taken deeper as composting progresses.

FIGURE 5
Typical temperature profile for a turned windrow



Adapted from Recycled Organics Unit, 2002b

Odour management

Odour management is an effective indicator of whether the pile conditions are aerobic and whether nutrient losses are occurring through ammonia volatilization. The main compounds responsible for odour generation are nitrogen compounds and volatile fatty acids. Odours associated with waste materials, such as livestock manure and highly putrescent wastes, generally disappear in the first two days of composting. Strong putrefied odours that smell of sulphur indicate anaerobic activity, particularly when low temperatures, high moistures and low porosity conditions accompany the odours. If excess moisture is not the cause, then the pile may be too large, leading to compaction and inadequate aeration. If the compost pile produces ammonia then add a carbon rich material to overcome the excessive nitrogen.

Moisture

Moisture conditions vary constantly throughout the composting period mainly because of large amounts of evaporation and the addition of water through rain. Improper moisture can slow or stop the composting process, leading to anaerobic conditions that produce odours. A simple method for checking moisture content is called the squeeze test. If the compost is damp to touch but not so wet that water can be squeezed out of a handful of compost, it has sufficient moisture to sustain composting.

Care must be taken to ensure that the compost does not dry out too quickly because decomposition will cease, resulting in partially finished compost. The simplest methods for correcting low moisture content are to spray water into the pile during turning or turning the pile after rainfall. To adjust high moisture content, dry bulky materials must be added and the pile turned.

Curing

By the end of the rapid phase of composting, a significant proportion of the easily degradable organic material has decomposed. Organic materials remaining after the active phase decompose slowly and microbial activity continues at a slower rate. This second phase, called curing, usually takes several weeks to months. During curing, after temperatures have gone down, fungi and actinomycetes re-invade the compost and decompose the more resistant materials. The curing phase is important to reduce the presence of phytotoxic compounds normally present in immature compost. Generally, curing uses passive aeration with occasional turning. As the pile cures, the micro-organisms generate less heat, the pile begins to cool and the compost becomes biologically stable.

Storage

Stable compost can be stored under cover for several months without the risk of spoilage. Stored compost should be kept dry to maintain product quality and minimize potential surface water contamination. This can be accomplished by covering the compost with tarpaulins or by storing it under a roof.

COMPOST MATURITY EVALUATION

Maturity of compost is essential for its optimum use as a soil amendment and a source of plant nutrients. The term mature also refers to the degree of phytotoxicity of compost. Even compost made of high quality materials that are applied too soon to plants may burn leaves, stunt growth or even kill sensitive plant species. Immature compost continues to break down once it is incorporated into the soil.Mature compost is material in which biological activity has slowed. A fine texture, dark colour and a rich earthy smell often characterize mature compost. No single test exists that can reliably verify the maturity of compost. The compost maturity indicator tests (Alberta Environment, 1999) recognized by several organizations in Canada, namely the Bureau du Normalisation de Quebec (BNQ), the Canadian Council of Ministers of Environment (CCME), and the Agriculture and Agri-Food Canada (AAFC) are indicated in Box 1.

BOX 1
Compost indicator tests

Compost is deemed mature if it meets two of the following requirements:

1. C/N ratio <=25
2. Oxygen uptake less than 150 mg O2/kg organic matter per hour
3. Germination of cress or radish seeds in compost is equal to more than 90 percent of that of a control sample, and plant growth rate in soil/compost mix is not less than 50 percent of that of a control sample
   - Compost must be cured for a minimum of 21 days and must not reheat upon standing to greater than 20^{o}C
   - Compost must be cured a minimum of 21 days and organic matter must be reduced by at least 60 percent by weight
   - Compost must be cured for a six month period
   - In the absence of other tests, the six months curing period under proper conditions can be considered sufficient to achieve maturity.

Source: Alberta Environment, 1999

There are commercial stability tests available at the Woods End Research laboratory (WERL), such as the Dewar test and the Solvita maturity tests (Brinton, 1997). The term stability often is used interchangeably with maturity. They are not really equivalent. Compost is considered to be mature when biological activity has slowed, as most remaining molecules are difficult to break down any further. Stability also refers to the slowing of biological activity but this may be because of a variety of factors, such as lack of adequate nitrogen or water for the process to continue. In that case, if the inadequate parameters are adjusted, biological activity will return to active levels.

Compost maturity also includes pathogen reduction to acceptable levels, as composting feedstocks sometimes contain pathogenic organisms. The most common methods used are the temperature-time method, also known as the process to further reduce pathogen (PFPR) criteria, and product specific criteria on the amount of coliforms and salmonella in the compost (Arnold, Dunn and Sievers, 1994).

The temperature time method is based on the fact that all living organisms can be killed when exposed to a specific temperature for a specific length of time; the greater the temperature the shorter the length of time necessary for composting. The temperature time criteria are valid also for destroying pathogens in other feedstocks and for destroying other organisms, such as nematodes, insects, and weed seeds. The United States Department of Agriculture (USDA) traditionally has used the temperature time criteria for controlling harmful pathogens in bio-solids in the 1980s (Box 2).

BOX 2
Temperature time criteria

TEMPERATURE
The compost product should be brought to a minimum temperature of 55^{o}C for three consecutive days for aerated static piles or fifteen days with five turns for turned windrows in order to fulfil the requirements to further reduce pathogens.

TIME
The compost product should be exposed to a minimum composting period of 42 days and a minimum curing period of 30 days prior to distribution.

Product specific criteria, on levels of faecal coliform and salmonella also form part of the pathogen reduction criteria. The ones applicable for *compost not containing feedstock known to be high in human pathogens* are indicated in Box 3.

BOX 3

Product specific criteria

Organisms shall not exceed

Faecal coliforms: <1000 Most Probable Number (MPN)/g of total solids calculated on a dry weight basis, and

Salmonella species: <3 MPN /4 g total solids calculated on a dry weight basis.

Chapter 3
Finished product evaluation and use

COMPOST QUALITY

Compost quality is determined by the composition of the feedstock, the type of separation process and the adequacy of the composting process. Compost is largely microbial cells and skeletons, by-products of microbial decomposition and un-decomposed organic and inorganic particles. Its chemical composition varies depending on the initial feedstock.

The quality of the compost required is dependent also on the end-use. Its physical, chemical and biological characteristics are important particularly when it is to be sold.

Physical characteristics

The physical characteristics used to determine compost quality are particle size, texture and the level of contaminants (Table 5).

Chemical characteristics

The chemical characteristics of compost are measured in terms of its:

- value as fertilizer or soil amendment;
- potential toxicity to plants;
- organic matter content;
- moisture content;
- pH and soluble salts;
- water holding capacity.

Nutrient value

Finished compost contains little nitrogen (N), phosphorous (P) or potassium (K). A typical breakdown of nutrients in manure-derived compost is shown in Table 6.

TABLE 5
Physical characteristics

Particle size	Uniform particle size < 12.5 mm for potting media and < 7 mm for higher grade compost
Texture	Soil like
Colour	Dark brown to black
Absence of inert material (plastics, glass and rocks)	Less than one percent (dry weight) of particles < 4 mm

TABLE 6
Typical nutrient value of compost

Nutrient	Dry weight
Nitrogen	<1% up to 4.5%
Potassium	0.5% to 1%
Phosphorous	0.8% to 1%
Calcium	2% to 3%
Magnesium	2% to 3%

Source: Composting Factsheet 382.500-15, 1996

Moisture content

In finished compost the desirable moisture content is 30 to 50 percent. Compost with moisture content greater than 60 percent tends to form clumps that are difficult to break apart. Dry compost with moisture less than 35 percent produces significant amounts of dust. Also, dry compost with high organic matter content is difficult to incorporate into soil because it tends to stay on the surface.

pH

The pH of compost should be between 6 to 8. Acidic or basic compost can be made depending on the crop to be grown and the sensitivity of the end use. For potting soil and germination mixes, a pH of 5.5 to 6.5 is best while for compost to be used as a soil amendment, top dressing or mulch, a pH of 5.5 to 7.8 is suitable.

Soluble salts

Soluble salts can be harmful to plants by reducing water absorption and producing toxic conditions. Potting soils require a soluble salt content between 2 to 4 mmhos/cm (Field guide to compost use, 1996). When used as a soil amendment or mulch compost can have a higher soluble salt content, for instance 12 mmhos/cm, as it is diluted with a large quantity of soil.

Organic matter content

The organic content of compost ranges from approximately 35 to 70 percent. The preferred range is from 50 to 60 percent.

Water holding capacity

Water holding capacity is a measure of the ability of the compost to hold water. For many composts, the water holding capacity ranges from 75 to 200 percent (on a wet weight basis). The preferred range is 100 percent or greater.

Biological characteristics

The three main desirable biological characteristics are the stability of the compost, absence of pathogenic micro-organisms and germination tests.

Stability

The stability of compost is measured to assess potential phytotoxic effects. Also, stability is used in combination with other chemical measurements to assess the degree to which compost suppresses plant pathogens.

A stability measurement determines the biological activity within a compost sample having adequate moisture and oxygen and not inhibited by high (> 50^0C) or low (< 20^0C) temperatures (VanderGheyst, 2000). There are three common measurements of stability:

- heat production;
- oxygen consumption;
- carbon dioxide production.

Since stability represents the state of microbial activity, measurements of respiration either through carbon dioxide evolution or oxygen uptake provide the best indication.

Oxygen uptake as a result of microbial activity has been used for many years (Epstein and Konhnke, 1957; Pressel and Bidlingmaier, 1981; Lasaridi and Stentiford 1997). The rate of oxygen depletion from the environment and/or the change in oxygen within the environment over a given period is used to determine a compost stability index (Table 7).

TABLE 7
Respiration rate and maturity

Respiration rate (mgO_2/gVS/hr)	Rating	Characteristics
0 - 0.5	Very stable	Well cured No odours No continued decomposition
0.5 – 1.0	Stable	Cured compost Limited odour potential Minimal impact on soil carbon and nitrogen dynamics
1.0 – 1.5	Moderately stable	Uncured compost Minimal odour production High phytotoxicity potential
1.5 – 2.0	Unstable compost	Very immature compost High odour and phytotoxicity potential Not recommended for growing plants from seed
> 2.0	Un-stabilized material	Extremely unstable Very high odour and phytotoxicity Not recommended for use

Source: Ianatti, Grebus, Toth, *et al.*, 1994

Determining the carbon dioxide respiration rate entails the incubation of a compost sample at 30^0C and subsequent daily determination of the weight of carbon dioxide (CO_2-C) evolved. A value less than 5 mg CO_2-C per g of compost per day indicates that the compost is stable. The Solvita index test, which simultaneously measures carbon dioxide and ammonia, is another method commonly used to determine maturity. A maturity index of 1 to 8 is used to grade the compost. Details of the Solvita index test are given in Annex 3.

Germination test

The germination test is used to determine stability and maturity. The cress seed germination test entails the germination of water cress seeds in a 5 percent compost -water extract (on a weight basis) A germination index is produced by taking the product of percent germination and root elongation and dividing by 100. An index below 60 indicates the compost is stable.

COMPOST QUALITY STANDARDS

There are no international standards for compost quality although several countries have established quality criteria for their compost (Table 8). The CAN/BNQ 0413-200 provides a voluntary standard to the composting industry (CAN/BNQ 0413-200, 1996). Part of the standards is indicated in Box 4.

TABLE 8
Quality criteria used by some countries

Test parameter	Germany	Australia	USA (WERL*)
Salt	<2.5 g/l	<2 g/l	<2 mmhos/cm
Average nitrogen (mg/L)	<300	800	100-300
Phosphate (mg/L)	<1200	<800	80-2500
Potassium (mg/L)	<2000	<1500	500-2000
Maturity	*	*	Solvita 7-8
Organic matter %	>15	>20	>30
pH	Declared	5-2.7	6-7
Foreign matter	Maximum 0.5% >2mm	Maximum 0.5% >2mm	(1%) 2mm

***** WERL – Woods End Research Laboratory
Source: Brinton, 2000

BOX 4
CAN/BNQ 0413-200 National Standard

Moisture content Not greater than 60 percent
Total organic matter content Not less than 40 percent (percent of oven dried mass)
Foreign matter content 0.5 percent (oven dried) with maximum diameter ≤12.5mm
Maturity Based on two of three requirements:

- C/N ratio ≤25;
- oxygen uptake ≤ 150 kg oxygen/kg of volatile solids per hour;
- germination rate for cress or radish seeds in compost of at least 90 percent of the germination rate of the control and plant growth in compost/soil mix shall not differ by more than 50 percent in comparison with the control sample.

Faecal coliform content <1000 MPN/g of total solids (oven dried mass)
Salmonella content No salmonella present on compost

Trace element	Concentration mg/kg(air-dried)
As	13
Cd	3
Co	34
Cr	210
Cu	100
Hg	0.8
Mo	5
Ni	62
Pb	150
Sc	2
Zn	500

BENEFITS OF FINISHED COMPOST

Compost has the ability to improve soil and growing media properties by giving structure and nutrients and also by improving beneficial biological activity. The benefits of using compost are long term and related to its content of living organic matter. The benefits include:

- reduced soil erosion, particularly in areas of exposed soils;
- increased water retention in the upper soil profile, thus reducing the frequency of watering;
- release of nutrients for plant growth, reducing the need for fertilizers;
- suppression of soil borne plant pathogens, reducing the need for fungicides and bactericides.

Physical benefits

In fine textured soil the addition of compost improves porosity and increases gas and water permeability, thus reducing erosion; helps resist compaction; increases water-holding capacity and improves soil aggregation because of its humus content.

In heavy clay soil compost particles bind with clay particles to form larger particles. Thus, surface water can drain between the larger particles while the compost portions hold the moisture inside the particles ready for plant uptake. Compost reduces the frequency and intensity of irrigation. The use of organic mulch can dramatically reduce the amount of erosion in irrigation practices and improve water infiltration rates by 50 to 60 percent (Brown, Robbins and Freeborn (1998).

TABLE 9
Potential uses of compost by category

Category	Market segment	Uses
Agricultural	Field crop growers	Soil amendment.
		Fertilizer amendment.
	Fruit and vegetable farmers	Crop maintenance
		Soil amendment
	Organic farmers	Fertilizer substitute
		Soil amendment
Non-agricultural	Garden centres	Resale to homeowners
	Greenhouses	Potting mix component
		Peat substitute
	Landscapers	Top soil substitute
		Soil amendment
		Mulch
	Land reclamation contractors	Top soil and soil amendment for disturbed landscapes
	Nurseries	Soil amendment and soil replacement
		Container mix
Residential	Homeowners	Soil amendment
		Mulch
		Fertilizer supplement

(Adapted from Rynk, Van de Kamp, Wilson, *et al.*, 1992)

Chemical benefits

- Stabilizes pH

The incorporation of compost has the ability to buffer or stabilize soil pH. The addition of a neutral to slightly alkaline compost to an acidic soil increases soil pH, if added in appropriate quantities.

- Increases cation exchange capacity

Compost can improve the cation exchange capacity (CEC) of the soil, enabling longer nutrient retention. Also, it allows crops to more effectively use nutrients, thus reducing nutrient losses by leaching.

- Provides nutrients

Compost contains a considerable variety of macro and micronutrients that are slowly released when applied to soil and plants. It can have a significant cumulative effect on nutrient availability as usually it is applied in greater rates than commercial fertilizers. Compost makes chemical fertilizers more effective on plants (Wolkowski, 1996).

Biological benefits

Compost contains a large range of micro-organisms, which proliferate within the soil media. These micro-organisms are useful in organic matter decomposition and promote root activity. Also, compost attracts earthworms. The tunnels created by earthworms aerate the soil and improve drainage while the burrowing process brings up minerals from the subsoil, making them available to plants.

The increased population of certain organisms and chemicals released from composting can suppress specific plant diseases (Hoitink and Krause, 1998). Beneficial micro-organisms in compost inhibit or simply compete with pathogens in soil, thereby suppressing some diseases.

COMPOST USE

Potential compost markets

Compost products can be marketed through numerous channels. The main uses of compost can be classified into agricultural, non-agricultural and domestic.

TABLE 10
Characteristics for different compost uses

Parameter	Grass	Vegetable crops	Mulch	Planting bed	Growing media
PH	5.5 – 8.0	5.5 - 8.0	5.5 - 8.0	5.5 - 8.0	5.5 - 8.0
Soluble salt (mmhos/cm)	4 (soil blends)	< 6	-	2.5	< 3
Moisture content (%)	35 – 55	35 – 55	35 – 55	35 – 55	35 – 55
Particle size (mm)	< 25	< 25	-	< 25	< 10
Stability	Stable to highly stable	Stable to highly stable	Medium to highly stable	Stable to highly stable	Highly stable

Source: Field guide to compost use, 1996

Examples of agricultural uses are sugarcane plantations and vegetable and fruit production. Non-agricultural examples are its use as a soil conditioner on golf courses, nurseries, horticulture areas and household gardens and for landscaping by municipal agencies, hotels, airports and universities. Innovative uses of compost include erosion control and bioremediation.

Compost specifications vary, according to market demands. Attention to customers' needs and a consistent supply of a quality product helps sustain markets. The potential uses for compost are primarily in agriculture, land development and horticulture (Table 9).

Application rates

Compost application rates to soil vary greatly but generally range from 25-100 t/ha, although higher application rates are not unusual. These rates provide for the optimum nitrogen needs of a growing crop without causing adverse environmental impacts (Tester, 1990; Ehrig and Stahr, 1989). Annual application rates greater than 100 t/ha must be carefully monitored to avoid excessive build up of one element in the soil, thereby causing plant nutrition imbalances. Compost applications to soil often are based on the assumption that only a single, large addition will be made. However, it has been found that it is better to apply small amounts of compost more frequently (Harada, 1990).

Compost application rates vary, depending on the mineralization rates and whether the compost is used as a soil inoculant or as a primary nutrient source. Characteristics for different compost uses are shown in Table 10 (Field guide to compost use, 1996).

Planting bed

One of the most popular uses for compost products by horticultural professionals is in planting beds for the establishment of ornamental plants. The characteristics of suitable compost are a pH of 5.5 to 8.0 and moisture content from 35 to 55 percent. The application rate is 2 to 4 m^3/100 m^2, evenly applied. Lower application rates can be used with compost possessing higher organic content or for salt sensitive crops. Coarse textured (sandy) soils require higher application rates.

Landscape mulch

Landscape professionals and homeowners commonly use compost derived from yard trimmings and bio-solids as mulch. It is recommended to apply compost at a rate of 2 to 6 m^3 per 100 $m^{2.}$ Yard trimming compost can be applied to a depth of 80 mm while compost from bio-solids should not be applied to a depth greater than 50 mm. Compost mulches with a coarser texture may be more effective in reducing weed growth and preventing soil erosion. Compost containing high salt levels and/or high ammonium levels should not be used as mulch on soils where there are crops.

Growing media component

Usually compost is used as part of the organic fraction of growing media. This use has been shown to reduce fertilizer and liming requirements and improve crop vigour and root growth.

The amount of compost used is based largely upon its characteristics and the crop to be grown. Typical factors limiting the inclusion rate of compost are its pH, soluble salts concentration, stability and particle size. Municipal solid waste (msw) compost has been used successfully at rates of 20 to 50 percent and yard trimmings compost at 33 to 47 percent (Field guide to compost use, 1996). Small test plots should be established before full-scale compost use is initiated.

Vegetable production

In vegetable production applications, compost should be applied at a rate of 10 to 60 t/ha although rates as low as 1 to 2 t/ha are common because of economic factors. Soil test results are helpful in establishing compost application rates for vegetable production. Less stable or mature compost can be used in vegetable production so long as it is incorporated sufficiently in advance of planting.

A sample calculation of application rates

Compost as a surface layer

Given compost with a bulk density of 400 kg/m^3, the amount necessary to cover 1000 m^2 with a 1 mm thick layer is calculated as follows:

Volume to cover the area: $1000 * 1 * 10^{-3} = 1$ m^3

As bulk density of compost is 400 kg/m^3, the amount of compost is 400 kg.

Table 11 shows the amount of compost required for an area of 1000 m^2 for layers ranging in thickness from 1 mm to 6 mm when used as a surface layer.

Compost as a nutrient source

The application rate for compost to be used as a nutrient source is indicated in Box 5

TABLE 11

Compost quantities for an area of 1000 m^2

Layer thickness (mm)	Volume required (m^3)	Weight required (kg)*
1	1	400
2.5	2.5	1 000
4	4	1 600
6	6	2 400

* bulk density of compost 400 kg/m^3

BOX 5

Sample calculation for compost application rate

Given a compost with the following analysis:

Total nitrogen (TKN): 1.59 percent

Mineral nitrogen (NH_4): 1 562 ppm

Nitrate: 672 ppm

Bulk density: 400 kg/m^3

The compost application rate to supply 200 kg of nitrogen to 1 ha is:

Assumptions made are

- 50 percent loss of ammonia (NH_4-N)
- 20 percent of organic nitrogen is available in the first year of application.

Total available nitrogen in first year: available organic + remaining ammonia + nitrate.

Total organic nitrogen: (TKN - NH_4) = 15 900 - 1 562 = 14 338ppm

Remaining ammonia: 1 562 * 50% = 781 ppm

Total available nitrogen: 14 338*20% + 781 + 672 = 4 186 ppm = 4 321 kg N/t

Amount of compost to be applied: 200/4.3 = 46.4 t/ha or 116 m$^{3/}$ha.

Source: Composting Factsheet 382.500-15, 1996

Chapter 4
Composting technologies

INTRODUCTION

Composting technology can be classified as open or closed, batch or continuous and small-scale or large-scale. Open or closed methods refer to composting in the open or in closed reactors, batch or continuous methods refer to the frequency at which the waste materials are composted while small-scale and large-scale methods refer to the quantity of material to be composted at one time. The amount of waste is a major consideration when deciding the method to use.

Small-scale technology is applicable to composting small amounts of waste, normally less than 500 kg, while the range for large-scale technology is between hundreds of kilograms and thousands of tonnes. Large-scale technology can be classified further into four categories: passive pile, windrow, aerated static pile (ASP) and in-vessel composting. The technologies vary in the method of air supply, temperature control, mixing/turning of the material and the time required for composting.

In this section, the technologies have been grouped as large scale and small scale. Supporting technologies for composting include pre-processing of waste substrates and post-processing of compost. Typical equipment for shredding and grinding wastes, turning windrows and screening compost are shown in Annex 4.

SMALL-SCALE TECHNOLOGIES

Small-scale composting systems adapted for households include heaps in and above the ground, pits, boxes, bins, garbage cans, drums and barrels, which can be outdoors or indoors. Each method has its advantages, but when choosing the composting method, factors such as space availability, neighbours, type of material and available construction facilities have to be taken into account.

A summary of small-scale methods is given in Table 12.

Heap

The simplest way to compost material is to build a heap. A small compost heap can be either in a stack above the ground or in a pit dug in the ground. A heap can be of any size but a manageable heap is 1 to 2 m wide and 1 to 1.5 m high, although considerable heat losses occur with small heaps. This method is appropriate for gardeners or farms that have plenty of space, ample materials, sufficient time and no nearby residents. The composting time is quite long, up to one year.

Bins and pens

The most common compost structures are bins made of concrete, brick, wood or masonry and pens made of wire or hardware cloth. Pens (Figure 6) have the advantage of allowing air circulation, however there is free circulation of flies and rodents. It is quite difficult to trap heat in a compost pen and therefore high temperature composting may not develop.

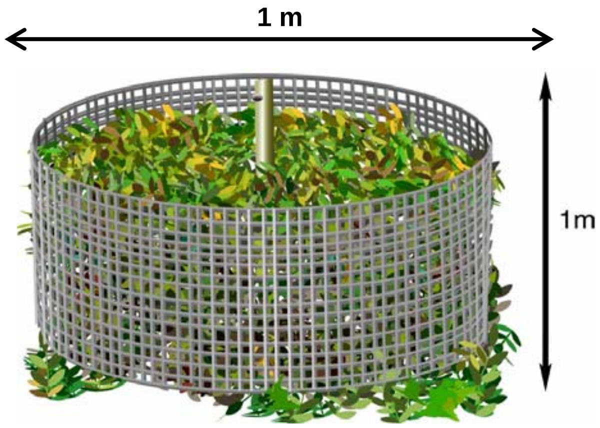


FIGURE 6
Circular pen

Adapted from Martin, Gershuny and Minnich, 1992

Bins are more stable and have a protecting structure. Pens and bins are classified as holding units while barrels and drums as turning units. Turning units produce compost more quickly than holding units because of the turning process.

Holding units

Cage type bin

The cage type bin (Figure 7) is a circular or rectangular structure made of wooden pallets and hardware cloth. Usually it is applicable for yard waste composting and is about 1 m^3 in size.

Block and brick bin

These are permanent structures (Figure 8) used to compost wastes. Blocks are lined in such a way as to allow for proper air circulation.

Three holding unit

A turning unit also can be three holding units placed side by side (Figure 9). Each unit is approximately $1m^3$ (1 m * 1 m * 1 m). One bin is full at a time and its contents are turned into the empty adjoining bin every week or two. The final bin provides the space for curing while a new batch of compost is started in the first bin. Average composting time is around two months. Commonly, the three holding unit is used to compost horse wastes on farms.

FIGURE 7
Cage type bin

FIGURE 8
Block and brick bin

Adapted from Martin, Gershuny and Minnich, 1992

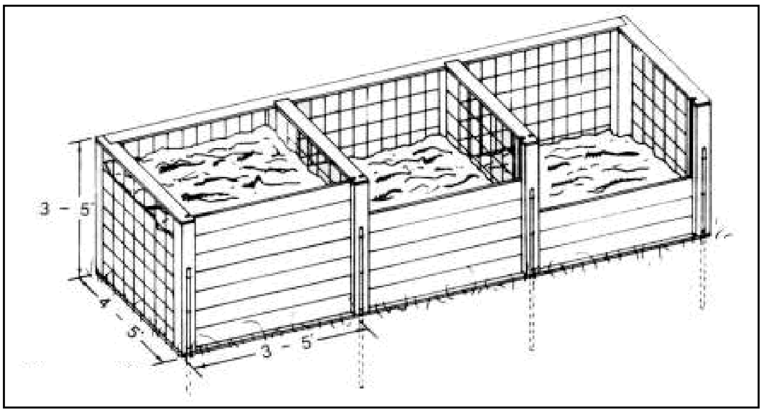
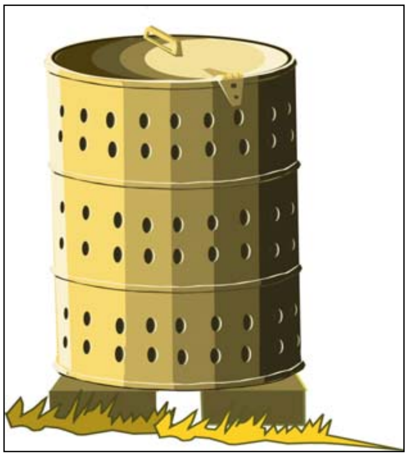


FIGURE 9
Three holding unit

Source: McLaurin and Wade, 1999

FIGURE 10
Vertical drum



Adapted from McLaurin and Wade, 1999

Plate 1
Passive composting pile
Source: Vogel and Block, 1998

Drums
Drums are very effective for composting kitchen waste. They can be used for households with small yards. Drums are waterproof. There are two types of drum compost systems:

- Vertical drums (Figure 10), which are not turned themselves, but materials can be turned using a fork.
- Horizontal rotary drums, which allow for easy turning. Rotary horizontal drums can be rolled on the ground or fixed to a support. When fixed to a support they are easy to turn and as the drum is above the ground it is easier to empty.

LARGE- SCALE COMPOSTING TECHNOLOGIES
Several large-scale composting methods are suitable for farms. The method chosen depends on available labour, resources, time, land and raw materials. The main large-scale composting systems are passive piles, windrows, aerated static piles and in-vessel systems.

In-vessel technologies will not be discussed here, as they are usually sophisticated systems requiring highly skilled manpower and high capital investment. Hence, they are not appropriate for individual farms or rural communities. In-vessel composting systems rely on a variety of forced aeration and mechanical turning technologies to speed up the composting process.
A summary of large-scale methods is given in Table 13.

Passive composting piles
The passive composting pile method involves forming mixtures of raw material into a pile (Plate 1). Typical dimensions are 2 m high and 3 m wide. Aeration is accomplished through the passive movement of air through the pile. However, the pile must be small enough to allow for passive air movement, otherwise anaerobic pockets will form.

Since no turning and moisture adjustment is made during the composting period, special attention should be given to the mixing of raw materials and their porosity and structure.

Minimal labour and equipment is needed with passive composting and therefore it is the least expensive large-scale composting method. It is very appropriate for leaves and yard trimmings and when compost is not needed quickly. Composting is slow, taking up to two years to stabilize the waste material.

TABLE 12
Summary of small-scale systems

System	Turning	Heat generation	Vectors	Duration
Heap	Easy	Rapid	Present	6 months - 1 year
Cage type + circular bins	Easy	Moderate	Present	6 months - 1 year
Block/brick bin	Easy	Moderate	Present	6 months – 1 year
Drums	Very easy	Very rapid	Present	2 - 4 months

Windrow composting

In the windrow composting method the organic wastes are piled in elongated rows that are turned regularly. Raw materials can be mixed as part of pile formation. Windrow shapes and sizes vary, depending on climate, equipment and the material used.

Typically windrows are 2 to 3 m high, 4 to 5 m wide and up to 30 to 40 m long. Frequent turning of the material (at least once a week) provides aeration, mixes the material, helps to control temperatures and redistributes moisture.

Windrows can be either left in the open or covered, depending on the climate and the moisture content of the material. If left in the open, the top part of the windrow in dry climates must have a concave shape to collect water to maintain pile moisture or in wet climates a triangular shape to allow water to run off (Figure 11). Large amounts of heat are lost from small windrows, especially when they are turned. The turning schedule during composting varies from operation to operation, depending on the pile temperature, season, labour availability and the desired compost quality.

The time required to complete the composting process ranges from five to ten weeks, depending on the type of material being composted and the turning frequency.

Passive aerated windrows

Passive aerated windrows are windrows that are not turned. They are used commonly for composting manure with straw or woody shavings and seafood wastes with peat moss. Aeration is solely by the passive movement of air through perforated pipes in the pile base.

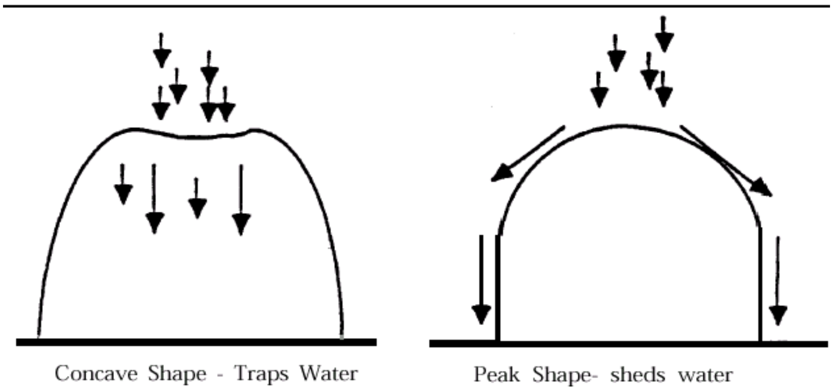
The windrows are built on top of a base layer, typically composed of straw, finished compost or bagasse. This layer must be porous so that air coming through the pile is distributed evenly. Aeration pipes are placed on top of the peat/compost base with their holes oriented downwards to minimize plugging and allow condensate to drain.

A top layer, composed of peat moss and/or finished compost, is used to cover the windrow. The main functions of the top layer are to retain odours, moisture, and ammonia and to insulate the pile. Also, it deters flies.

As in passive pile composting, it is important to have a mix with good porosity and structure to allow for adequate aeration. Typically, passive aerated compost systems are 1 to 2 m high and about 3 m wide. The bottom and top layers should be about 100 - 150 mm thick.

The average composting time is six to ten weeks.

FIGURE 11
Shape of windrows



Adapted from Richard, 1992

Aerated static pile

Waste materials are arranged in long rows, in a similar way to windrows. Air is introduced via a network of perforated pipes in the base layer of the pile (Figure 12). An aerated static pile differs mainly from a passive aerated windrow in that it uses fans to either suck air out of, or blow air into the pile.

Aeration fans not only provide oxygen, but also cooling. Fans can be run continuously or at intervals and can be activated either at set times or based on compost temperature. Fan aeration with temperature control allows for greater process control than windrow turning (National Engineering Handbook, 2000). A forced aerated static pile (ASP) has a base layer of porous material, such as wood chips and/or bagasse and a top layer similar to the passively aerated windrow.

The use of the forced aeration technique requires calculations on aeration rates, size of the fan and the number, length, diameter and types of pipes. Aeration rates vary according to the materials being composted and whether aeration is used to provide oxygen, remove heat or aid drying (Haug, 1993). Batches of 10 tonnes of horse manure may require around 432 m^3/day of air (Nardeosingh, 2003) while a similar amount of yard waste trimmings would need 200 m^3/day (Eustasie, 2003).

Quick composting can be achieved with an ASP, the active composting period being completed in approximately three to five weeks. The length of an ASP is limited by air distribution in the aeration pipes. If the pile is too long, air might not reach the far end. Typical pile lengths are 12 to 15 m.

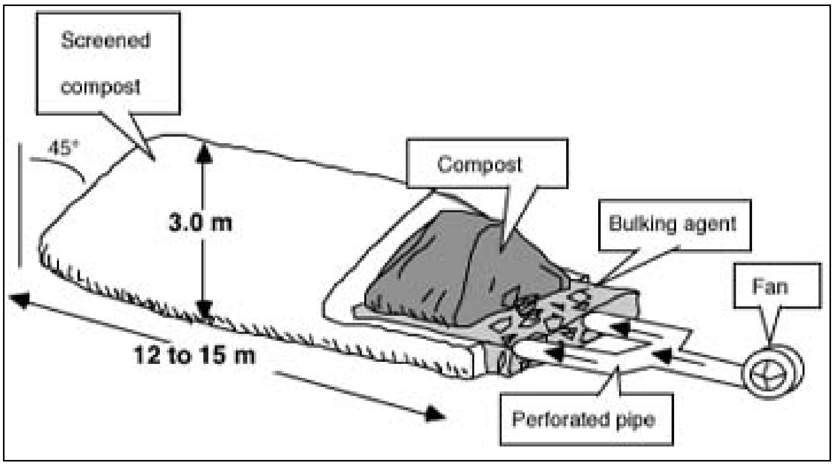
Because of the high costs of operation (energy supply) and temperature equipment for greater process management aerated static piles are not used often in farm-scale composting systems.

Extended aerated static pile

The extended aerated static pile (EASP) composting method is similar to the aerated static pile except that a new cell is constructed on the flank of the preceding cell, to form a flat-topped pile that increases in width with the addition of each new cell. Adjoining cells are constructed by placing aeration pipes on the pad parallel to the long side of the initial cell. This process can be repeated daily for a period of around four weeks, thereby forming an extended pile. At the end of active composting, the cells are broken down separately in the same order that they were constructed.

The EASP method requires four to five times less area than the turned windrow method and because of the large mass of composting material the method is self-insulating. By converting the system from a turned windrow to an EASP method of composting, the area required for composting is decreased by a factor of four (Moon, 1997). This has the added benefit of significantly decreasing the volume of leachate needing to be collected, stored and treated, all of which decreases the cost of operation. The amount of bulking agent or finished compost required for covering the pile is reduced also.

FIGURE 12
Aerated static pile



Source: Hansen, Marugg, Keener, *et al.*, 1995

TABLE 13
Comparison of large-scale composting systems

Parameter	Passive pile	Windrow	Passive windrow	Aerated static pile
Process time (month)	12-24	6-12	6-12	3-6
Process control/management	Minimal	Moderate (turning)	Minimal	High
Potential for odour generation	High because of anaerobic pockets	Moderate only when turning	Minimal (odour absorbed in top layers)	Minimal (with sucked air)
Capital investment	Low	Low	Moderate	High
Operation cost	Low	High (labour)	Low	High
Compost quality	Poor	Moderate	Low to moderate	Good
Important parameters	Porosity/structure	Porosity/structure	Porosity/structure	Porosity/moisture (Pile can settle)
Materials targeted	Leaves/yard trimmings	Mixed wastes, manure most widely used by farmers	Manure, seafood wastes	Sludge, mixed wastes, manure

UNIT OPERATIONS TO IMPROVE COMPOST QUALITY

There is a succession of operations, such as shredding, mixing and storing materials prior to the active composting phase, involved in a composting system. Sometimes several secondary operations are necessary to condition raw materials for composting, to recover un-composted material from the finished compost or to improve the compost quality for sale or use. It should be noted that not all pre-processing operations are needed. These usually depend on the substrate and the final use of the product. The more processing the material has to undergo, the higher the capital costs.

Feedstock preparation

The feedstock has to be processed to adjust its chemical and physical characteristics to help microbes perform efficiently. Several materials are combined to balance the carbon to nitrogen ratio. Water is mixed in to adjust the moisture content. Shredding to increase the surface area and create a uniform particle size reduces the size of the waste. The following are the main types of shredding/grinding equipment used for composting (Diaz, Savage, Eggerth, *et al.*, 1996).

Hammer mills

There are two categories of hammer mills: horizontal and vertical. Both types have hammers that rotate within the shredder causing particle size reduction through collision with the added material. The hammers are mounted on the shredder rotor either in a fixed or freely swinging manner. The horizontal hammer mill is used commonly in mixed waste processing.

Shear shredder

A shear shredder is used to reduce the size of mixed wastes, particularly for materials difficult to shred. It consists of two horizontal counter-rotating shafts, each shaft containing cutters to tear and shear the material.

Tub grinders

Tub grinders use a rotating tub to move material into either a hammer mill or a shear shredder. The material is then broken down until it can pass through a discharge screen, or grating. Once through the grating, the material is moved up an incline conveyor and is discharged into a pile. Tub grinders are mobile and can be powered by a tractor, a gas or diesel motor.

Mixing and pile formation

Commonly available farm equipment can be used for the initial mixing, pile formation and turning (Rynk, Van de Kamp, Wilson, 1992). Most windrow operations use bucket loaders for mixing, pile formation and turning. Sometimes manure spreaders are used to construct windrows. Backhoes and diggers are used for small amounts of waste. Dump trucks, wagons and bucket loaders can be used for pile formation. Also, there are specialized windrow turners, equipped with blades to promote aeration as the material is turned.

Windrow turners

Methods used to turn windrows include rotary drum, elevated face and auger turners. Rotary drum turners straddle the windrow and as they move forward the rotating drum stirs the windrow. Also, the rotating drum helps reduce the particle size of the material. An elevated face turner aerates the windrow by lifting the material and dropping it. Auger turners aerate the windrow by displacing the windrow, moving it to one side.

Tractors and loaders are used to turn windrows in a variety of ways. One way is to pick up a bucket of material and to form a new windrow beside the windrow being turned. Loaders are used for windrow construction, windrow turning and edging windrows after turning with a windrow turner.

Screening

Screening separates materials of different slices/shapes. In composting it separates the portion of mixed wastes to be composted from contaminants, recovers the bulking agent from compost for reuse and improves the final compost quality. There are many different types of screens: trommel, shaker, vibrating and rotating screens. Trommel and vibrating screens are most commonly used. If small amounts of compost are generated on the farm, a screen using wooden pallets and hardware cloth can be constructed easily and fitted over a wheelbarrow or garden cart (Figure 13).

Trommel screens

A trommel screen is a rotating drum with holes. The drum is inclined so that materials are moved through as it rotates. The large particles are retained within the drum while the fine particles fall through the holes onto a conveyor.

Shaker screens

Shaker screens have a reciprocating motion, which bounces the material along the screen length. The motion helps segregate the large and small particles, reduces binding, and moves oversized particles off the screen.

Vibrating screens

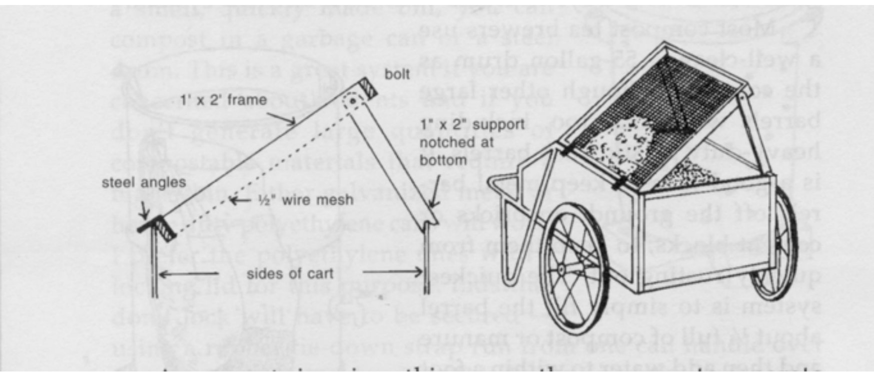
Vibrating screens use an oscillating motion to enhance separation. The vibration is much faster than that of a shaker screen. The vibration plus the slope of the screen moves the oversized particles. These screens are used to separate fine materials, both wet and dry.

Auger and trough screens

These screens consist of a perforated trough containing an auger that moves the materials from one end to the other. The fine material drops through the holes, and coarse materials pass on to the end. Multiple auger screens can be combined to achieve multiple separations of sizes. This equipment is designed to remove soil and fine materials from wood chips.

Diagrams of different types of pre-processing and post-processing equipment, such as hammer mills, windrow turners and screens, are shown in Annex 4.

FIGURE 13
Simple compost sieve



Source: Noyes, 1995

TYPICAL ELEMENTS IN AN AGRICULTURAL WASTE FACILITY

Typical operations encountered in an on-farm agricultural wastes composting facility, namely waste collection, unloading, processing and curing, and the storage and sale of finished products are shown in Figure 14.

Wastes reception and pre-processing

Once the agricultural wastes have been collected at the site, they need to be processed. The wastes are spread on a paved area and contaminants removed. A staging area consisting of a surface with low permeability can be used, which would enable the sorting of contaminants and materials to be mixed in the proper proportions.

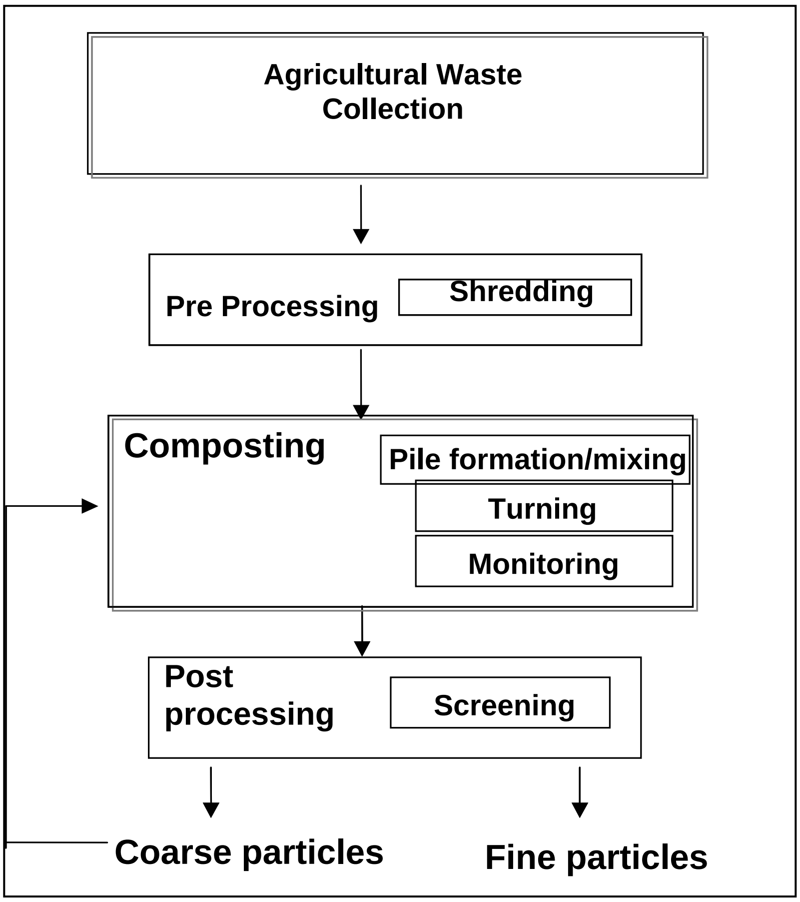
Grinding and shredding

Grinding the agricultural wastes accelerates the decomposition process by exposing more surface area of the material to micro-organism activity. Size reduction is necessary for woody materials such as branches, as these decompose very slowly. Also, shredding leaves reduces the time required to produce finished compost. However extensive size reduction can be undesirable as aerobic conditions can be inhibited.

Mixing

Often, mixing is required to achieve optimal composting conditions. For simple composting operations such as agricultural wastes, mixing can be done during size reduction or pile formation.

FIGURE 14
Flow diagram showing operations for a typical agricultural waste facility



Windrow composting

Within the four categories of composting systems; turned windrows, passive piles, forced aerated static piles and in-vessel composting, turned windrows are most appropriate for agricultural waste. Passive pile composting, whereby the feedstock is arranged in piles and rarely turned, is simple and appropriate for homogeneous wastes. However, the composting process is very slow and is more suitable for materials having a uniform particle size. To produce finished compost from agricultural wastes using the passive pile method would take more than a year. In addition, the minimal turning can result in the formation of anaerobic conditions.

The aerated static pile (ASP) uses higher technology to compost agricultural wastes. It is more expensive than turned windrows as air has to be supplied continuously to the pile. Also, this method tends to dry the compost pile and therefore is more suitable for wet materials. Agricultural waste can be reasonably dry material if it contains large amounts of woody material. Therefore, the ASP method can tend to remove too much moisture from the pile, inhibiting the composting process.

In a typical windrow setup the agricultural wastes are arranged in long rows, aerated by convective air movement, diffusion and periodic mechanical turning. The windrows have to be turned frequently to ensure all the material has been exposed to high temperatures. A front-end loader is a satisfactory and cost effective means of turning the material.

The width of a triangular cross-section windrow is usually about twice the height, typically ranging from 3 to 5 m wide and 1 to 3 m high. This height allows the composting material to be properly insulated and at the same time preventing the build-up of excess heat. Windrow widths can vary, according to the tendency of materials to compact and the turning equipment used. Windrows can be of any length.

The time required for composting depends on the system used, the initial feedstock, the particle size, nutrient balance and moisture content. Composting of agricultural wastes takes around two to three months in a turned windrow. Then the material is removed for curing during which the slow biodegradable material especially, will further decompose.

Curing compost

Slow decomposition occurs when curing compost derived from agricultural wastes. The curing operation can be conducted on available sections of the compost storage and processing area. Curing times for agricultural waste compost are four to six weeks.

Monitoring the compost process

Ongoing monitoring of the compost process is important to the quality of the compost. Monitored parameters include moisture, temperature, leachate generation, pH and aeration. The oxygen level must be carefully monitored and turning frequency adjusted to avoid anaerobic conditions that can shut down the process as well as produce odours.

The moisture content of the pile should be checked every three to four days. Water content should be adjusted so it is not limiting. Also, too much water can lead to high leachate production.

Post-processing/screening

Screens are used in the finishing step to produce a uniform, high quality compost product, for instance, when agricultural wastes containing bushes and branches have been composted and a fine product of uniform size is needed. Screening removes debris and oversized materials, which can then be mixed with active composting material to increase material throughput. Commonly, rotating trommel screens are used for this operation.

Product quality

Mature compost derived from agricultural wastes has a dark colour and a pleasant earthy smell (USEPA, 1994). It contains a mix of fine particles with larger ones. It should not contain hazardous components and contaminants such as heavy metals. Agricultural waste compost might contain pesticide or herbicide residues because of its vegetable and grass content. However, microbes and sunlight usually break these down during the first few days of composting. Generally, agricultural waste compost is a safe material.

OPERATIONAL BEST PRACTICES FOR MANURE COMPOST FACILITIES

Usually, manure composting is conducted on-farm. The main facilities include:

- waste preparation;
- active composting and curing;
- compost storage.

Waste reception and preparation

Manure is placed on a surface with low permeability: unwanted items and incompatible wastes are removed. Leachate, which is highly polluting, must be minimized and contained. The coarse organic portions of the bulking agent, for example branches or wood chips, need to be shredded prior to mixing with high nitrogen, wet manure.

The most commonly used materials are manure mixed with bedding materials. Often manure is wet and contains high amounts of nitrogen, as the usual practice is to use considerable amounts of bedding material to capture the nutrients in the animals' urine. Manure and bedding vary in the carbon to nitrogen ratio from about 10 to 25. Typical C/N ratios, water content and pH of manure are shown in Table 14. Potential amendments when using high nitrogen manure are dry, high carbonaceous materials such as sawdust, garden wastes, leaves, wood and branches. If the bedding/manure ratio is high and the manure dry, it might be beneficial to water the material with a high nitrogen additive.

The conditions on each farm are unique and giving a general recipe is difficult. Each farmer should experiment with readily available materials and techniques.

Composting technology

Turned windrows are appropriate for composting manure. Farm equipment, such as tractors or loaders, can be used to build and turn windrows. Windrows should be covered with a layer of finished compost or plastic material, as manure attracts flies encouraging larvae development within the pile. Also, covering helps maintain warm conditions in cold weather and reduces odours.

To prevent overheating, which kills the composting organisms, the composting material should be turned whenever the temperature rises above 60^0C. Manure windrow temperatures should not be allowed to rise higher than 50 to 55^0C to reduce the loss of nutrients, especially nitrogen in the form of ammonia gas. Adding some clay soil to the materials will help, as it holds any liberated ammonia within the heap (Canadian Organic Growers, 1992). A temperature below 45^0C may indicate lack of adequate oxygen and a need for turning. If the temperature does not rise above 45^0C after turning, the compost should no longer be turned but left for at least one month of curing to complete the composting process.

To turn the piles a front-end loader can push them over, reforming them. Manure piles that are turned as frequently as other materials are likely to have high nutrient losses. However, a weekly turning is necessary to provide oxygen to the decomposable substrates. Also, since manure tends to form lumps, the pile must be loosened on a regular basis. A six to eight week active composting period, coupled with a windrow turning of at least twice per week should be sufficient to stabilize the manure.

Moisture should be monitored as usual. The substrates should be moist enough to allow the decomposition process but not so moist that air in the pile is replaced by water.

TABLE 14
Characteristics of manure

Characteristics	Nitrogen (% dry weight)	Phosphorus (% dry weight)	Water content (% wet weight)	C/N	pH
Beef cattle	0.2-3.0	0.1-1.2	20-80	10-20	6-8
Chicken manure	0.8-2.5	0.3-0.7	50-87	4-18	6-7.5
Broiler litter	1.7-6.8	0.8-2.6	22-29	6-24	6.5-8.5
Turkey	1.2-1.8	0.3-0.9	50-87	4-18	6-7.5

Source: Bahman, 1998

Maturation/final preparation

Screens can be used for the finishing process, unless the final use is for bulk application. Most on-farm composting facilities produce compost for on-farm bulk use. If compost is to be bagged for specialized markets, then post-screening is necessary. Compost derived from manure is fine textured and has a small particle size unless a high amount of bedding material was used, in which case the bedding can be removed and recycled back as an amendment for future composting. Difficulties can be encountered while sieving wet compost derived from manure. In this case it is better to air-dry the compost before screening.

Compost quality

Composted material is an odourless, fine-textured, low-moisture material with little odour or fly breeding potential. It can be used in gardens and nurseries, for potting, or used as fertilizer on cropland. Compost derived from manure (Table 15) is an excellent source of organic matter, nitrogen and other nutrients. The nitrogen in compost is stabilized and not as easily available to the crop as nitrogen from the raw material. However, the availability of phosphorus, potassium, and micronutrients from compost should be similar to, or higher than, manure or other organic residues used for composting. Since compost is fine textured and has less water than the raw material, it can be applied more uniformly and with better control. Also, the composted material can be stored and applied when convenient. Weed seeds or pathogens that can create problems with direct manure application, or other organic residues, are not usually a concern with properly made compost.

Certain composted manures, for example compost derived from swine wastes, have a high soluble salts concentration and contain high levels of nitrogen. Young compost is high in soluble nutrients whereas mature compost has a higher proportion of stable humus.

TABLE 15
Physical and chemical characteristics of beef cattle manure

Properties	After curing process
Moisture (% wet weight)	41
Total carbon*	27.2
Total nitrogen*	2.39
Total phosphorous*	0.56
Total sulphur*	2.66
C/N ratio*	13:1

*% dry weight
Source: Saskatchewan Agriculture and Food, 2002

Chapter 5
Planning the composting facility

THE PLANNING PROCESS

Before deciding to build and operate an on-farm composting facility, a number of technical, economic and social issues have to be addressed: development of compost markets, the site of the compost facility, choosing the appropriate compost technology and the acceptance of the product are important considerations. Without proper planning, a great deal of effort and money can be spent producing a material that cannot be marketed.

To develop and implement a successful composting programme, the following must be carried out:

- establish a team to assist in developing the programme;
- identify goals/objectives and scope of the composting project;
- make an inventory of potential sources of suitable materials to compost;
- undertake a pilot project;
- identify potential sites and environmental factors and determine site requirements;
- identify potential compost uses and markets;
- design and construct composting facilities and purchase collection equipment;
- initiate composting operation and monitor results;
- initiate public information programmes and educate stakeholders.

Establishing the team

The first step is to establish a team of farmers and major stakeholders in the rural community, such as potential compost users, technical experts and members of Non Governmental Organizations (NGOs). The terms of reference of the planning team are to:

- promote proper waste management practices;
- decide upon the composting technology to be adopted;
- liaise with the general public;
- communicate with potential/current compost users;
- advise on regulatory standards for compost;
- respond to specific community concerns.

Identifying project objectives

The project can have multiple goals. Defining the project's goals helps to focus on important activities and resources, preventing wasting efforts on non-contributing activities.

Composting farm and rural household wastes is a good waste management practice as it reduces the amount of waste to be sent to a landfill or incinerated. Also, it provides compost that is of a standard acceptable to the community.

Defining an operational plan

An operational plan must be prepared to help the community understand the proposed on-farm composting programme. Also, it can be used as a basis for community discussion and for developing strong political support.

The operational plan will stipulate the chosen technology (turned windrows, aerated static pile or in-vessel composting); the equipment needed; the proposed site design; the permits required; pollution, nuisance and odour control methods; the personnel required to operate the facility and the extent of their required training and the procedure for compost product marketing/distributing. In most countries, permits are not required for on-farm composting and use. However, before starting a composting operation, the local health/environment departments should be contacted to determine the requirements, if any, for a new composting facility. Remember, all elements of a composting programme are inter-related. For example, a variety of factors such as the type of materials to be processed and the market for compost influence a composting site design. The compost market affects the site design by specifying the quality of the desired compost and the need for pre-processing equipment.

Making an inventory of potential sources of suitable waste materials

The planning process should include an accurate assessment of the quantities of material available for processing, their composition and source. Such data determines the size and type of necessary equipment and the space requirements for the composting facility.

Choosing a composting method

The most appropriate composting method is selected only after markets have been identified and their requirements known. A market survey has to be carried out before a farm household invests in a facility. Designing the compost process to meet market specifications is critical to the long-term success of the facility.

The survey should be designed to collect data on the required types/quality of soil amendments and also assess potential interest in the use of compost produced from manure, crop residues and off-farm wastes.

It is very important to know whether compost production is planned with the aim of reducing on-farm wastes and environmental threats or to be sold to high value markets, such as landscaping or to be distributed freely to the community.

With a market survey, it is possible to assess the compost requirements of potential users, identify competing products currently used, evaluate the distribution options and gain feedback on the composting facility. This enables the proper design of the composting facility and provides details on the required composting operations.

The market survey is done in three steps:

- identify the existing and potential compost users;
- develop the survey;
- survey the identified users.

The first step in the market survey is developing a list of appropriate people/organizations to contact. When developing the survey document, relevant questions about compost use and its required specifications, environmental and health concerns, transportation distance and market value have to be asked. The analysis is best conducted by way of interviews to determine the needs and interest of customers. Interviews should be conducted with representatives of groups that are potential users of the product.

Undertaking a pilot project

Single farmer

A single farmer can choose to promote composting as a means of disposing on-farm generated wastes while at the same time producing compost for his/her own use on-farm. The first step is to estimate the quantities and types of wastes generated on-farm. This can be done by collecting and direct weighing or through the help of experienced composting persons. A pilot-composting set-up helps judge the quality of the finished compost. Information about the type of process can be obtained from the Internet, brochures or extension/agricultural officers.

Community of farmers

A pilot programme in which a few farms collect a small portion of farm wastes for composting helps assess the programme potential. Pilot project farmers must be receptive to composting education and hosting demonstration events at their sites. Written and final documentation of the project will be of benefit while promoting compost through the media and local community activities. Testing the finished product, making these results available and offering samples to the public helps build support for the composting programme.

Pilot plant establishment
Steps in establishing a full programme are:

- defining responsibilities;
- identifying farmers;
- educating participants on proper siting, recipe building and efficient operation;
- publicizing the programme.

Programme initiation can come from a farmers' group through co-operative extension. A potential valuable element in establishing the programme is the creation of a project team to carry out the initial steps and to advise, support or run the programme (Christian, Evanylo, Pease, *et al*., 1998). The project team should include a programme/farm manager, a project field co-ordinator, the key farmer responsible for composting, a composting consultant, a waste handler, community members and other interested parties. The roles of the members of the project team are shown in Figure 15.

DESIGN OF A COMPOSTING FACILITY

The design of a composting facility mainly consists of two design criteria; the facility design and the process design criteria. The facility design criteria include area requirements for windrows, dimension of windrows, active composting pad, windrow cover, compost curing area, rainwater drains, leachate drain, screening/sorting area and access road. Process design criteria address all necessary steps needed to produce compost including supplying oxygen to the composting pile for windrows and pre/post-processing of materials.

Siting the composting facility on farm

When determining the site of composting facilities, considerations are:

- potential for release of contaminants to surface/ground water;
- traffic, roads to and from the facility;
- buffer zones for visual/noise screening and odour reduction;
- availability of appropriate utilities;
- appropriate soil types for absorption, leachate collection and geo-technical conditions;
- distance from where the feedstock materials are generated to the compost facility;
- site accessibility.

The most important accessibility factors for a composting site are its proximity to basic utilities, compost markets and waste collection routes. Often the major cause of complaints near a waste facility has been directly linked with the carrying and storage of wastes.

Site components

Typical elements of a composting site consist of windrows, curing piles, space for sieving and storing compost, an area to unload and mix wastes, drains and collection pond for leachate and storm-water management (Figure 16).

FIGURE 15
Roles and linkages in the project team

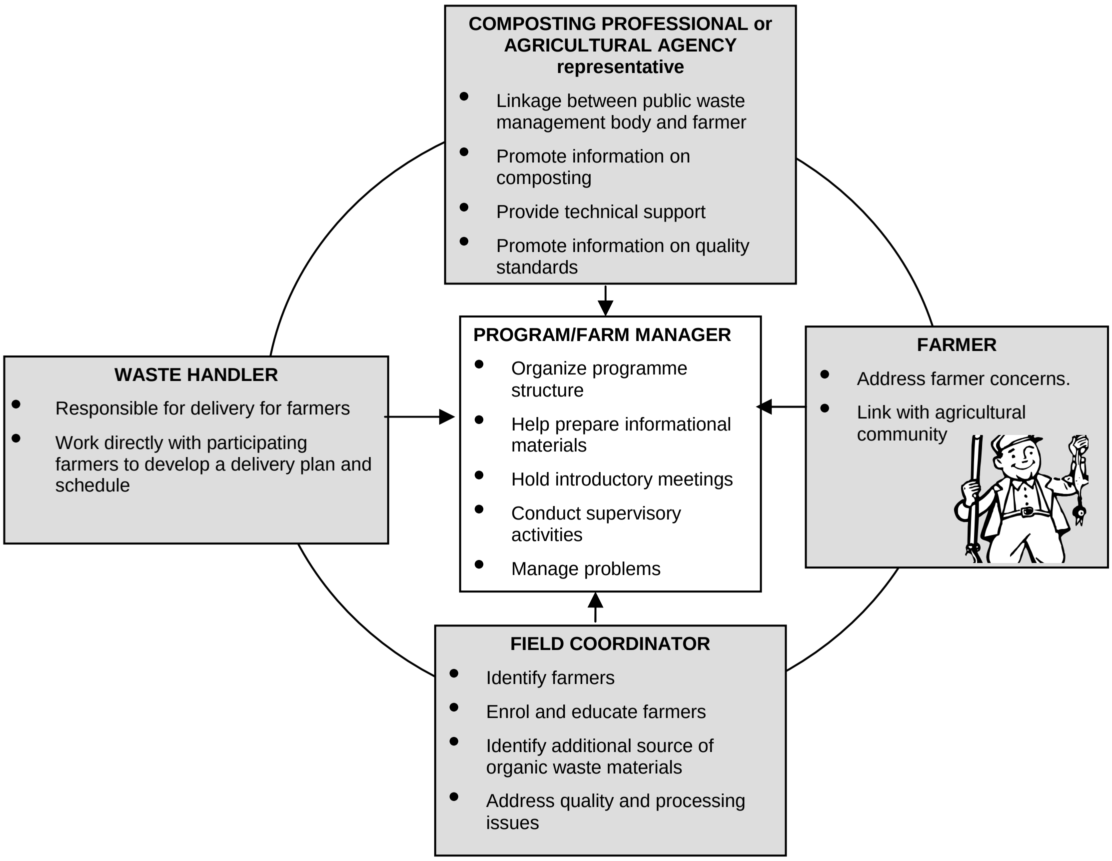
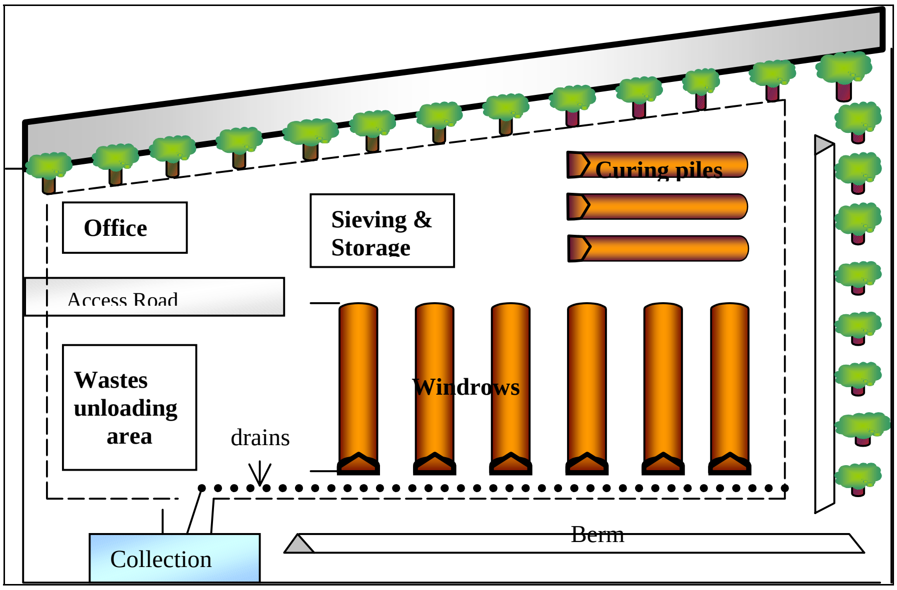


FIGURE 16
Horse manure composting facility



Mohee, 2002

The selected composting facility site must adhere to the following:

- The site should be graded to a slope of 2 to 4 percent, parallel to the windrows.
- A minimal paving base should be made for the wastes. To avoid groundwater contamination, the site should be paved with either concrete or asphalt. After heavy rain it is easy to drain the water on a concrete floor.
- Berms should be built along adjacent sides of the site for controlling runoff and leachate migration.
- A visual screen of trees and shrubs must be planted to merge the site into the natural landscape.
- There must be a sufficient area for storage of materials, processing, composting and post-composting facilities.
- Storm water drains should be installed around the site to divert rainwater from the composting site to a collection pond. Also, runoff needs to be prevented from leaving the site. Runoff can be directed to a holding pond where it can be used as a source of irrigation water for the compost during dry periods.
- An all-weather access road to the site, with an effective barrier to prevent unauthorised dumping and entry, is necessary.
- The site must have adequate buffer zones with respect to surface water, ground water, nearby streams and residences.

Buffer zones

The buffer zone required by an on-farm composting facility largely depends on the type of feedstock being composted and the level of technology (in terms of monitoring and odour control) used. In general, the larger the buffer zone, the greater the acceptance of the facility among residents. State and local regulations frequently specify minimal buffer zones or the distances that composting operations must be from property lines, residences, or adjacent businesses and from surface water or water supplies.

It is prudent to provide at least 15 m between the composting operation and the property line. At least 50 m must be allowed between composting activities and any sensitive neighbouring land uses, such as commercial property or monuments. Additionally, at least an 80 m buffer is needed between composting activities and a place of human occupancy (house, school, etc.). Minimal separation distances for facilities composting green wastes are given in Table 16. For more difficult wastes, zones could be extended.

Access roads

Proper roads should lead to the tipping and storage areas within the farm. Access roads should be gravelled or paved to handle large vehicles during adverse weather. However, such surfacing is expensive.

Drainage requirements

Water must be drained off-site, be it surface water or leachate from waste decomposition. Poor site drainage can result in ponded waters, odours, saturated compost material, muddy site conditions and anaerobic conditions at the base of the piles. To avoid standing pools of water, the land slope at the site should be around 2 to 4 percent. A bigger slope will move run-off water too quickly and may pose problems for farm equipment movement.

TABLE 16
Minimal separation distances allowed for composting facilities

Navigable lake or pond	300 m
Navigable river or stream	150 m
State, federal, or interstate highway or public park boundary	300 m
Airport runway	300 m
Public or private water supply	400 m

Source: WDOE & EPA, 1991

Compost pad

The composting site should be located on moderately drained to well-drained soil. For many windrow composting facilities, a working pad surface of compacted sand and clay is appropriate. However, in some cases with highly putrescent wastes, an asphalt/concrete pad is more convenient. Also, when gravel or soil is compacted to form a working base, with the passing of farm equipment, the ground does not stay compacted but becomes mixed with finished compost. Concrete floors are more expensive than asphalt, but asphalt floors deteriorate faster (Composting Factsheet 382.500-6, 1996).

The pad surface should be resistant to wheeled traffic and withstand the scrapping of front-end loaders and other equipment. Other pad alternatives are hardened mixtures of ash.

Defining the compost system

Choosing the composting technology

Since the quality of compost is determined by the feedstock composition and process, user requirements of the compost become the basis for feedstock and facility design decisions.

The three methods commonly used when composting large amounts of waste are turned windrows and piles, aerated static piles and in-vessel systems. Each system differs primarily in the method used to aerate the compost. Turned windrows are labour intensive, less costly and more flexible. Aerated static piles and in-vessel systems are capital intensive but provide better control of the composting operation.

The selection of a specific composting method is based on factors such as capital and operational costs, land availability and operational complexity (Table 17). The characteristics of the feedstock being composted also need to be considered. For example, for green wastes, a turned windrow system and a grinder may be adequate. For high moisture food wastes where odour is a major problem, more specialized equipment may be necessary to rapidly compost the wastes.

Area requirements

Land area requirements are based on the type and quality of the feedstock, equipment selected, vehicle traffic patterns, raw material storage, curing and storage space requirements and buffer areas. A completed composting site should have sufficient land for the composting pad, curing/storage areas, separation distances and drainage.

For turned or static windrows and piles, the surface area required for composting pads depends on the volume of material, shape of the pile/windrow and space for the equipment. The requirements for an extended aerated static pile system generally are less than those for windrow methods because of potentially shorter total retention times and more compost processing. About the same space required for the composting process should be available for curing.

Sizing of compost pad for active composting

The flowchart in Figure 17 refers to the steps that need to be carried out while determining the dimensions of a windrow composting pad, based on the volume of wastes received on a daily basis.

TABLE 17

Comparison of composting technologies

Technology	Product quality	Process	Speed	Capital & operational costs	Process control
Turned windrow	average	simple	short	high	medium
Aerated pile					
In-vessel	good	complex	shortest	highest	excellent

Sample calculation for composting area

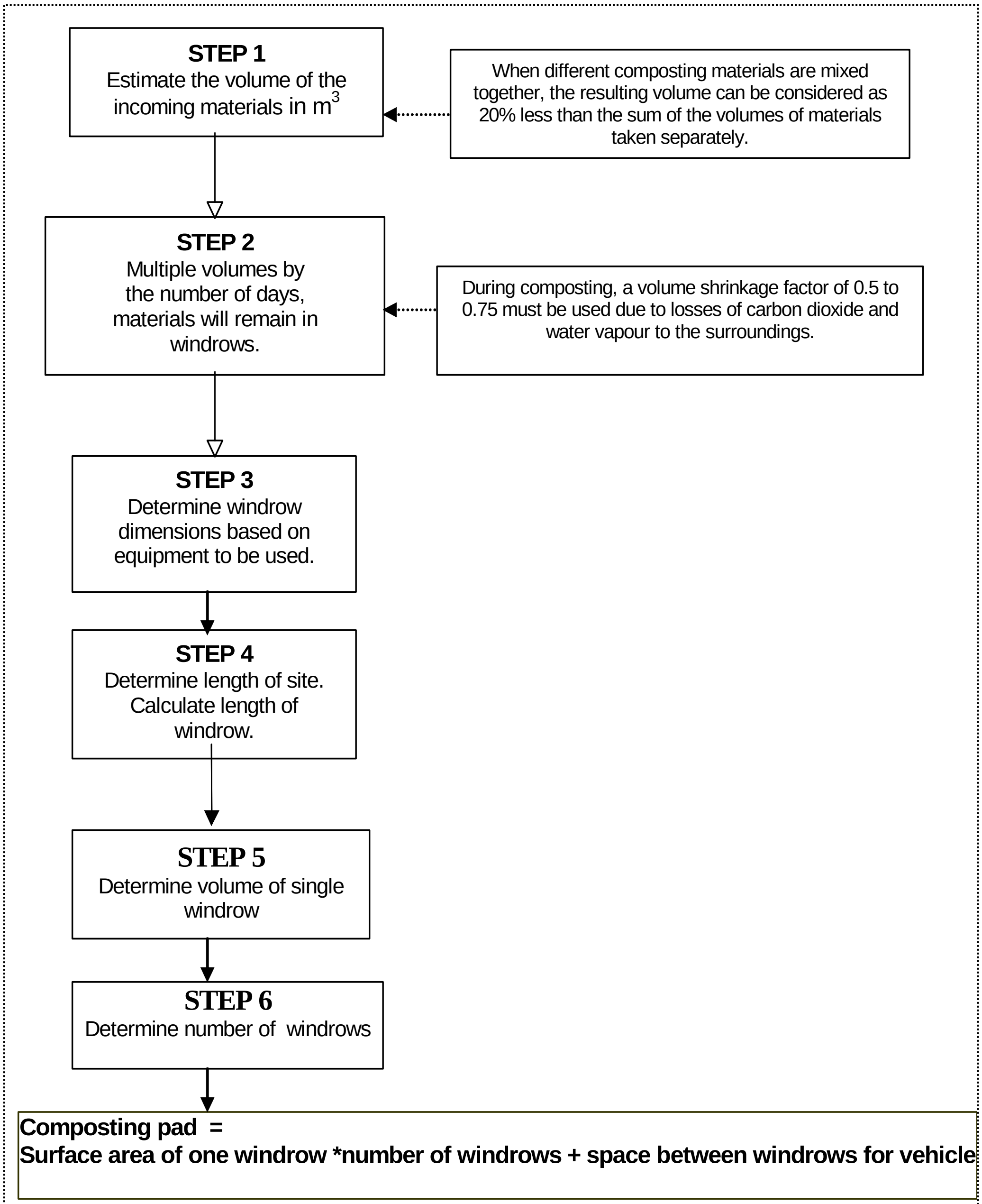
A farm handling around 80 tonnes of horse manure per month wishes to compost in windrows. The selected site is far from residences, wells and nearby surface watercourses. The bulk density of horse manure is around 400 kg/m^3 so that the volume received is 200 m^3/month or 50 m^3/week.

Based on the monthly volume received and assuming the time the material will remain in the piles is six weeks, the area required for the composting facility is:

- active composting 485 m^2
- curing 156 m^2
- pre-processing and post-processing 128 m^2

Thus the total area to compost 80 tonnes of horse manure per month is 769 m^2. Details of the calculation and the layout for windrows and curing piles are in Annex 5.

FIGURE 17
Sizing pad flowchart



Adapted from Rynk, Van de Kamp, Wilson, *et al.,* 1992

THE ECONOMICS OF ON-FARM COMPOSTING

The decision to compost on-farm is a matter of listing potential costs and benefits of the project. However, expenses, revenue, opportunities and environmental constraints vary greatly from one farm to the next. For on-farm composting, the economics are more complicated than revenue versus cost of production because other factors on the farm need to be considered also (Rynk, Van de Kamp, Wilson, *et al.*, 2002).

Identifying potential costs

When evaluating a proposed composting system identifying the capital and operating costs is important as these are the main costs. Capital (fixed) costs include the cost of land and equipment as well as site improvements. Operating costs include labour, maintenance, and utilities. Besides capital and operating costs, expenses related to planning, marketing and legal should be identified and evaluated. Additional costs for a farm-composting programme include publicity and enrolling and educating the farmers.

Composting costs are variable. It is difficult to compare the costs of potential composting facilities because of the wide variations in size, operation and wages in different countries. The costs of a composting project can be determined only after considering all factors affecting the design and construction of the facility and position of the site.

The capital and operating costs can be separated into five main cost elements: pre-start-up costs, land acquisition, materials acquisition, materials handling equipment and labour. Although, land may be available on-farm there might be more competitive uses for the land.

Pre-start-up costs

Costs associated with the start-up are one time costs and include land, labour, time, equipment and capital investment in site preparation, including grading, surfacing, drainage and access road surfacing.

Capital investment typically increases in the order:

- passive pile approach;
- windrow composting using a loader for turning;
- windrow composting using specialized windrow turners;
- aerated static pile;
- In-vessel systems.

Compost production costs are highest for in-vessel systems and lowest for passive windrows (Figure 18). An in-vessel system seldom would be used on farm unless there was already a suitable enclosure on site. Aerated static pile composting costs are highest and passive pile composting costs are lowest (Table 18). As the volume of materials to be composted increases, the tendency is to increase labour and then use more sophisticated composting equipment.

Cost wise, turned windrows are a reasonable option for producing good quality compost on the farm.

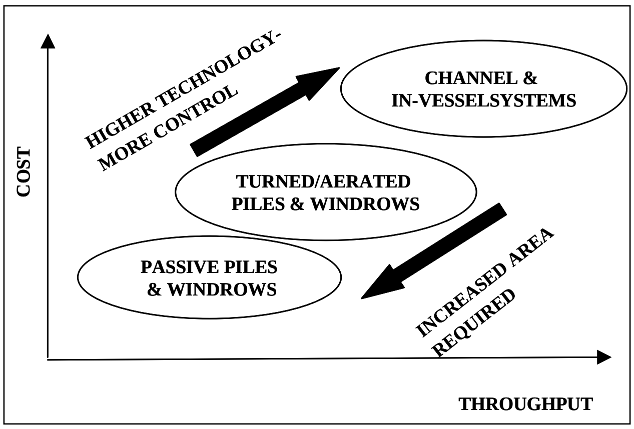


FIGURE 18
Comparison of composting technologies

Source: Leonard, 2001

TABLE 18
Costs comparison of composting methods for 2050 t/yr manure and 1400 t/yr bulking agent

	Passive windrow	Turned windrow	Aerated static pile
Compost produced (tonnes/year)	1806	1806	1806
Labour (hours/year)	271	745	596
Investment level ($)			
Equipment[a]	50 000	80 000	60 000
Buildings[a, b]	0	29 447	110 948
Aeration system	0	0	26 590
Operating expenses ($/year)	45 423	68 918	79 920
Compost production cost ($/tonne)	23.15	38.16	44.25

a: comprises mixing, composting, curing and storage
b : Pole type building with open walls

Source: Composting Factsheet 382.500-16, 1993

Quantity and price of available land

The land occupied by the compost operation on the farm is a production cost. Static piles and windrows are land intensive. At least half a hectare of unused land with suitable slope, drainage and access is required. Depending on the method used, half a hectare can handle a very small quantity up to several thousand cubic metres of compost per year.

Availability and price of raw material

The main material from the farm is manure. Other farm material can be used as an amendment, for instance crop residues and spoilt straw. In these cases costs are minimal. Potential off-farm sources are other farms, municipalities and food/food waste processes. Off-farm material and municipal wastes would be available either free or with a tipping fee. The cost of bulking agents such as chips and sawdust need to be considered, especially transport costs, which can be quite high.

Labour

The cost of labour (time and effort) is difficult to define. The cost applied to first learning and managing the new composting technology depends on firstly the value of the time of the operator and secondly, the level of the operation’s desired efficiency.

Labour costs can be divided into operation costs, such as materials collection and handling and maintenance costs, such as the maintenance of the equipment and composting pad.

Material handling

There are costs associated with turning piles. Handling equipment depends on the method used and equipment availability. High volumes and dense materials require more time. The turning cost decreases as the composting process advances because there is less volume to handle.

Compost marketing costs

The cost of compost marketing, promotion, bagging, transportation and/or use such as blending have to be considered.

Table 19 summarizes the capital and operating costs of producing compost. Initial outlay for site preparation, planning and permits plus other investment in equipment and the site can range from a few hundred dollars to hundreds of thousands of dollars. A key to minimizing the costs/tonne is scaling the operation to make possible the efficient use of costly fixed investments like specialized composting equipment or land. For farmers with low amounts of wastes, a centralized composting facility at one of the farms or within the rural community might prove to be more economic.

TABLE 19
Capital and operating costs requirements

	Farm expenses	Farm labour	Farm machine
Site preparation:			
Land value	√	-	-
Preparation of site	-	√	√
Materials collection & purchase	√	√	√
Pre-processing		√	√
Pile formation	√	√	√
Maintain and monitor	-	√	√
Field spreading	-	√	√
Utilities	√		
Materials - on-farm		√	√

√ means required

Adapted from Rynk, Van de Kamp, Wilson, *et al.*, 1992

Benefits

By composting, on-farm costs that can be lessened or avoided and the income provided by the completed compost provide a threshold against which to compare the potential benefits of investing in a composting facility. There are numerous ways that composting can result in savings to the farm.

Avoided costs

Costs avoided because of compost are disposal fees, haulage charges and the costs of soil amendments (mulch and bark), irrigation and pesticides/herbicides (Clean Washington Centre 1997). The most important avoided costs are manure handling and weeding. Other indirect avoided costs are:

- extended landfill longevity;
- reduced or avoided landfill or furnace tipping fees for crop residues;
- environmental benefits from reduced landfill and furnace use;
- creation of new jobs;
- reduced transport costs;
- improved neighbour relations because of fewer odours;
- lower risk of dispersing pathogens.

Revenue from compost

Revenue from compost sales helps to offset the production costs of compost, although most compost produced by farms is used on the farm itself. Very little farm compost is marketed at a high price. The price charged for compost depends on its consistency, overall quality, promotion and packaging. Typical market values of compost for agricultural use ranges from US$10 to US$25 per tonne (Spencer and Tepfer, 1993). Bulk compost prices range from US$20 to US$22/m^3 compared with US$26 to US$29/m^3 for delivered compost (Bulk compost prices, 2001).

The net cost of a composting programme can be obtained by estimating all capital and O&M costs and subtracting any revenue or avoided costs generated by running the programme. However, compost can be produced using technologies or management systems that employ different combinations of land, labour and equipment, thus allowing the farmer to use the least costly factors.

Chapter 6
Managing for long-term success

COMMUNITY PARTICIPATION IN ON-FARM COMPOSTING OPERATIONS

Like any successful waste management project, an on-farm composting programme requires members of the local community to become involved and the public at large to participate. People can be involved as waste collectors and haulers, or as part of the recycling industry, local utilities and environmental groups, or simply as interested private citizens. Providing these groups with a forum to express their ideas/concerns is important.

Developing awareness programmes for community members

The key issues to be addressed in an awareness programme involve the identification of objectives, target audiences, key messages and methods to implement the stated objectives.

Identification of objectives

A community awareness education programme is required to:

- Create community awareness of the environmental benefits of composting.
- Promote participation in collection services.
- Provide advice on correct composting practices.
- Efforts must be made by farm households and relevant authorities to let people know that a different way of handling waste may be preferred to their historical way and good reasons for considering a change to their waste management practice exist.

Identify the programme to be communicated

The programme must have information on composting fundamentals, systems and process management, the expected length of the composting time and use of the compost.
Emphasis must be made on feedstock quality, wastes that are being composted, expected quality of the finished compost as well as benefits of composting.

Developing communication vehicles

Communication vehicles can be general talks, brochures and leaflets, and TV and radio shows. Visits to demonstration sites and backyard composting demonstrations along with informal meetings and training sessions can be very helpful. Farmers can play a big role by setting up on-site demonstration facilities.

Low cost methods include news articles and announcements on radio and television. High cost efforts include billboards, advertisements or using public relation firms. Also, nationwide events help stimulate public awareness.

Some methods to develop awareness of composting are described below.

Information

Simple, pictorial brochures, leaflets or posters on composting can be prepared and distributed to citizens. Once interest from citizens is gained, more elaborate programmes by farmers on composting issues can be undertaken. Proactive use of the mass media can be an effective means of communicating the messages of the awareness programme to the target audience. However, it should be noted that the ultimate aim is not only to give information to the public but also to change their habits, convincing them to produce and use compost.

Tours of compost demonstration facilities

Conducting field visits to on-farm composting operations and compost application sites are effective components of an educational programme. Brochures describing the facility and its operations should be printed and distributed throughout the community. Neighbours, university organizations and school groups should be encouraged to take educational tours of the facility. Periodically the public should be informed of the type of materials accepted, those not accepted and the collection schedule so they can participate in the on-farm composting programme.

On-farm meetings and training sessions

Informal meetings and educational events can be held to explain the role farm composting can play in a farmer's management programme. Informal meetings can include a slide or video presentation on creating compost, the use of compost and the economic benefits to the farm and community. Sharing finished compost samples and presentations by farmers who produce successful compost are useful.

Compost use demonstration programme

Compost use studies should demonstrate both agronomic and economic benefits. The results should be published both via field and nationwide events. Tree planting ceremonies using compost to prepare the soil should be encouraged.

Maintaining a positive community profile

Awareness campaigns on composting require continuous, organized efforts, using a range of methods and imaginative approaches. Once individuals show interest information must be made available to them on how to become involved in implementing the waste management initiative. The availability of ongoing advice is an essential element of any encouragement programme.

It is essential that the community perceive they will receive a direct benefit from the farm-composting programme. Also, education is important to avoid problems with the spread of pathogens, weeds and seeds and in reducing the level of contamination in the bins where the community can place their organic waste when participating in a composting programme.

Consideration should be given to offering incentives within the rural community to those who keep uncontaminated waste for transport to farm composting facilities or reduce their waste stream or assist other members of the community to participate in the on-farm composting programme. The rewards could be presented in the local papers.

The role of NGOs and other groups

Non Governmental Organizations (NGOs) and Community Based Organizations (CBOs) can participate in the programme team meetings and promote the programme as an outreach function. This ensures the programme gets proper support from citizens and other relevant stakeholders. NGOs and other groups such as youth clubs can provide an interface between farmers and the public. They can help farmers/citizens address their concerns about farm-generated wastes. Also, they can help community leaders understand the importance of waste minimization, recycling and the economic/social benefits of farm waste composting for the whole community. The NGO can provide a forum for discussion, and organize talks by composting or gardening experts.

MARKETING AGRICULTURAL COMPOST

If producing a marketable material and making an income by selling the compost is a goal, then a detailed market evaluation should be made. Instead of applying the compost to the land, the farmer can choose to sell the compost to other people in the rural community, in which case there needs to be a market, either existing or developed, for the finished product.

Elements of a marketing plan

The elements of a marketing plan include promotion of the product, identifying and characterizing markets, surveying potential buyers in the region and identifying potential competitors (Texas Municipal Compost Marketing Manual, 2000).

Promotion of on-farm compost

Technical product specifications, compost use guidelines, pricing structure and public awareness programmes must de developed when promoting the product.

Develop a product specification

The marketing plan needs to specify the important product parameters and the minimum quantity that can be bought. It is recommended to create a technical data sheet. Parameters to be included are pH, soluble water content, nutrient content, water holding capacity, moisture content, organic matter content and particle size.

Develop a programme budget

A budget is based on decisions about the level of effort and resources committed to the marketing programme. Major expenditure includes product testing and promotional campaigns.

1. Develop product use guidelines

   It is important to provide users with guidance on how to use the compost. Good guidelines encourage proper use of compost, which in turn gives satisfied users. Guidelines are available for different end users and market sectors.

2. Determine the pricing structure

   Based on information from the survey, the market plan must establish the unit price for the products and determine whether different prices are appropriate for different grades. Some programmes set a lower unit price for larger bulk purchases. The pricing structure can favour a particular product. The price should be competitive with other similar products, such as manure, available on the market. Typically, farmers sell compost in bulk, unless a much higher price is obtained for retail compost, which then would justify the additional operations required.

3. Plan public education and education activities

   Ongoing education and promotion is essential to sustain and expand markets for compost and mulch products. An ongoing demonstration site should be set up at a composting facility, as it is one of the most effective marketing devices. Articles describing uses and benefits of compost for potting soil mix and mulch can be placed in local papers. Displays of potted plants, grass growth comparisons and product samples can be made at garden centres and local events. Community organisations, schools, garden clubs and other organizations can be targeted.

Identify and characterize markets

Potential buyers include the horticulture industry, bulk suppliers of compost, public agencies and land reclamation contractors.

Survey the market in the region

The market region first must be defined. The requirements of the potential buyers of compost must be analyzed.

Within the local area, the potential buyers of compost products should be surveyed to determine whether they would purchase compost, how much they would be willing to pay, how and when they would use compost and what would be the desired specifications for the compost.

A survey conducted by mail, phone or in person is necessary to understand the needs of the end users. Contents of the survey include:

- information on the use of existing products;
- familiarity with compost and mulch;
- the product quality requirements: grade size, moisture content, pH, nutrient content, colour, odour, salinity;
- specific use and logistical requirements: bulk versus bagged, delivery, transportation;
- user concerns.

The next step is to determine the market within 40 to 80 km of the composting facility, as the transportation cost of compost usually is high compared with other production costs.

Identify potential competitors

It is important to identify current and future competitors who are producing composts and mulches. This information may help decide how the distribution and marketing programme will be set up.

ENVIRONMENTAL MONITORING

In composting operations, the environmental impact level depends on the types of waste and whether the composting process is an enclosed or open system. Environmental factors such as noise, dust, odour and visual impacts are common to all waste management facilities including on-farm composting facilities.

A site for an agricultural composting facility must provide the required area and conditions for all weather composting as well as limiting the environmental risk associated with odour, noise, dust, leaching and surface runoff. There are operational procedures to minimize the environmental impact of composting facilities. The sources of impacts as well as best practice techniques for minimizing the impacts on the environment follow (Environment Agency, 2001).

Odour

Odour has been, and is, the main reason for shutting down composting facilities. Often, it is the most noticeable air quality concern (Composting Factsheet 382.500-11, 1996). Odour control is a primary concern for any composting operation within range of sensitive areas. Having a properly designed and laid out system and managing it well minimizes odours from the composting process.

Odour sources can be divided roughly into two groups; the first group consists of odours that are emitted during delivery of fresh material and the second group, the formation and turning of materials in the windrows. Generally, farms produce the wastes to be composted on site, so there are few problems linked to delivery of fresh material.

Sources of odour emission are:

- mixing of raw materials and shredding;
- anaerobic conditions in windrows or piles;
- ammonia lost from open air composting areas;
- release of odour during windrow forming and turning operations;
- wet and dirty decomposition areas, vehicles and machinery;
- leachate forming from the composting process.

Odour control

The best defence against odour complaints is to prevent their generation. The following will minimize odour production.

- Contaminated or odorous wastes (stored too long) should not be incorporated in the compost pile.
- Use a good mix of raw materials, which do not have excessive moisture content. Adding a high carbon source can combat any pungent ammonia odours. Ensure the carbon to nitrogen ratio is between 20:1 and 40:1. Always have a stock of porous, high carbon material on hand that can be mixed immediately with the incoming material. This will help to balance the C/N ratio, absorb the moisture in wet materials, and add porosity to the mixture.
- If material must be spread before blending, add a bucket of finished compost to the outside of the pile to act as a built-in bio-filter. Static piles should be covered with mature compost to act as a bio-filter.
- Use good practice procedures to prevent anaerobic conditions occurring. Be sure that material is turned or aerated often enough to maintain aerobic conditions.
- Avoid delaying the composting of fresh raw wastes and rapidly decomposing feedstock materials.
- Incorporate drainage at the base of the pile or windrow, e.g. woodchips or prunings to encourage the movement and absorption of leachate.
- Regularly clean operational areas such as roads and drainage channels to discourage odour generation from old degrading materials. This can be achieved easily through good housekeeping.
- Implement a turning and shredding regime that should avoid hot or windy days and not be undertaken during public holidays or weekends, to reduce the impact of odour.
- A greater distance between a composting site and sensitive areas will lessen the impact of any odours generated on site.

Leachate

Composting can create leachate as a result of high moisture levels in bio-wastes and putrescent wastes. The high potential for leachate release is the first two to three weeks and generally during thermophilic conditions. Leachate has a high content of organic substances that can pollute surface and ground water and affect plant life. Leachate often contains high BOD (biological oxygen demand) concentrations and high levels of phenols (a by-product of the decomposition of lignin in leaves) that might exceed acceptable discharge limits.

Even well managed composting facilities generate small quantities of leachate. Leachate pools are a result of poor housekeeping and may act as a breeding place for flies, mosquitoes and odours. Leachate can contaminate ground and surface water with excess nitrogen. Piles left outdoors generate leachate, so minimize leachate production and divert any surface water runoff from the piles. Sound practices for managing leachate are:

- Avoid discharging leachate into water sources. Capture or divert all leachate to areas where they can be absorbed in sand and soil. The composting pad must include a paved floor equipped with drains that lead to a leachate collection tank.
- Leachate can be collected separately via a leachate collection system, which should be separate from the surface water drainage system. If required, the leachate can be stored in tanks or lagoons as an interim measure.
- If leachate is generated in sufficient quantities it can be re-circulated into the composting process. It may be advisable to provide a collection system in order to do this. However, leachate can contain pathogens; it can be sprayed on wastes at the start of the composting cycle but must not be put on material that has been through the pathogen destruction stage already.

- Any leachate that cannot be re-circulated into the composting process must be collected and taken away to a leachate treatment facility

Dust

Dust can be emitted in considerable quantities particularly when dry composted organic material is being screened, turned or shredded. Also, it can be generated through vehicle and machinery movements on site. Dust can be controlled by:

- Monitoring the moisture content at all stages of the composting process to avoid the waste and materials drying out and forming dust.
- Avoiding forming or turning windrows and piles on windy days, if possible. Screen and shred when wind speeds are low or wind direction is away from sensitive areas.
- Regularly damping down and/or sweeping site surfaces such as roads, tracks and the piles or windrows to suppress dust.
- Installing physical barriers such as mounds or walls to prevent dust leaving the farm.

Noise

Sources of noise are vehicles collecting material and turning, shredding and other machinery operations. To decrease noise levels, all machinery used on site should be fitted with appropriate silencers. Also, the use of machinery should be reduced or avoided if possible on days when wind speeds are high and during public holidays or weekends, particularly when they are near sensitive areas. Windrows, piles and earth bunds can be used effectively as acoustic barriers and trees as screens.

Fires

Composting materials can be a fire hazard if they have very high temperatures, a high proportion of carbon based materials and low moisture content. The possibility of fires should be planned for when stockpiling chips or compost. If the material does dry out and gets too hot, combustion can occur. Organic material can ignite spontaneously at moisture contents between 25 and 45 percent. Sometimes, this happens to stored hay or silage, and can happen to compost. Keeping the piles under 3 m tall and aerating the compost when temperatures exceed 60^0C, not only constitutes good compost management, but also provides fire protection. Turning windrows or piles allows temperatures to reduce for a time. In the event of fire, whether by spontaneous combustion or vandalism, the site must have an adequate water supply. Maintaining clear aisles between piles provides easy access in case of fire.

Pests

Pests such as vermin, insects, or scavengers can be a nuisance but are dependent on the type of waste being composted. Putrescent wastes in particular are a food source for certain vermin and insects. Pests can be disease vectors.

Good housekeeping and process control deters pests. The storage of fresh waste feedstock should be managed effectively. This includes limiting the amount of waste stored, regular cleaning of waste reception areas and the use of buildings to enclose wastes. Measures include:

- avoid delaying the composting of freshly received material;
- cover piles with matured compost to act as a barrier to pests;
- ensure correct temperatures within windrows and piles;
- keep high protein and fatty food wastes out of the composting pile in areas where pests may be a problem;
- control fly development by turning compost piles frequently to encourage heating, as fly larvae die at high temperatures.

HEALTH AND SAFETY RISKS OF A COMPOSTING OPERATION

Health concerns

Micro-organisms of major concern in an on-farm composting facility are pathogens and airborne micro-organisms, including bio-aerosols and endotoxins. Elevated numbers of micro-organisms are released into the air when any agitation of the organic material occurs, be it turning, screening or shredding.

Bio-aerosols

Bio-aerosols, which are organisms or biological agents transported through the air, are a health concern in the operation of composting facilities. They include bacteria, fungi, and actinomycetes. Those of main concern at composting facilities are *Aspergillus fumigatus* and endotoxins, which are present in various kinds of decaying organic matter and in a variety of locations. Bio-aerosols, because of their small size, can escape the filters in the nose of humans penetrating deep in the lungs. Because they appear in high concentrations some of these small particles can be harmful to human health.

Concentrations of bio-aerosols are highest during dust production activities such as shredding and screening and during the mixing of vegetable material and woodchips. Bio-aerosols released during composting are confined mostly to the composting area and have minimal impact beyond 100 m from the composting site.

Endotoxins

Endotoxins are metabolised products of bacteria remaining in the bacteria after it has died. Although not known to be toxic, endotoxins through air born transmission can cause symptoms such as nausea, headache and diarrhoea.

On site operational controls can reduce the formation of airborne micro-organisms.

- Damping down operational areas and the organic materials will reduce the potential of micro-organism generation. Undertake turning, screening and shredding when wind speeds will not cause micro-organisms to become airborne or conduct these operations within an enclosure so that any emission can be controlled.
- Maintain moisture content over 40 percent to help reduce dust formation.
- Limit the exposure of on-farm compost operators by being upwind of any screening, shredding or turning and staying within vehicle cabs or other protected environments.

A simple yet effective safety precaution is to wear a respirator that can filter out small particles. To minimise the risk of infection, Occupational Safety and Health Administration (US Dept of Labour, 1997) recommends wearing dust masks or respirators under dry and dusty conditions.

Pathogens

Infections are caused by pathogenic micro-organisms that can invade body tissues and grow within the individual. Most pathogens in composted wastes are present in small numbers, thus posing only a limited risk. However, immuno-supressed individuals are at higher risk than the general public.

Control of pathogens

The primary method of controlling pathogens is to expose them to elevated temperatures for an extended time. The high temperatures experienced in properly controlled composting processes reduce the number of pathogenic organisms, thereby reducing the risk to workers and the public. Temperatures should remain at or above 55^0C for up to 15 days depending on the type of composting technology to ensure adequate heat for destruction of the majority of pathogens (USEPA, 1999). Health concerns relating to compost are dependant both on the individual and on the material being composted. While few human pathogenic organisms are found in vegetative wastes or yard wastes, normal sanitary measures are important. While many compost operations have run smoothly for years without unusual health or safety problems, there are some unique concerns in composting of which workers should be aware. Workers with low resistance to diseases normally should not work in a composting operation.

Health and safety precautions

Proper attention to health and safety concerns can minimise most occupational risks at composting facilities. While composting and shredding wastes are not inherently dangerous activities, precautions are necessary to protect against injury and possible illness.

Safety issues for composting primarily concern the operation of power equipment and the potential health effects of working with decomposing organic matter. Operators should be specifically trained to use the equipment and should not operate machinery if they are taking certain types of medication. Proper personal protective equipment (PPE) including gloves and eye, hearing, and respiratory protection should be used if needed. If front-end loaders or other standard heavy equipment is used, ear protection and other normal safety precautions apply. Composting and chipping equipment have additional dangers (Rynk, Van de Kamp, Wilson, *et al.*, 1992). Typically, these contain powerful mixing flails, knives, or hammers that rotate at speed and therefore should be well shielded from human contact. Equipment operators must insure a safe clearance on all sides of the operating machinery.

RECORD KEEPING

Maintaining detailed records provides an historical record of the operation and the improvements made over the years. Also, good records provide a basis for proper communication with all stakeholders. Periodically evaluating records helps identify where improvements are needed and provides information necessary for making the operation more efficient. A list of records that could be kept is:

- raw wastes (solid and liquid) weights and types;
- amount of compost made/shipped in different forms (buyer/client lists);
- amount of time required to make the compost (time, material received, placed into windrows, turning frequency);
- routine monitoring data;
- marketing and distribution;
- permits and approvals;
- monitoring and testing;
- accidents;
- expenses and income;
- public information and education activities.

Chapter 7
Organic waste recycling applications in sub-Saharan Africa

This section illustrates pilot projects which have been undertaken in Sub-Saharan Africa, namely Mauritius, Kenya, Zimbabwe and South Africa, within the past five years to promote the production and use of compost among farmers. Emphasis has been put on using locally available wastes and choosing the simplest technology most adapted to local conditions in each country.

MAURITIUS

Several projects have been conducted in Mauritius to encourage farmers, cooperative members and rural communities to recycle organic wastes. These projects addressed community initiatives to reduce the causes of land and water based sources of pollution associated with the management of organic wastes and to produce a material beneficial to agriculture. The UNDP Global Environment Facility Small Grants Programme (UNDP GEF/SGP) funded most of the projects carried out in Mauritius and the Mauritius Research Council funded the project on compost application for large-scale farmers in sugarcane plantations.

Windrow composting of horse manure on a farm

Introduction

A community of farmers regrouped under “Les Marianes Cooperative Society” had been assigned the contract of hauling 100 to 150 tonnes of horse manure from several horse rearing facilities on a monthly basis in Mauritius. The cooperative society was involved also in the cultivation of cane, vegetables and fruit. The possibility of converting the raw horse wastes into compost was looked into as a means of proper disposal of wastes and to obtain a substitute for fertilizer.

Aims and objectives

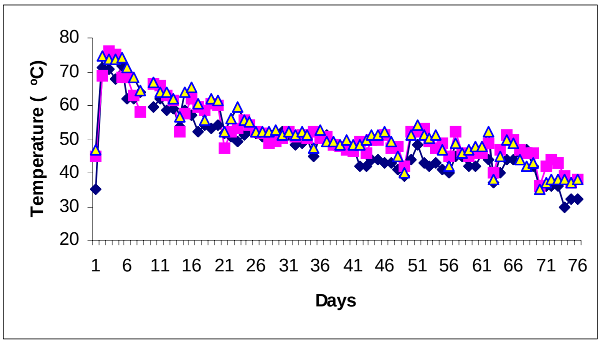
This project looked into safely treating the 1500 to 2000 tonnes of horse manure produced annually by preventing nutrients and bacteria present polluting watercourses. The overall objective was to ensure safe disposal of horse manure through composting and promote the application of composts to growing crops. Secondary objectives included producing a safe compost of good quality, training people in compost making, constructing large-scale facilities to compost large amounts of horse wastes and applying the compost produced to vegetables in order to reduce the use of chemical fertilizers.

Methodology

The project involved constructing windrow facilities (Plate 2) to compost horse manure as well as monitoring process parameters within the windrow and finally ensuring a compost of good quality. Windrows have been designed and constructed on a plot of land belonging to the cooperative society. Design items included a composting pad under a roof, curing pad, drainage pipes, leachate pipes, storm water drains and collecting pond. Around 60 tonnes of horse manure was composted in batches each week. As bedding material (straw, newspaper and weeds) was used to collect the horse excreta, no additional carbon amendment was needed for the composting process. Measuring daily temperature changes, weekly moisture content, pH and volatile solids degradation was carried out to monitor the process. A curing process of four weeks completed the composting process. The final product was assessed for its maturity, fertilizer value, salinity content, water-holding capacity and phytotoxicity properties.

Plate 2
Horse manure windrow composting

FIGURE 19
Temperature evolution for horse manure composting



Results
Temperature and volatile solids degradation were indicators of the efficiency of the composting process. The temperature pattern (taken at three different positions in the pile) followed a typical profile for turned windrows (Figure 19). Thermophilic temperatures (greater than 45°C) were obtained for the first 25 days of composting.

Compost quality
The compost was well stabilized and ready for application. A Solvita index of 7 was obtained for the compost, showing that the compost was well cured and had few limitations for use. The Solvita index ranges from 1 for raw compost to 8 for mature compost. The pH was 7.2 showing neutral compost favourable for plant growth. The electrical conductivity was 1.4 mmhos/cm, which fell well below the higher range allowable for compost, which is 3.5 mmhos/cm.

The compost produced is being used on the farms of the members of the cooperative society as well as being sold to planters. It is envisaged to bag the screened portion of the compost for high quality markets.

Backyard composting of chicken wastes within a farming community

Introduction
The National Federation of Young Farmers Clubs is a youth organisation working under the aegis of the Ministry of Agriculture and Natural Resources in Mauritius. It is an umbrella organisation with 3 000 members in 150 affiliated clubs in different villages of the country. Its main objectives are to provide sustainable agricultural development by training young people to keep up-to-date with new technology, diversify agriculture and act as facilitators for small-scale planters in the region.

Aims and objectives
The project demonstrated the feasibility of making organic compost and applying it to vegetables (Mohee, 1999). Locally available wastes were used along with simple technology to produce high quality compost that could be applied to land without any adverse environmental effects.

Methodology
In this project, two techniques were used to produce compost on a large and a small scale.

Large-scale composting
One to three tonnes of chicken waste and bagasse were composted using windrows (Plate 3). This demonstration of large-scale composting was undertaken at the Belle Mare National Federation of Young Farmers Centre (NFYFC). It was used as an ongoing

composting process to train young farmers. The compost produced was applied to the vegetables growing at the NFYFC.

Small-scale composting
Chicken waste and bagasse was composted using a rotary backyard composter. A preliminary survey had shown that farmers preferred small-scale composting in their backyards. This demonstration of composting on a small scale was carried out in the backyard of 30 families (Plate 4). The families were trained to make compost and used the compost for growing vegetables in their kitchen gardens.

Both the rotary backyard system and the windrows used chicken waste and bagasse provided by the Belle Mare National Federation of Young Farmers Clubs. The compost process was monitored for eight to ten weeks by taking daily measurements of temperature and weekly measurements of moisture content, pH and bulk density. The fertilizer value of the final composts was assessed and the compost was used by the farmers to grow vegetables and for other gardening purposes.

Results

- The high temperatures reached after only two to three days of composting and maintained for four to five weeks in the large-scale windrows showed that the raw materials would compost well.
- Starting from 2.6 tonnes of raw materials, around one tonne of finished product was obtained. The efficiency, on a mass basis, was about 40 percent.
- The rate of water evaporation was high; hence water was a limiting factor at Belle Mare. Moisture content was monitored closely during the composting operation.
- Around 30 farmers are now conversant with composting techniques and are applying only compost to their crops.

Large-scale application of composted sugarcane wastes

Introduction
The sugar industry plays an important role in the Mauritian economy. Around six million tonnes of cane and 600 000 tonnes of sugar are produced in Mauritius yearly (MSIRI annual report, 2002). About 16 sugarcane factories operate in Mauritius. The area under sugarcane cultivation is 77 000 ha and out of a total area of 186 500 ha represents almost 93 percent of the cultivated land. During the last two decades, the average yield of sugarcane plantations has remained quasi-stable at around 70 tonnes/ha. The stress in cane cultivation always has been on producing higher yields to maintain sugar production at levels necessary to meet the country’s export quota commitments. Almost 70 000 tonnes of straight and complex inorganic fertilizer as well as 540 tonnes (active ingredients) of biocides for weed control are used in sugarcane cultivation (Mohee & Panray, 1999).

Plate 3
Windrow composting of chicken wastes at NFYFC

NATIONAL FEDERATION OF YOUNG FARMERS, MAURITIUS 1998

Plate 4
Filling the rotary composter

TABLE 20
Mean cane yield for year one

	With compost	Without compost
Mean cane yield (t/ha)	129.4	103.5
Richesse* as at 3.6.97	12.71	12.68
Number of cane stalks	38 654	116 049
Height (m)	2.3	2.68

* sucrose percent cane

Aim

This study looked into increasing the yield of cane using compost produced from the industry's by-products (Mohee, 1998). The main organic materials generated as by-products of cane processing are bagasse and filter cake. Specific objectives included:

- identifying the optimum compost mix;
- composting in windrows;
- producing high quality compost.

ROSEBELLE SUGAR ESTATE, MAURITIUS, 1997

Plate 5
Field application of compost

Methodology

Mixtures of moist bagasse (50 percent moisture) and filter cake were composted in windrows of 60 tonnes. The moisture content of the resulting mix was 50 percent and the C/N ratio around 30. The bagasse/filter cake mixture was stacked in piles and arranged in long parallel rows on an asphalt pad. The piles were aerated by turning the material twice weekly for the first three weeks and once weekly for the rest of the process by using 60 kw capacity front-end loaders available in the factory.

Monitoring of process parameters such as temperature, volatile solids, pH and respiration rate was carried out to achieve a high compost yield.

The compost produced was applied to a sugarcane field of 6.0 ha at the rate of 5 t/ha/year. An experimental control was provided by a neighbouring 6.0 ha lot where all plantation and agronomic conditions were maintained in a similar way except for the addition of compost.

Results

The main findings were:

- Mature compost was obtained after eight weeks. The mass ratio of final compost to organic substrate was 50 percent. The final compost was dark in colour and had an earthy smell.
- Windrowing was the most cost effective option for sugarcane plantation.
- Compost made from sugarcane residues when applied to sugarcane plantations had the potential to substantially increase cane yield (Plate 5).
- The application of 5 t/ha/year of compost improved both the physical and chemical properties of the cane (Table 20). The number and height of cane stalks as well as the sucrose content of the cane improved substantially. The number of cane stalks increased from 38 654 to 116 049 and the average height of cane stalk from 2.31 to 2.68 m, leading to an overall increase of 30 percent in cane yield compared with the control. These results were obtained for the first harvest of the cane plantation seven-year plant cycle. The second and third harvest of cane gave yield increases of 20 percent and 15 percent respectively, and with the single compost application only.

- A life cycle analysis of the sugarcane process was carried out and it was seen that composting the waste and applying it to the field could effectively increase cane yield (Mohee & Panray, 1999).

RODRIGUES

Rodrigues is a small island of 108 km^2 with 35 000 inhabitants. It is situated in the Indian Ocean about 200 km from Mauritius. The main economic activities are fishing, agriculture and tourism. Traditionally, farmers in Rodrigues have used manure to boost agricultural yields. However, during the past years, because of soil erosion livestock numbers have been reduced and consequentially the quantity of manure has declined. The topography of Rodrigues is such that valleys are situated near the sea, and the soil is not very fertile. To compensate for the lack of manure, the farmers are buying and using chemical fertilizers.

A participatory approach to developing sustainable agricultural technologies with women in Rodrigues

Introduction

Women have an important role in the Rodriguan economy and agriculture: as farmers, household providers and the main cultivators of kitchen gardens. These women are barely educated and have assumed the responsibilities of motherhood and looking after the family at a very early age. They carry the responsibilities of food production and their children’s education. They play a key role in contributing to food self-sufficiency. A pilot project has been developed with the women farmers; it uses a participatory approach towards composting technology development and extension processes (Mohee, 2001).

Aims and objectives

The aim of the project was to determine whether sustainable, livelihood practices of small-scale community based farms could be improved by the use of environmentally friendly technologies. The objective of the project was to encourage the use of compost instead of chemical fertilizers in sustainable agricultural practices. The project hoped to achieve:

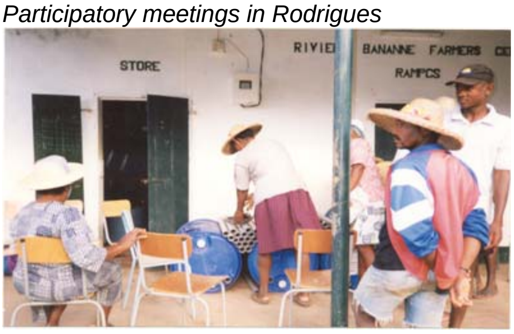
- an increased level of domestic food production;
- an increased income in rural households;
- a raised profile of the role of rural women as agricultural producers and processors at both household and community levels;
- the training of women in one valley to act as pioneers, so as they could share their knowledge in other villages.

Methodology

Phase one: Explanatory phase

A preliminary survey was carried out to understand the role of compost in agriculture. Meetings were held to discuss the project (Plate 6) and how it could be implemented. Data obtained from the survey and meetings provided important information, which guided future actions in the project, such as setting up centralised or backyard composting, whether household and agricultural/animal wastes could be used, etc. Training needs for compost making and use were identified also.

Plate 6
Participatory meetings in Rodrigues



Phase two: Demonstration phase

Phase two of the project consisted of training the women to produce compost, especially the process monitoring and use of the final product. Pilot demonstration windrow composting as well as rotary composting and demonstration gardens were set up to do this.

Results

Green wastes, dried maize and goat manure were mixed. The mixture, which had a moisture content of 70 percent and a C/N ratio of 28, was compacted and introduced into the rotary composter. On day three the temperature, which was high from the start and taken at two different positions in the pile, reached 60^0C. It remained high for around six days but then dropped to around 30^0C (Figure 20). The volume of material also dropped showing that the rapidly decomposable wastes had been degraded. The raw materials were removed from the composter and remixed. The temperature then rose to 50^0C, showing that air and/or moisture distribution had been limiting factors.

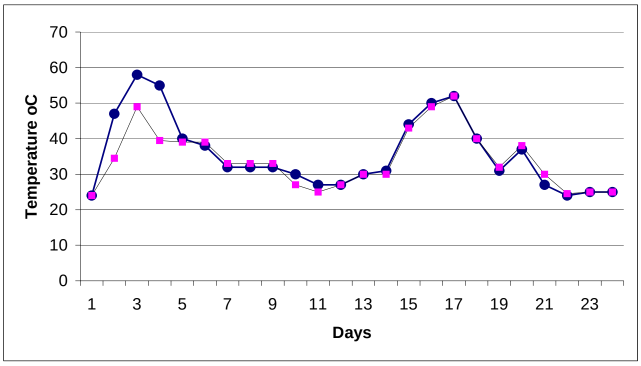
Conclusion

The general findings were:

- All the women showed a deep interest in the subject. They looked after their composting documentation and helped colleagues develop good waste management habits.
- The women improved the construction of the composter, indicating their keen interest in producing compost (Plate 7).
- Soil fertility benefits while using compost and the long-term added benefits of controlling soil erosion were impressed upon the community.
- After two years, the women were still actively producing compost.

This project very successful disseminated information. It had been in the form of “Train the trainers”. The women were ready to act as pioneers and indicated their interest in training people in other communities about making compost. Furthermore, the women demonstrated their willingness to encourage composting by teaching their children about composting.

FIGURE 20
Temperature evolution during composting



AGRICULTURAL COMMUNITY OF RIVIERE BANANES, RODRIGUES , 2001

Plate 7
Rodriguan women composting agricultural wastes

KENYA

In 1987, a Kenyan agronomist, Dr. John Njoroge, started the Kenya Institute of Organic Farming (KIOF) with a view to promoting more productive and sustainable smallholder farming practices, particularly through composting, double deep digging and water harvesting. Since 1986, over 200 farmers' groups with about 5 000 members have been trained in organic farming.

Compost users project by the Kenya Institute of Organic Farming (KIOF)

Introduction

This project was initiated to recycle crop residues and animal manure to produce high quality compost for growing vegetables (Njoroge 2002).

Objectives

The objectives were to:

- demonstrate various stages of the decomposition process;
- generate high quality compost from organic wastes, vegetable materials and animal manure;
- provide a learning forum for farmers and university students wishing to specialize in organic composting;
- exchange data with similar compost demonstration projects in eastern and southern Africa.

Methodology

Raw materials were collected from nearby agro-industries such as the avocado oil processing plant, local vegetable markets and household wastes (Plate 8). Preliminary sorting removed plastic and other material that could not be composted. The wastes were chopped and arranged into compost piles (Plate 9) (Annex 6). Moisture content was adjusted and the pile covered. Turning was done every three weeks for three months. The final product was sieved and analyzed to determine quality. It was stored for use and shown to visiting planters. Regular visits and talks were organized for farmers.

Findings

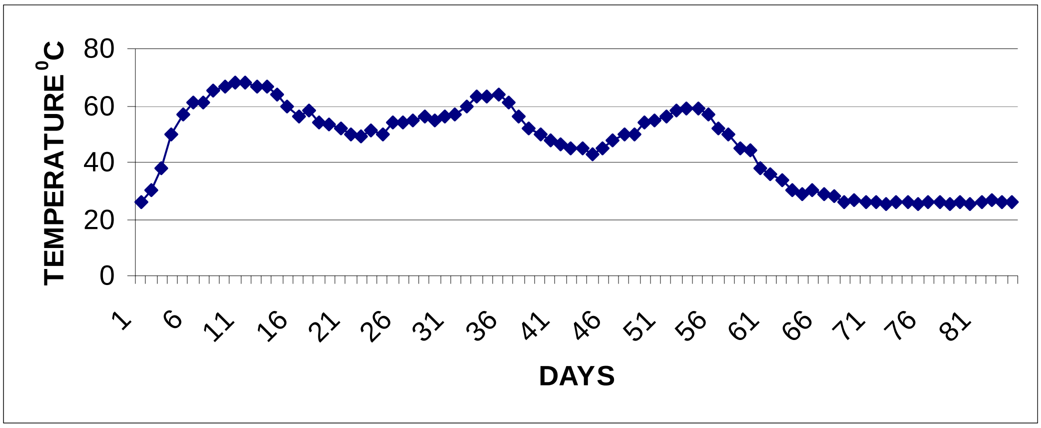
Temperature was taken as an indicator of composting activity. A typical temperature profile (Figure 21) was observed whereby the temperature rose as a result of microbial breakdown, dropped when the pile was turned and then rose again. Temperatures first rose to a maximum of 68^0C then dropped steadily to 50^0C just before the first turning. The temperature changes showed the rate at which microbial activity had occurred during the composting process.

NJOROGE JOHN, KENYA INSTITUTE OF ORGANIC FARMING, KENYA, 2002

Plate 8
Farmers gathering material for composting in Kenya

Plate 9
Set up of compost piles in Kenya

FIGURE 21
Temperature evolution



Height of the pile
The height of the pile, which was initially 1.5 m, fell to 1.2 m after one week, 0.9 m after two weeks and to 0.8 m in the third week. It was observed that the compost height fell faster during the first three weeks compared with the consequent weeks. This was because of increased microbial activity in the first three weeks. Changes in the pile height showed that the material had decomposed, reducing the volume.

TABLE 21
Compost quality parameters

Parameter (on a dry weight basis)	Value
pH	7.6
Electrical conductivity (mmhos/cm)	3.0
N (%)	3.4
P (%)	0.03

Compost quality
The final compost quality was measured in terms of pH, electrical conductivity, nutrient content and cation exchange capacity. Results showed the compost had a high nitrogen value of 3.4 percent (Table 21). Also, it was observed that the electrical conductivity was slightly higher than existing compost norms in Kenya. Care must be undertaken when applying this compost to plants as the high electrical conductivity can affect plant growth.

The effect of compost on maize
A control experiment was carried out to determine the effect of compost on maize. Indicators used were colour, height and yield. It was observed that the control crop had a pale green colour compared with a dark green colour for the crop with compost. The average height of the control plants was 1.35 m compared with 2.6 m for the plants that had compost. The yield of maize with compost was higher than the control crops by an average of 15 percent on a dry mass basis.

The compost produced was sieved and packed in 15 kg, 35 kg and 70 kg bags for use and exhibition. Farmers' days were organized to disseminate information on composting. The farmers were given an opportunity to observe and ask questions about composting. At an education session farmers were taught the essentials of good composting. Around three sessions have been organized since the beginning of the project. Currently 61 farmers have attended these sessions.

The following benefits have been realized from the project:

- the participants (farmers, extension workers, and academicians) have appreciated the idea of composting as the only cheap way to gain a healthier harvest;
- a forum where farmers, extension workers, and academicians can learn about high quality compost processes has been created;

- an avenue for getting high quality compost has been created for farmers who need to use compost immediately but have not yet learnt composting techniques.

Conclusions

The compost project was implemented both on an experimental and large-scale basis. The compost produced has become a source of income. It has had a marked effect on crop yield, proving more effective than chemical fertilizers. Furthermore, plants where compost was applied were found to be more disease resistant.

ZIMBABWE

Agriculture in Zimbabwe is divided into two distinct sectors; large-scale commercial agriculture, which is mainly privately owned, and the informal sector which is dominated by subsistence farming. Smallholder farmers always have used organic wastes for agriculture, in the form of livestock manure, crop residues and household wastes. Household wastes are mostly food, vegetable scraps and yard wastes that often are composted in pits close to their homes. However, the use of household organic waste has been constrained by other competing uses, such as giving food scraps to livestock and pets.

Developing partnerships with farmers to increase soil fertility

Introduction

There were issues of decreasing soil fertility in Zimbabwe with a need to replenish soil fertility by the addition of organic matter. Many farmers realised that organic inputs could improve crop yields and soil fertility, but the biggest constraints on producing and applying organic fertilizers were high labour and transport requirements (Chuma, Mombeshora, Murwira, *et al.*, 2003). Efforts have been made by the Tropical Biology and Soil Fertility programme (TSBF) at the University of Zimbabwe to explore ways to improve the quality and effectiveness of compost. The project was set up in 2002 and involved the farmers from the beginning. A pilot composting and demonstration project using household wastes was established (Murwira, 2002). The Participatory Rural Appraisal (PRA) tools were used to identify key areas of intervention in manure management and urban waste use. Five trials were set up in farmers' fields to evaluate the effectiveness of existing and new practices. Farmer workshops were used as a forum for the presentation of results and experiences. Exchange visits involving farmers from different areas were encouraged.

Aim and objectives

The goal was to promote composting through participatory demonstration trials targeting rural and urban communities. Specific objectives were:

- to enhance the use of locally available organic resources through farmer participatory composting research;
- identify locally available organic resources in the study area;
- enable farmers to assess different composting technologies;
- identify key criteria used by farmers to identify composting technologies.

Methodology

Two rural communities situated in the Zvishavane district, the Harawa and the Vukusvo communities, comprising groups of farmers were selected. Also, one urban secondary school was selected to represent urban and peri-urban environments.

Focus group discussions and presentations (Plate 10) were used at meetings to identify farming practices and organic resources required for composting. Also, the group discussions were used to identify and compare composting strategies used by farmers in the community as well as constraints and barriers towards the adoption of composting. At each site farmers gathered materials for composting over a period of one week, stockpiling the materials under a roof.

Plate 10
Presentations at Harawa community, Zimbabwe

Plate 11
Composting at the Harawa Community, Zimbabwe

Materials used for composting by the different groups varied. Harawa farmers used maize stocks, partially decomposed tree leaves and garden weeds (wilted green grass mixed with a few broads). Vukusvo farmers used maize stalks, groundnut stalks and goat manure mixed with soil.

The Harawa farmers constructed their compost in piles (3 m * 2.5 m * 1.2 m) on the ground and used twigs as the first layer for improved aeration (Plate 11). They used temperature measurements to track the composting process. The Vukusvo farmers did their composting in pits (0.70 m * 4 m * 2.5 m) and covered the piles with soil. The compost temperature was measured daily in the centre at three different positions in the pile and the moisture content monitored weekly.

Results

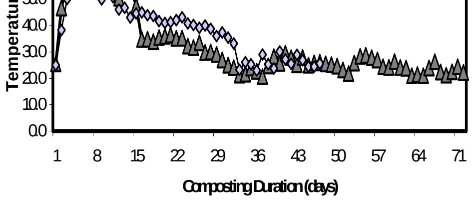
In both cases, the farmers identified several benefits of composting and were enthusiastic to continue testing different composting practices. The period from April to June was identified as best for composting, since farmers would start getting more organic material by clearing their gardens and harvesting. The major constraint identified was that the time when compost needed to be produced coincided with the busiest weeding period of the month.

Composting trials

Harawa (pile compost)

Temperature measurements were an average of three readings. The temperature in the centre of the compost rose to 70^0C in six days (Figure 22). It remained thermophilic until day 13 of composting and then stayed above 50^0C for 15 days, gradually declining to the ambient temperature thereafter. No further temperature rise was observed after day 56.

FIGURE 22
Temperature profiles for Harawa and Vukusvo compost piles



Vaka (pit compost)

The pit compost attained a maximum temperature of 54.5^0C within four days of composting (Figure 22). Thermophilic temperatures were recorded up to day 14 after which the temperature gradually declined to below 30^0C after 31 days of composting. Thus changes in the temperature profile of the pit compost were more gradual than in the pile compost. Mixing resulted in the rising and falling of the mean compost temperature.

Conclusions

The composting processes were carried out successfully and farmers were able to explain the process and the importance of aeration as well as the biological activity of micro-organisms. The farmers showed a lot of enthusiasm for the project and expressed further interest in finding out about the:

- advantages and disadvantages of different types of composts;
- advantages of adding ash to compost;
- benefits of “hot” composting as opposed to trenching and other types of “cold” composting;
- temperature changes during composting.

SOUTH AFRICA

In South Africa, agricultural activities are promoted in rural areas as a means of addressing food security, health, job creation and income potential. The National Department of Agriculture recently has implemented a strategic plan with a core focus to enhance farmers' capacities to use resources in a sustainable manner and to ensure the judicious use and management of natural resources (Reinten, 2003). One of the problems facing farmers is the lack of infrastructure and means to buy fertilizers and pesticides. The need to use the available natural resources and to combat moisture loss from the soil prompted an investigation into compost-making trials and training for rural use.

Compost making and training for rural areas in South Africa

Introduction

Since many soils are poor in nutrients and organic matter, compost can play a major role in rural areas of South Africa. This project investigated composting methods suitable for small-scale farmers and rural communities.

Objectives

Specific objectives included:

- to develop methods of making compost in rural areas;
- to develop and prepare a mechanism of technology transfer - keeping literacy and different local languages in mind;
- to prepare a manual and presentation to be used in several rural regions;
- to evaluate the different methods used for composting;
- to conduct field trials with vegetables, using different compost compositions and applications so as to develop demonstration material.

Methodology

At the experimental farm in Elsenburg, two composting experiments were made to simulate two different rural areas. The use of the static heap method is the most popular, although labour intensive. Other methods of handling large quantities of raw material to make compost with an inexpensive infrastructure will be investigated.

A manual and presentation with visuals and text are being developed and put together to use in the transfer of technology. The use of different languages is envisaged and the cultural practices of the rural regions will be taken into account before the final presentation is printed.

Four rural communities have been visited and the current methods of making compost have been identified, evaluated and compared. The final compost products have been chemically analysed and parameters for testing identified.

Various vegetable trials, using the different 'types' of compost, will measure and compare yields and growth.

Results

- Three communities involving around 80 people have been trained. These farmers grow mainly vegetables.
- During discussions held with communities in Ceres, Clanwilliam, George/Oudtshoorn and Stanford, the main observations were that compost making and recycling of nutrients (use of natural resources such as vegetable waste and fruit peel) were not practised. It was further found that animal waste (manure) was mostly in the wild, and manure from the night shelters was occasionally used for crop production. It was mentioned that food crop production benefits from compost use and needs to be maintained.
- The manual and presentation (Annex 7) was used in several regions, the slides were in English and included lots of graphics and pictures but verbal translations were made into either Xhosa or Afrikaans, depending on the group.
- The static heap method for composting was identified as being the best option for rural communities with a limited infrastructure.
- Different waste materials were put together (Plate 12). This included building heaps with horse manure, pig manure and various dry and green materials. Compost heaps were built manually and also in bins for smaller quantities of wastes (Plate 13).
- The temperature was taken daily to monitor the degradation process. Results were that when too little manure was included in the heap, it quickly lost temperature. Another observation was that the heaps quickly dried and lost moisture, which resulted in a rapid decrease in temperature. Moisture was being adjusted regularly by using a watering can (Plate 14).

This project is ongoing and future work will consist of developing field trials with vegetables using different compost compositions and propose standards for compost to be accepted and used for rural communities in Southern Africa.

REINTEN, EMMY; ARC-ROODEPLAST, SOUTH AFRICA 2003

Plate 12
Raw materials collection

REINTEN, EMMY; ARC-ROODEPLAST, SOUTH AFRICA, 2003

Plate 13
Heap building process

REINTEN, EMMY; ARC-ROODEPLAST, SOUTH AFRICA 2003

Plate 14
Adjusting moisture in compost piles

Chapter 8
Conclusions

Concerns about water and air quality are being posed increasingly to farmers in the context of sustainable farm management. However, agricultural industries, such as nurseries and greenhouse growers, as well as farmers are looking more and more for organic supplements to improve soil fertility. Composting organic wastes produced on farm can bridge the gap between the waste generators, the agricultural community and the public at large.

The basics required for composting are readily available on the farm: feedstocks such as livestock manure and crop residues, along with readily available bulky materials, air, water, space and time. However, like any additional on-farm operation, composting requires additional equipment and facilities although the initial investment for a composting operation can be low when composting small quantities of wastes. For larger volumes of wastes, the area required for the composting site, storage of raw materials and finished compost could occupy a considerable amount of space.

The main drawbacks to composting organic wastes on farm are the production of odour and use of resources such as land, time and money. Composting operations, if mismanaged, can produce offensive odours, which generate complaints from nearby residents. However, offensive odours can be minimized through proper process control and good housekeeping procedures. Costs of any particular compost operation depend on a large number of specific variables that will vary from farm to farm. Economic analyses of costs and benefits of composting organic wastes are needed. Tradeoffs between farm income and environmental impacts need to be assessed. Today, compost can be produced using technologies or management systems that employ different combinations of land, labour and equipment, thus allowing the farmer to use lest costly factors. To achieve economies of scale, farmers within a rural community can combine to operate larger scale composting facilities.

Composting is a promising technology for farmers and their households to reduce environmental impacts associated with organic waste management. A number of successful composting projects are already operational. However, there are certain issues that must be addressed at the farm and community level for the technology to be sustainable. Future challenges for the farming community are:

- Finding clean sources of low moisture, high carbon amendments.
- Most waste materials on the farm are high in moisture and nitrogen. The challenge is for farmers to find dry, high carbon amendments. Some promising amendments are leaves, bedding material, wood chips, sawdust, paper and cardboard.
- High equipment costs and significant economies of scale.
- Even a medium scale operation would under-use the specialized composting equipment. Efforts have to be made by farmers who need specialized equipment to either upscale their operations or share the resources with other farmers.
- Lack of a strong compost market and competition from other products.
- Usually compost markets are split between high value nursery and greenhouse uses and low value agricultural, topsoil and reclamation uses. High value markets are small so most on-farm produced compost is used in bulk in farm applications.
- Lack of awareness of compost attributes such as biological control capabilities and soil fertility effects.

The agricultural community needs to know which by-product materials can be applied to land, how much can be applied and which methods of application are environmentally safe. Expenses may have to be subsidized and additional steps may be needed at production sites to make products more valuable for agricultural and horticultural use. These costs may be small compared with the potential benefits to be gained through environmentally safe use of by-products in agricultural operations. The public will need to be convinced that recycling of agricultural wastes is environmentally safe, cost effective and does not pose a human health risk.

Chapter 9
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Chapter 10
Annexes

ANNEX 1: ANALYSIS TECHNIQUES

Moisture Content (MC) and Total Dry solids (TS)

Three samples of 100 g each of material were taken and dried to constant weight in an oven at 105^0C for 24 hours and cooled in a dessicator. The difference in weight was recorded. The moisture content was calculated as:

$$\text{Moisture content (wet weight basis), \%} = \frac{Loss\ in\ weight * 100}{Net\ wet\ weight}$$

$$\text{Total dry solids (TS), \%} = 100 - Moisture\ Content\ \%$$

Total Volatile Solids (Organic Matter) and Ash

Samples of 3 to 5 g of dried material obtained from determination of total dry solids or that dried separately were taken in triplicate, and were ignited at 550^0C for two hours in a muffle furnace. The difference in weight before and after ignition was calculated and the volatile solids content was calculated as:

$$\text{Volatile Solids (VS), \% (dry weight basis)} = \frac{Loss\ in\ weight * 100}{Net\ dry\ weight}$$

$$\text{Ash, \% (dry weight basis)} = 100 - Volatile\ Solids\ \%$$

Estimating Carbon Content

Carbon content can be estimated from the volatile solids content of a material. Volatile solids content (VS) are the components (mainly carbon, oxygen and nitrogen) that burn off a sample ready for testing in a laboratory furnace at 500 to600^0C. leaving only the ash (largely calcium, magnesium, phosphorus, potassium and other mineral elements that do not oxidize). For most biological materials the carbon content is between 45 to 60 percent of the volatile solids fraction. (Haug, 1980) stated that the following formula can be used to estimate carbon content:

$$\%\ Carbon = \frac{\%\ Volatile\ Solids}{1.8}$$

Bulk Density

Bulk weight was determined by filling and weighing a cylinder of known volume (V) with material loosely packed.

$$Bulk\ Density = \frac{(W_{A.F} - W_{B.F}) \times 100}{V}$$

Where:
$W_{A.F}$ = *Weight of cylinder after filling, kg*
$W_{B.F}$ = *Weight of cylinder before filling, kg*
V = *Volume of cylinder in* m^3

pH

Water (20 ml) is added to 5 g of material and the suspension continuously stirred for 5 minutes. It was left to stand for about 15 minutes to allow the suspended waste to settle. The pH of the solution was measured with a pH meter.

ANNEX 2: TROUBLE SHOOTING GUIDE

WHAT DO I DO IF…?	DIAGNOSE THE PROBLEM	CURING THE PROBLEM
My compost smells bad	Does your compost smell like: Sulphur (rotten eggs) If your pile smells likes sulphur, it is too wet. Ammonia (acidic) If your pile smells like ammonia, it has too much nitrogen from green waste.	For a sulphur smell: Mix in dry ingredients, such as soil, dried leaves, shredded newspaper or grass clippings. Make sure it is not too wet. For an ammonia smell: Add material containing carbon, such as ash or dolomite. If it still smells bad, turn the pile to push air through the heap and help with the intermediate odour problems or mix in materials that do not compact, such as green twigs and plant stems, to help create more air spaces.
My compost pile will not heat up!	Your pile could be cold because it lacks: • moisture; • nitrogen.	Check the moisture level of the pile. It should be as moist as a well-wrung sponge. Add high nitrogen materials (fresh grass or vegetable scraps, blood and bone).
My compost takes too long to breakdown!	Your compost could have any one of the following problems: The pile may be too dry. The balance of 'browns' and 'greens' may not be right. The pile may not have enough air.	Water: Is it wet enough? Food: Have you added equal amounts of 'browns' and 'greens'? Air: Is your pile getting enough air?

Source : How to home compost. Nature's recipe for recycling. Ecorecycle. http://www.ecorecycle.vic.gov.au/

ANNEX 3: SOLVITA TEST

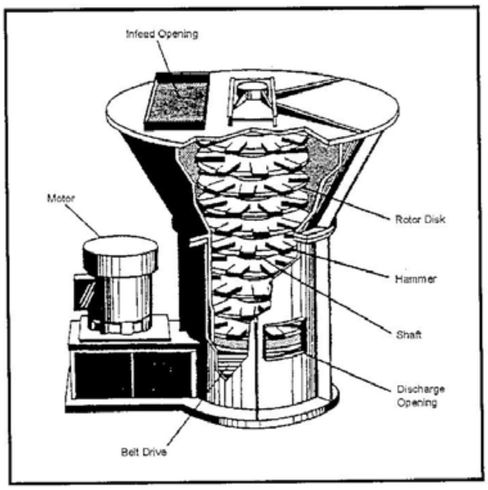
The Solvita test is a procedure that gives a Maturity Index for any sample of active or aged compost. It is based on measuring carbon dioxide respiration and ammonia content simultaneously. It measures total respiration in a specified volume of compost and gives a semi-quantitative colour response.

Solvita Maturity Index	Stage of composting process	Major class is
8	Inactive, highly matured compost No limitations for usage	FINISHED COMPOST
7	Well matured, aged compost, curing grade Few limitations for usage	
6	Curing, compost ready for piling	"ACTIVE COMPOST"
5	Compost ready for curing	
4	Compost in moderately active stage of decomposition	
3	Active compost	
2	Very active putrescent fresh compost, high respiration rate	RAW COMPOST
1	Fresh, raw compost	

Source: Brinton (1997). Basis for interpretation of waste and compost tests. Journal of the Woods End Research Laboratory. Woods End Research Laboratory, Mont Vernon. ME 04352

ANNEX 4: DIAGRAMS OF HAMMER MILL, WINDROW TURNER, TUB GRINDER AND MANURE SPREADER

FIGURE 23
Vertical hammer mill



Source: Diaz, *et al.,* 1996

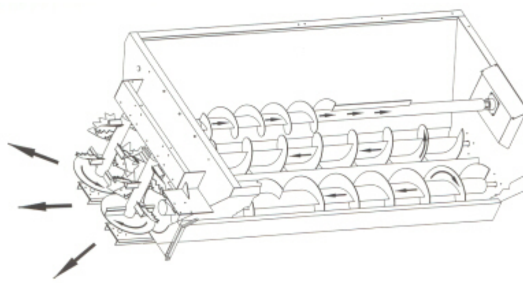
Plate 15
Windrow turner

Source:
www.allubuckets.com/images/as38work_01.jpg

Plate 16
Compost grinder

Source: Pennsylvania Department of Environment Protection - http://www.lower-allen.pa.us/Twpinfo/recycling-trash/recycle.htm

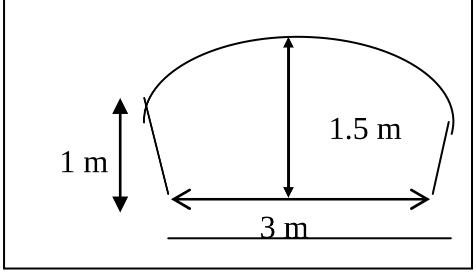
FIGURE 24
Manure spreader



Source: Farm equipment buyers trust the name Meyer at http://www.meyermfg.com/spreader.html

ANNEX 5: SAMPLE CALCULATIONS

FIGURE 25
Windrow dimensions



Sample calculation for composting area

A farm household handling around 80 tonnes of horse manure per month wishes to compost in windrows. The site selected is far from residences, wells and surface streams. The bulk density of horse manure is about 400 kg/m^3 so the volume received on a weekly basis is 50 m^3.

Active composting area

Volume received per week = 50 m^3

Number of weeks the material will remain in the piles = 6 weeks (Horse manure typically takes around five to six weeks for active composting)

Volume of material the composting pad will need to hold = 50 * 6 = 300 m^3

Given that the dimensions (Figure 25) of one windrow are:

- Width of windrow = 3 m
- Height of windrow side = 1 m
- Cross-sectional area of windrow = 3.53 m^2
- Proposed length = 15 m

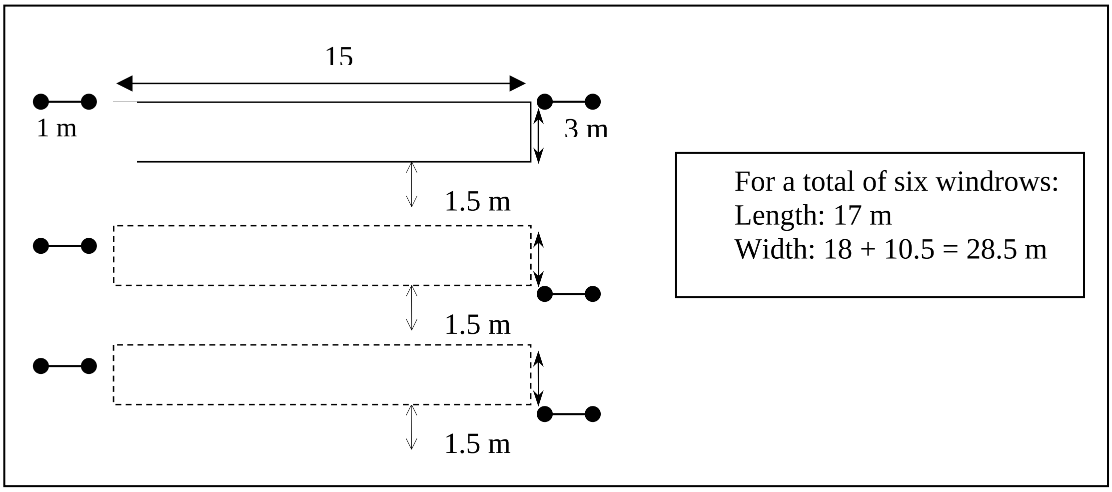
The volume in one windrow is 3.53 * 15 = 52.95 m^3

Compost area calculation

- Number of windrows: 300/52.96 ≅ 6
- Space required at the ends of each windrow: 1 m
- Thus, the length of one windrow on the compost pad = 17 m
- Surface area of one windrow* number of windrows = (17 * 3) * 6 = 306 m^2
- Space between windrows (allow 1.5 m between windrows for vehicle access) and along the sides: (17 * 1.5) * 7 = 178.5 m^2

Area of composting pad (Figure 26) = 306 + 178.5 = 484.5 m^2

FIGURE 26
Windrow layout for active composting



Curing area

Typical dimensions of curing piles are 3m wide and 2m high. The proposed length is 10 m. Therefore the volume of a typical curing pile is 3 * 2 * 10 = 60 m^3.

Assuming a 40 percent reduction in volume after composting for a period of 6 weeks,
Volume of compost to be cured = 300 * 0.6 = 180 m^3.
Number of curing piles required = 180/60 = 3.

Allowing 1 m between piles and at the end of each curing pile;
Area required for curing pad (Figure 27) = 12 * 3 * 3 + 12 * 1 * 4 = 108 + 48 = 156 m^2

Pre-processing and post-processing area

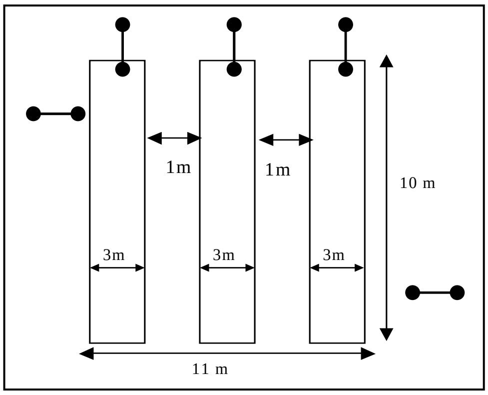
Around one fifth of the area will be needed for pre-processing and post-processing.

The total area for the composting facility is:

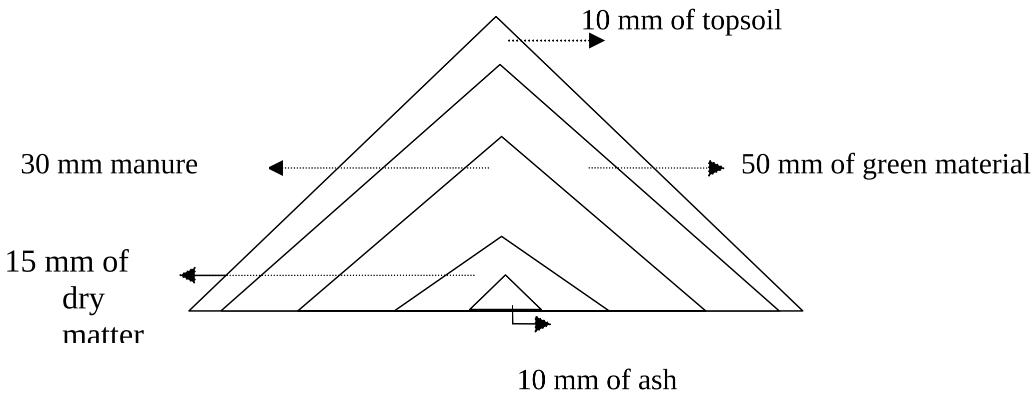
- active composting 484.5 m^2
- curing 156 0 m^2
- pre-processing and post-processing 128.0 m^2

Thus the total area required for a facility composting 80 tonnes per month of horse manure is 768.5 m^2.

FIGURE 27
Curing piles layout

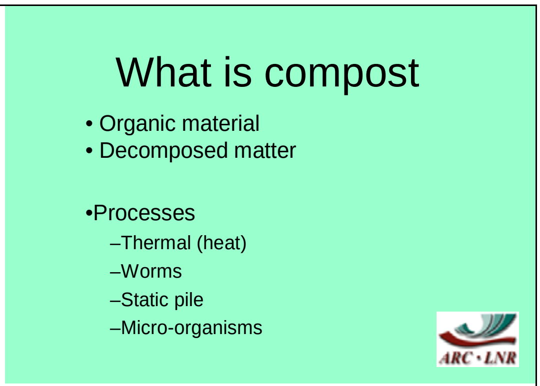


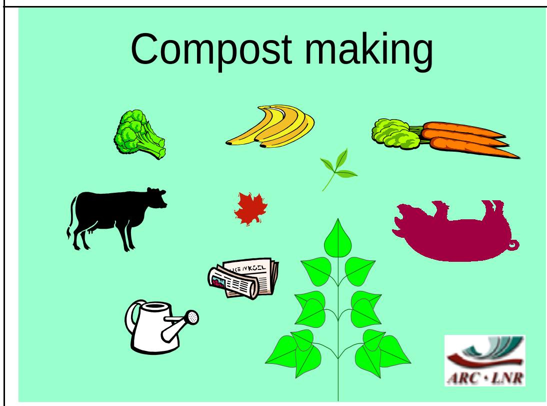
ANNEX 6: LAYOUT OF MATERIALS IN KENYA (KIOF) PILOT COMPOSTING PROJECT

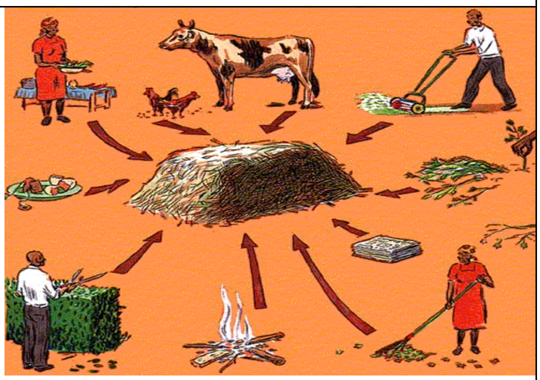


ANNEX 7:TRAINING MATERIALS USED IN COMPOST MAKING IN RURAL REGIONS IN SOUTH AFRICA

Courtesy: Mr W. Mgcoyi & Dr E. Reinten, Agricultural Research Council, Roodeplat, Elsenburg, South Africa.







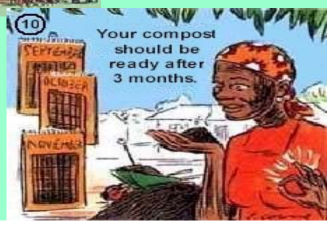
Layers in compost heap

- Do not use !! -

- Disinfectants + detergents
- Meat, oils, fat
- Salt
- Fruit fly infested fruits
- Plastic & glass

Maintenance

of heap



ANNEX 8: GLOSSARY OF TERMS

TERM	DEFINITION
ACTIVATOR	Activators are additives to the compost pile, which might comprise of nitrogen materials or sugars. Their purpose is to increase microbial activity.
AERATED STATIC PILE	Composting system that uses a series of perforated pipes as an air distribution system running under the compost pile and connected to a fan.
AEROBIC	Occurring in the presence of oxygen.
ANAEROBIC	Occurring in the absence of oxygen.
ASH	Product remaining after incineration in laboratory combustion.
BACTERIA	Micro-organisms that break down organic materials in the first stages of composting.
BAGASSE	A fibrous carbonaceous material, by-product of the sugarcane industry.
BIODEGRADABILITY	The potential of an organic substance to be broken down into simpler compounds or molecules through the action of micro-organisms.
BIOLOGICAL OXYGEN DEMAND (BOD)	Together with COD, BOD is the measure of the pollution potential in water and organic wastes. A laboratory test is used to measure the amount of dissolved oxygen consumed by chemical and biological action when a sample is incubated at 20^0C for a given number of days.
BULK DENSITY	Mass per unit volume for soil or manure or other substances.
BULKING AGENT	Material, such as wood chips, added to compost primarily to help create good pore structure for airflow.
C	Carbon
C:N RATIO	The amount of total carbon divided by the amount of total nitrogen contained in, e.g. livestock manure, etc. Manures with a high C:N ratio such as farmyard manure usually take longer to break down, or mineralise, in the soil than those such as slurry with a lower C:N ratio.
CATION EXCHANGE CAPACITY	A measure of the negative charge on soils, primarily on clays and organic matter.
CH_4	Methane
CO_2	Carbon dioxide
CO-COMPOSTING	The composting together of a mixture of different organic substrates.
COMPOST	Completely decayed organic matter.
COMPOST REACTOR	A closed, aerated vessel for rapidly composting organic substrates such as solid manures and producing high quality compost.
CONDENSATE	Liquid which is obtained when water vapour condenses
CURING	The last stage of composting that occurs after much of the readily metabolized material has been decomposed.
DEWAR TEST	It is a self-heating test based on the highest temperature achieved during residual heating of compost sample over a period of several days. The highest temperature achieved rates the maturity.
DRY MATTER (DM)	The residue remaining following heating under standard conditions (usually around 105°C to constant weight) to drive off water. Often expressed as a percentage of the weight of original material.
FORCED AERATION	Composting through the use of perforated pipes or a porous floor to force air into the solid manure or other organic material.
FRESH MATTER (FM)	Unmodified, wet, un-dried material.
INOCULANTS	Dominant micro-organisms, which may be added to a compost pile.
IN-VESSEL COMPOSTING	Composting in a compost reactor as opposed to a windrow.
K_2O	Potassium oxide (K), potash

TERM	DEFINITION
LANDFILL	Pleasant term for a garbage dump that is located in a cavity in the ground so that, when full, it may be covered up to look like part of the land.
LEACHATE	Liquid "run-off". Leachate from the compost pile contains nutrients generated in the composting process.
LIGNIN	A hard substance embedded in the cellulose of plant cell walls that provides support.
MATURE COMPOST	The stabilized and sanitized product of composting; it has undergone decomposition and is in the process of stabilization.
MINERALS	Supply food and nutrients for plants and micro-organisms.
MOISTURE CONTENT	Weight of water divided by weight of solids in material.
MULCH	Covering for soil. Mulch should not be mixed into the soil; it is not a fertilizer or soil amendment.
N_2	Nitrogen.
N_2O	Nitrous oxide.
NH_3	Ammonia.
NH_4^+	Ammonium.
NO	Nitric oxide.
NO_3^-	Nitrate.
NO_X	Nitrogen oxides usually N_2O, NO.
N-P-K	N-P-K is an abbreviation for nitrogen (N), phosphorus (P), and potassium (K).
O_2	Oxygen.
ORGANIC	All compounds whose molecules contain carbon, with a few exceptions such as carbon dioxide.
ORGANIC MATTER (OM)	Residues derived from plants, animals and micro-organisms in various stages of decomposition.
P_2O_5	Phosphate.
PASSIVE AERATION	Composting through the use of open-ended perforated pipes or a porous floor at the base of the composting material for convective movement of air into the solid manure or other organic material.
PATHOGEN	An organism including viruses, bacteria, fungi and protozoa capable of producing an infection or disease in a susceptible host.
pH	A measure of the hydrogen ion concentration of a solution and an indication of its` acidity or alkalinity. Expressed on a scale from 0 to 14, 7 is neutral, higher values more alkaline, lower values more acid.
PHYTOTOXIC	Toxic to plants.
PLANT NUTRIENTS	Elements needed for normal plant growth. Usually divided into macronutrients (nitrogen, phosphorus, potassium, magnesium, calcium, sulphur) and micronutrients (e.g. copper, zinc, manganese etc.)
RECYCLE	Systems which may be run by private enterprise or local government to gather recyclable materials and remake them into similar or dissimilar products for market.
REPRESENTATIVE SAMPLE	A sample (e.g. of liquid or solid manure) that is elected in such a way that its characteristics and properties are representative, or typical, of the bulk of material from which it was taken.
REUSE	Practices, which find alternate uses or alternate avenues for use of an item rather than expending energy to dispose it or alter its form by recycling or composting.
S	Sulphur.
SOIL AMENDMENT	Matter than, when added to the land, will make the soil healthier by such means as balancing and adding nutrients, balancing the pH, encouraging the presence of micro-organisms.
STABILITY	The degree to which the composted material can be stored or used without giving rise to nuisances, or can be applied to the soil without causing problems because of incomplete degradation of

TERM	DEFINITION
	readily biodegradable materials.
SUBSTRATE	Raw materials for composting.
THERMOPHILIC	Relating to organisms growing at high temperatures (40^0C - 60^0C).
THERMOPHILIC BACTERIA	This group of bacteria species work to break down organic matter under "hot" conditions of 45^0C - 70^0C.
TOTAL AMMONIACAL NITROGEN (TAN)	The total amount of ammonium and ammonia nitrogen contained in, e.g. livestock manures. (NH_4)
TOTAL KJELDAHL NITROGEN (TKN)	Total amount of organic and reduced forms of nitrogen contained in, e.g. livestock manures, excluding nitrates. (NO_3)
TOTAL SOLIDS (TS)	Dry matter
TOTAL VOLATILE SOLIDS (TVS)	The weight loss after a sample of total solids is ignited in a furnace (heated to dryness at 550^0C).
TRACE ELEMENT	A chemical element that is required in very small quantities by plants or animals for normal functioning, growth and health. Includes iron, zinc, boron, copper, manganese, cobalt and molybdenum.
TURNING MACHINE	A machine designed to turn and mix solid manure to encourage composting often in windrows.
VOLATILE SOLIDS	Total Volatile Solids
WINDROW	A long heap (typically 1 to 3 m high, 2 to 5 m wide and of indeterminate length, of solid manure, usually undergoing composting.
WINDROW SYSTEM	Composting mixture is placed in elongated piles called windrows.

ANNEX 9: LIST OF UNITS

mm: millimetres
m: metres
m^2: square metres
m^3: cubic metres
kg: kilograms
ppm: parts per million
t/ha: tonnes per hectare
t/yr: tonnes per year
g/l: grams per litre
mg/l: milligrams per litre
kg/m^3: kilograms per cubic metre; unit of density
m^3 air/day: cubic metres of air per day; unit of volumetric flow rate of aeration
$mgO_2/gVS/hr$: milligrams of oxygen per gram of volatile solids per hour; unit of respiration rate
gO_2/g substrate: grams oxygen per gram substrate
mmhos/cm: milli “mho” per cm; unit of electrical conductivity

ANNEX 10: SOURCES OF ADDITIONAL INFORMATION

Compost for manure management
Bio Cycle
419 State Ave
Emmaus, PA 18049
610-967-4135
610-967-1345
biocycle@jgpress.com
(http://www.jgpress.com/)

B.C. Agricultural composting handbook published by British Columbia Ministry of Agriculture
Resource Management Branch
B.C. Ministry of Agriculture and Food
1767 Angus Campbell Road,
Abbotsford, B.C.
V3G 2M3
604-556-3100
604-556-3099 Fax
(http://www.agf.gov.bc.ca/)

Woods End Agricultural Institute in Mt. Vernon, Maine
(http://www.woodsend.org/)
Composting fish by-products: A feasibility study
Organic growing mix: Use of compost in potting mixes
Polycyclic aromatic hydrocarbons (PAH) in paper bedding
Compostability, health risks and bio-degradation

Recycling of organic wastes of agricultural and domestic origin
(http://www.agric.uwa.edu.au/soils/soilbiol/ORGWAST.HTM)

Assessing composting as an effective means of sanitizing agriculture and horticulture waste.
MAFF Central Science Laboratory, Sand Hutton, York, Y0411 1LZ
(http://www.compost.org.uk/images_client/faq/plant%20health.pdf)

Two composting systems, which use waste biomass (agricultural wastes)
(http://www.rdrop.com/users/krishna/composti.htm)

Greenhouse gas emission from agricultural wastes
(http://www.agric.gov.ab.ca/sustain/grnhouse_gas/greenhousegas0102.html)

Support system for on-farm composting; Characterization & remediation
Agricultural wastes; Pathogen transport and dissemination
(http://iapreview.ars.usda.gov/research/programs/usmap.htm)

Farm management of animal wastes and other agricultural effluents
Agricultural systems 2001 2002
For on-farm composting 2001 2002 Fate
(http://iapreview.ars.usda.gov/research/programs/programs.htm)

Developing linkages for farm composting and use of municipal yard wastes
Crop and Soil Environmental News, December 1996
(http://www.ext.vt.edu/news/periodicals/cses/1996-12/dec1204.html)

International workshop on compost production and use
Compost quality
(http://www.agnet.org/library/article/nc132c.html)

On farm composting work shop
Market goals
(http://www.cwc.org/wood/wd973fs.pdf)

Large-scale composting of industrial and agricultural wastes
(http://www.wastenot-organics.wisc.edu/library/compostart/industrial.htm)

The aerobic composting of agricultural and industrial wastes.
(http://www.engr.usask.ca/societies/csae/protectedpapers/c0155)

Disposal or land application on a farm of the agricultural waste
(http://www.dnrec.state.de.us/DNREC2000/Divisions/AWM/hw/sw/pdf/sec02.pdf)

Use of compost in agriculture
(http://www.remade.org.uk/Organics/organics_documents)

On farm composting agriculture and biological engineering
(http://www.age.psu.edu/extension/factsheets)

Agricultural waste control regulation
(http://www.qp.gov.bc.ca/statreg/reg/W/WasteMgmt/)

Science and engineering of composting: Design, environmental, microbiological and utilization aspects
BioCycle
419 State Ave.
Emmaus, PA 18049
610-967-4135
610-967-1345
biocycle@jgpress.com
(http://www.jgpress.com/)

WOODS END PUBLICATIONS

Bavarian on-farm composting
(http://www.woodsend.org/ebersbe.pdf)

The Dewar self-heating procedure
(http://www.woodsend.org/dewar.pdf)

Sustainability of modern composting: Intensification versus costs and quality
(http://www.woodsend.org/sustain.pdf)

Compost use for control of powdery mildew (*Uncinula necator*)
(http://www.woodsend.org/will2.pdf)

Volatile organic acids in compost
(http://www.woodsend.org/voa-new2.pdf)

Dynamic chemical processes in biodynamic horn-manure preparation
(http://www.woodsend.org/bd_500.pdf)

Living compost - Living carbon
(http://www.woodsend.org/live-com.pdf)

EPA solid waste management: Composting resources
Innovative uses of compost: Disease control for plants and animals
(http://www.epa.gov/epaoswer/non-hw/compost/disease.txt)

Innovative uses of compost: Erosion control, turf remediation and landscaping
(http://www.epa.gov/epaoswer/non-hw/compost/erosion.txt)

Innovative uses of compost: Reforestation, wetlands restoration and habitat revitalization
(http://www.epa.gov/epaoswer/non-hw/compost/reforest.txt)

Analysis of composting as an environmental remediation technology
(http://www.epa.gov/epaoswer/non-hw/compost/analysis.txt)

Appropriate technology transfer for rural areas (ATTRA) publications
Compost teas for plant disease control (ATTRA)
(http://attra.ncat.org/attra-pub/comptea.html)

Worms for composting (Vermicomposting) (ATTRA)
(http://attra.ncat.org/attra-pub/vermicom.htmlattra-pub/vermicom.html)

Disease suppressive potting mixes (ATTRA)
(http://attra.ncat.org/attra-pub/dspotmix.htmlattra-pub/dspotmix.html)

Organic potting mixes (ATTRA)
(http://attra.ncat.org/attra-pub/potmix.htmlattra-pub/potmix.html)

Alternative nematode control (ATTRA)
(http://attra.ncat.org/attra-pub/nematode.htmlattra-pub/nematode.html)

Sources for organic fertilizers and amendments (ATTRA)
(http://attra.ncat.org/attra-pub/orgfert.htmlattra-pub/orgfert.html)

Composting animal manures: Precautions and processing
University of Hawaii, College of Tropical Agriculture & Human Resources
(http://www.ctahr.hawaii.edu/publications/freepubs/pdf/AWM-1.pdf)

In-vessel composting research & development and Rotating tank in-vessel composting demonstrations, Texas A&M University
(http://www.TAMU-commerce.edu/coas/agscience/dept-res.html)

Organic composting for horticultural use
North Carolina Cooperative Extension Service
(http://www2.ncsu.edu/bae/programs/extension/publicat/wqwm/ebae171_93.html)

Composting manure and other organic residues
University of Nebraska Cooperative Extension Service
(http://ianrwww.unl.edu/pubs/wastemgt/g1315.htm)

Utilization of organic wastes: On-farm composting
West Virginia University Extension Service
(http://www.wvu.edu/~agexten/wastmang/utiliow.htm)

A cost analysis of municipal yard waste composting
Department of Agricultural and Resource Economics, North Carolina State University
(http://www.ces.ncsu.edu/resources/economics/compost/)

Effect of windrow composting on weed seed germination and viability
(http://www.agric.gov.ab.ca/research/ari/matching/96-97/96m018.html)

Low cost compost screener
Producer Grant, Southern Region SARE
(http://www.carolinafarmstewards.org/compostmixer/)

Urban and peri-urban agriculture publication
(http://www.sustainweb.org/urban_chsum.asp)

Farm-based composting: Manure and more, NRAES-150, was produced by the Cornell Waste Management Institute
(http://www.nraes.org/publications/nraes150.html)

AGRICULTURAL AND FOOD ENGINEERING WORKING DOCUMENTS

1. Meeting consumers' needs and preferences for fruit and vegetables, 2005 (E)
2. Food product innovation, 2006 (E)
3. Agro-industrial parks, 2006 (E)
4. Conservation agriculture in northern Kazakhstan and Mongolia, 2006 (E)
5. Small mills in Africa, 2006 (E)
6. Waste management opportunities for rural communities, 2007 (E)

Ar	-	Arabic	Multil - Multilingual
C	-	Chinese	
E	-	English	* In preparation
F	-	French	
P	-	Portuguese	
S	-	Spanish	

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Web site: http://www.fao.org/ag/ags/index_en.html