The Organic Waste Flow in Integrated Sustainable Waste Management

Tools for Decision-makers
Experiences from the Urban Waste Expertise Programme (1995-2001)

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Cover photos:

Photo 1: Packed compost in plastic bags, Argentina – *Photo: ©WASTE, Inge Lardinois*

Photo 2: Neighbourhood composting, Brazil – *Photo: ©WASTE, Inge Lardinois*

Photo 3: LADAMU, a GIE (MSE) in Mali that provides a variety of urban waste management services – *Photo: ©WASTE, Arnold van de Klundert*

The Organic Waste Flow in Integrated Sustainable Waste Management is part of a set of five Tools for Decision-makers. The other four documents cover:

- Integrated Sustainable Waste Management - the Concept
- Community Partnerships in Integrated Sustainable Waste Management
- Micro- and Small Enterprises in Integrated Sustainable Waste Management
- Financial and Economic Issues in Integrated Sustainable Waste Management

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Gouda, May 2001

Arnold van de Klundert
UWEP Programme director

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Chapter 1. **What is this Document**

1.1 Overview

This document is an invitation to identify and understand the role that composting can play in integrated waste management systems. It is one of a series of decision-makers' guides to various aspects of waste management in Southern ('developing') and Eastern European ('transitional') countries. It has been written to synthesise the experiences of the Urban Waste Expertise Programme 'UWEP' and to make them available to political and technical decision-makers. It is primarily designed for decision-makers in local authorities, municipal governments, and regional or provincial authorities, but it may also be useful for private entrepreneurs, community groups, local experts and agriculturists.

The structure of this document is designed to allow for selective reading: you can skip the sections that do not apply to your situation and go directly to the ones that interest you.

Chapter 1 is an introduction to the document, and provides an overview. Then it outlines how composting can be useful for the municipal manager. The third section places composting in the context of Integrated Sustainable Waste Management, the framework concept that has been developed out of the UWEP experience.

Chapter 2 is a general introduction to composting, and defines some key concepts and terms.

Chapter 3 explains the basic choices, or parameters, which should be taken into account when deciding to begin a composting project. These choices include technology, materials, marketing strategy, and the like. Our focus on cities in the poorer countries leads us to focus the rest of the document on the simpler, more reliable low-cost and low-technology approaches, leaving aside enclosed systems since they are most of the time inappropriate from a resource availability and sustainable perspectives, they require training, expertise and operation and maintenance costs, which are real limiting factors. This chapter is illustrated with examples and lessons that illustrate the key points for making the decision.

Chapter 4 presents the basic operational steps in composting, explaining what happens in each step, and providing information on what is involved in the process. If you do not know very much about composting, you might want to read this chapter before you read Chapter 3. This chapter is not sufficient to actually guide you to operate a composting facility, but it will give you an idea of what such a facility has to include.

Chapter 5 examines the economic and marketing aspects of composting in the context of municipal waste management, analysing to what is paid for and how. The marketing strategy is based on product, price and promotion. These aspects are key factors in determining the sustainability of a composting enterprise, since without a market – or a use that substitutes for a market – composting just becomes an expensive form of landfilling.

1.2 Composting for municipal managers

This document is addressed to the municipal manager who:

- Believes that composting has a role in his or her waste management system, but is not sure what that role is or how to go about managing it.
- Is looking for first hand basic knowledge on composting approaches in use in the South.
- Would like a basic overview of key points on the technical, economical and marketing components of composting.
- Is not necessarily planning to construct and operate a city-owned composting plant, but who is willing to support (and would like better to understand) composting initiatives by other stakeholders (non-governmental organisations – NGOs -, micro and small enterprises – MSEs – and community based organisations – CBOs -) and use of compost in other municipal bodies, such as horticultural departments, parks and gardens.
- Is willing to improve health, both human and environmental.
- Is actively involved in composting and wants to improve and optimise his or her current practice, based on low-cost composting technologies.

Santa Maria Municipality, the Philippines
The municipality of Santa Maria teamed with an entrepreneur and signed a **memorandum of agreement** for the operation of a composting plant. The town approved the use of 2000 square metres of public land for the plant within the 2.5 hectares municipal landfill. It allocated a budget for equipment and building expenses while the enterprise is responsible for the other duties.

Composting in Yemen
In Dhamar city, Yemen, a private contractor has shown interest in buying and marketing the compost and adapting the composting process and therefore established a clear relationship and a contract with the municipality to have direct access to the land of the composting plant and to the waste.

1.3 What is Integrated Sustainable Waste Management (ISWM)?

Integrated Sustainable Waste Management (ISWM) is the leading concept of the Urban Waste Expertise Programme (UWEP). Integrated Sustainable Waste Management is a concept that has been articulated and refined in the Urban Waste Expertise (UWEP) Programme; it is the result of working more than 15 years on waste issues in Southern countries, and coming to understand that it is not the technical issues, but the other aspects of waste management, which are most likely to influence the success or failure of interventions. ISWM addresses the management of the solid waste stream as a set of resources rather then waste, thus ISWM considers the waste stream not as a homogeneous mass but as a set of individual materials that can be handled in different and appropriate ways to maximise recovery and minimise disposal.

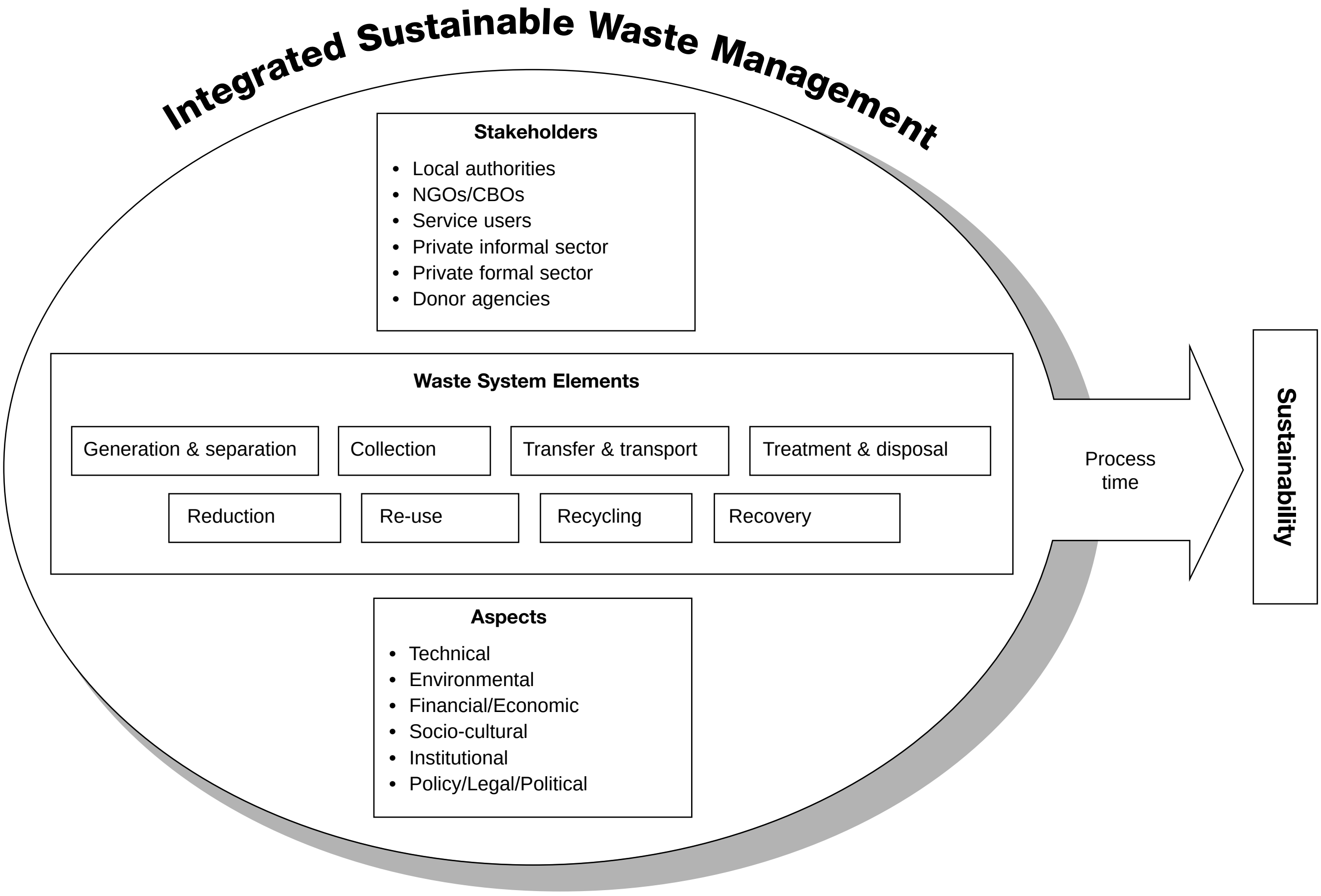

Figure 1. Integrated Sustainable Waste Management

WASTE has been developing ISWM for multiple purposes: (1) as an analytic framework for understanding waste management systems; (2) as an assessment methodology for predicting feasibility and sustainability; (3) as a description of an urban development process. Figure 1 illustrates the three dimensions, six aspects and eight waste system elements of ISWM.

This document focuses on the role of organic waste management, one approach to the waste element ‘processing and treatment’, which is one of the eight waste system elements. The waste system element ‘recycling’ is also mentioned in Figure 1, since composting is a form of recycling.

While there are recovery and recycling systems in place in most developing countries, the organic waste stream remains the largest fragment, and the one that has the least chance of being recovered without an intervention.

Chapter 2. **Composting in Municipal Waste Management**

For purposes of this document, composting is defined as a method of waste management, in which organic waste materials decompose in a controlled environment. Composting is a natural micro-biological process where bacteria break down complex organic molecules and release water vapour and carbon dioxide resulting in organic materials and mineral nutrients to be used for improving soils and aiding in the growth of plants.

The outcome of the active biological activity is a material or product called compost. Compost is a safe and/or ready for use on native soils. It smells like earth. It is not a fertiliser, because the level of nutrients it contains, is rather low.

The high organic content in the municipal waste stream of developing countries is ideal for composting, but there is not enough accurate, unbiased information available to municipal managers, who may be familiar with composting in agriculture, but do not see it as a way to solve their urban waste problems.

Composting in waste management is different from agricultural composting because:
- It involves a greater variety of materials selected among the waste stream.
- It is a controlled process, designed to deliver finished compost in a shorter time.
- The mineral value of the compost is lower, making it a good soil conditioner but not a rich fertiliser.
- The rate of action of the micro-organisms is controlled by regular turning or aeration.

2.1 Compost and the municipal manager

Composting is interesting to the municipal waste manager because:
- Putrescible (decomposable) organic waste represents the largest fraction of the domestic waste stream in most cities in Eastern Europe and the South.
- Recovery of organic materials through separation and composting decreases the amount of waste requiring final disposal, saving landfill space and prolonging the life of existing landfills and dumps.
- Composting can accommodate and help to manage seasonal fluctuations in waste volume or composition, combining such diverse waste streams as leaves, kitchen wastes; agricultural and crop residues; food processing wastes; and excreta sludge.
- Health hazards[1] associated with untreated disposal of putrescible wastes decrease significantly under controlled conditions of composting, where the heat of the bacterial action actually sterilises the materials; kills pathogens; and deactivates weed seeds and fungal spores.
- Managed composting of organic waste under controlled conditions can redirect or manage materials that are the greatest sources of nuisance and pollution[2] at landfill sites.

2.2 Benefits of compost use in agriculture, horticulture and open space management

The use of compost as a **soil amendment** (soil conditioner) in agriculture, horticulture, and open space management has the following significant benefits:
- While its nutrient levels are low in comparison to chemical fertiliser, compost is a source of valuable mineral and organic materials, including slow-release nitrogen.
- Research has shown compost is most effectively used with crops when it is used in conjunction with fertiliser, because it provides the ‘spurt’ requirements for the younger plants and the compost allows more of that fertiliser to remain in the soil matrix, rather than being washed away, resulting in more efficient use of the fertiliser and less need for large quantity fertiliser additions.
- Application of compost can improve the soil structure since compost mitigates compaction from high-use, maintaining the ability of air and water infiltration to the root zones. It can therefore be applied to sports fields; municipal parks; green areas; cemeteries; golf courses; central city plazas and plantings; municipal gardens and nurseries.

[1] Transmission of diarrhoea and dysentery by houseflies, breeding of mosquitoes and contamination through scavenging animals.
[2] Odours, water pollution, gas emission.

- Due to compost, particle adhesion increases on a slope and the raindrop erosive force is mitigated by the absorbing power of a high tilth soil. This makes it a good choice for erosion control on hillsides, in forested highlands, in mine and other land reclamation, and for use as daily or final landfill cover.
- Compost can be used to re-establish soil where it has been completely loss, like for example mines, gravel pits and the like.
- Blending of compost with agricultural chemicals can reduce the required levels of fertiliser, herbicide and fungicide.
- Compost lasts longer than other traditional fertilisers, usually 3 times longer; the nutrients are released over a period of three to ten years, depending on the local conditions and the intensity of use, becoming a kind of 'soil bank'.
- Compost improves the water holding capacity for soil prone to drought cycles and conversely the water infiltration and drainage improvement in soils prone to rainy seasonality.

2.3 Overview of composting technologies

There are about 10 basic composting 'technologies', all of which are based on the biochemical activity of soil microbes and bacteria. One basic distinction is between aerobic composting, which proceeds in the presence of oxygen, and anaerobic digestion, which is based on the activities of bacteria which do not require oxygen. This document is limited to the discussion of aerobic composting.

Chapter 3. **Options in the Selection of Composting Technologies**

This chapter presents the most basic options or parameters for choosing composting technologies, the materials to be composted, the collection strategy and how it integrates with the waste management system, the type of compost to be produced, and the manner in which it will be marketed. Each sub-section describes one set of choices. For example, if you already know what materials you will use, you can skip that section.

This chapter is closely related to the material in Chapter 4. If you want to understand the steps in most composting processes, you might want to read Chapter 4 before this one.

There are two fundamental types of composting techniques: open or windrow composting, which is done out of doors with simple equipment and is a slower process, and enclosed system composting, where the composting is performed in a building, a tank, a box, a container or a vessel. In-vessel systems are oriented towards less operators and direct contact with materials while enclosed system may be utilised due to climatic conditions, need for visual impact mitigation or better control of the occurrence of off site nuisance and health impacts in a tropical climate. They are able to deliver finished compost in a shorter period of time. Open systems are simpler, less expensive, use less energy, but require more space and more time in order to produce finished compost. They also require greater oversight management so as to avoid potential health, environmental or nuisance conditions.

3.1 The most fundamental choice: open versus enclosed composting

Within aerobic composting, all technologies can be classified as belonging to two basic technical approaches:
- The open, or windrow composting approach, with active piles or passive aeration
- The enclosed or in-vessel composting method

The technical principles of each category are shown in the following figure.

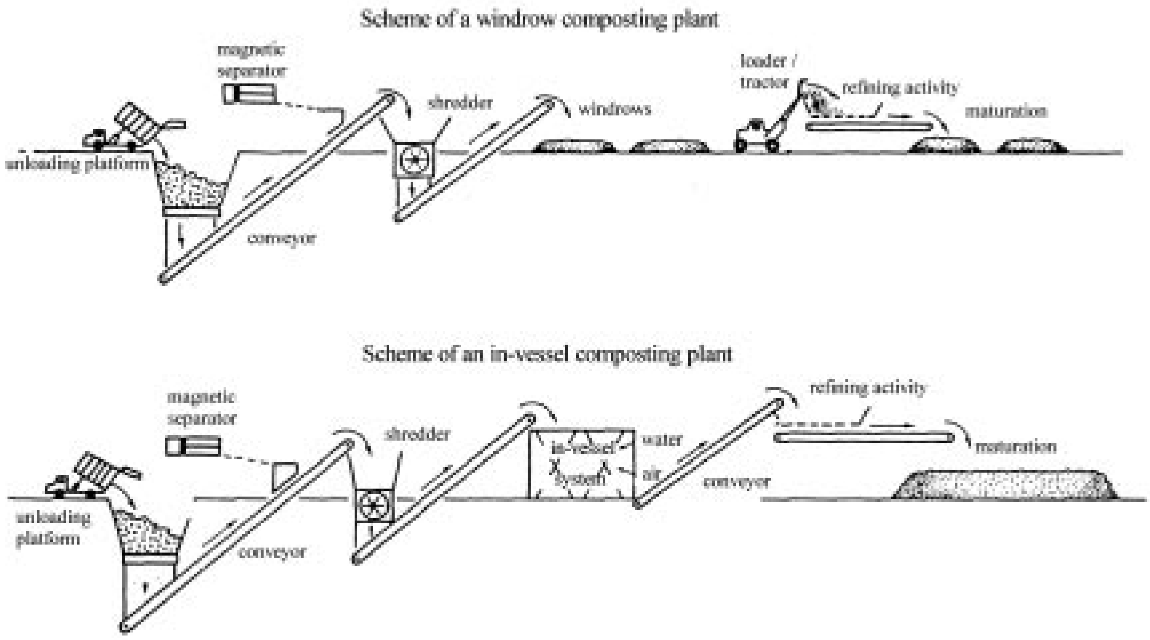

Figure 2. Schematic presentation of windrow and in-vessel composting plants

Source: Le compost, Michel Mustin, 1987

3.1.1 In-vessel or enclosed systems

In-vessel systems, such as drum or agitated bed technologies, or any technical system enclosed in a building, require complex equipment. These systems are highly engineered, capital intensive and require day to day management due to the automated systems and the design which has necessarily incorporated mitigation of potential worker health, environmental impact and nuisance conditions. They also use substantial amounts of energy. On going operation and maintenance is critical and less forgiving than more passive approaches and it requires access to specialised pieces of equipment that usually have to be manufactured and delivered at a high price. The equipment may have been designed for specific climatic conditions and may not be universally applicable. They allow for the use of less land and they produce compost in a shorter time than open systems. Automated in-vessel systems can not respond always to the realities of socio-economic realities of different locations in the developing world (e.g. limits of education, limits to existing institutional infrastructure support, labour rich/capital poor economies). Their operating costs usually start at US $ 40 per ton, for the least expensive variant; more expensive systems can cost up to $ 100 per ton.

3.1.2 Open or windrow systems

Open composting processes are simpler, require less capital, and use less energy. They generally rely more on land and labour and less on machinery. They use to require quite a lot of land, and produce compost in a longer period of time than enclosed systems. In the labour-rich and capital-poor cities of Eastern Europe and the South (where enclosed systems have a rich history of failure) they are usually more reliable and suitable to local needs and the capabilities of local authorities to sustain operations over a longer period of time. The exception is when there is a shortage of available land, or in some cases when the materials to be composted are dangerous and require intensive management. Operating costs range from US $ 5 to US $ 20, depending primarily on the accessibility of the site and the frequency of turning. compares the main parameters governing this basic decision.

Parameter	Open or windrow process	Enclosed or in-vessel process
Capital cost (for the same flow of materials)	• Low to medium cost of equipment & infrastructure	Medium to high depending on what we see as an enclosure
Technical applicability and durability (after training)	• Multifunctional • Extensive capacity • Easy to operate • Long life time • Can accommodate many types of materials in one system	• Inflexible • Simple to operate, difficult to maintain • Renew of equipment and machinery more frequently but not necessarily any less than a mobile piece of equipment used for windrows
Equipment, personnel, energy	• Use of equipment that municipalities have access to already • High labour to capital ratio means continued or increased employment	• Requires significant capital purchases • High capital to labour ratio usually results in few workers • Often energy intensive
Design requirements Environmental issues	• High land requirement • Accommodate flexible volumes • More selectively in sites and initial design due to possible on and off-site impacts • Limited control of air and water discharge • Limited control of vectors and pest attraction	• Low land requirement • Limited flexibility in volume • Less constraints in selecting sites due to built in controls for on and off site impacts • Significant control of air and water discharge • Better vector attraction control
Source of 'technology'	Necessary equipment is present in most municipalities.	Specialised equipment most often acquired from international companies.
Initiative and management	Can be initiated and managed by municipalities, individuals, farmers, NGOs, CBOs, civic organisations, MSEs or other formal or informal groups.	Level of technology and equipment usually demands the involvement of the municipality, the national government (as aid recipient or bank guarantor) and international suppliers.
Cost of composting	5 to 20 US $/ton	40 to 100 US $/ton
Commonest technologies	• Active windrows • Aerated static piles	• Agitated bed • 'Hot Box' • Drum composter

Table 1. Comparison of open and in-vessel systems

3.2 Feedstock choices

The second basic choice in composting is the choice of materials to compost. This can be a choice of **waste streams** to be composted, and also of specific **waste materials.**

The choice of the organic materials to be composted depends first on the goal of composting. Where the goal is waste management, the largest determinant is the available materials in the household waste stream, **which are not already being captured by other recovery activities.**

When there is a commercial interest in the compost product, this choice will include an assessment of the other available materials, focusing on **quality, quantity and accessibility.**

3.2.1 Domestic, institutional, industrial or commercial materials

The origin of organic material is not only domestic. There are opportunities to compost waste from commercial activities or industries: aquaculture, agriculture, horticulture, livestock and slaughterhouse, and food processing; forestry and forest products; sugar, wine, brewery and alcohol production; and the oil industry.

The list of materials suitable for composting is almost endless because composting is a flexible process. Very wet material with little structure like fish processing waste can be composted if managed properly by adding large amounts of other materials, special handling and odour management.

3.2.2 Faecal matter in compost

Another basic choice is whether to include only domestic solid wastes, or to include faecal materials, septage, latrine and wastewater treatment plant sludges, and the like. Inclusion of these materials introduces some complexities into the composting process and raises the requirements for strict control, but it also gives composts of much higher nutrient value.

3.2.3 Different types of compost

Because there are different types of soils, crops, weather, location and farming methods, there is a need for different compost. Nutrient values and physical characteristics define the quality: concentration in N, P, K and organic matter, particle size (coarse, fine, and extra fine), stability and maturity. They are also other parameters such as sand content, salt content, presence of heavy metals or additives that limit the wide ranging use of compost.

The main categories and their definitions belong to the following list:

- Raw compost, which is constituted by waste not decomposed or not disinfected, with foreign objects.
- Fresh compost or unstable compost, which is going through early stages of a biological degradation process or still going under rapid decomposition and can tie up nitrogen from the soil.
- Stable compost with nutrients available for release into the soil.
- Special compost which is a compost with special requirement such as screening or ballistic separation, addition of mineral substances.

Following are the physical qualities of two different types of compost:

	Compost with very few impurities	Compost with a lot of impurities
Organic content	70 to 75%	25 to 30%
Metal content	0%	0 to 1%
Glass, stones	0 to 2%	Up to 40%
Plastics	1 to 2%	5%
Impurities (>2mm)	3%	44%
Impurities (>5mm)	1 to 2%	Up to 20%

Table 2. Guidelines for compost quality

3.3 Source of organic materials: from source separation, co-collection or mixed waste

The high organic content in the municipal solid waste stream is ideal for composting. However, the municipal waste stream contains increasing quantities of glass, plastics, metals and hazardous materials, which make operations difficult and can contaminate the finished compost.

The next key decision is whether the materials will be (1) **sorted at the composting site,** (2) **sorted** by the collectors **during the collection process** or (3) **separated at source,** where the generators hold them apart for **separate collection**. Each of these approaches has a range of consequences and implications for the type of compost produced and the manner in which it is handled.

3.3.1 Post-collection sorting at the site When raw materials are wet, separating contaminants from the raw material at the compost site ('sorting', or 'post-collection separation') is inefficient in the case of hazardous materials that can permeate an entire batch (e.g. liquid form) since in most cases the contaminants have already affected the quality and purity of the compostable organic fraction. However, for many heavy metals and contaminants, it is the composting environment and the associated activities of mixing and size reduction that subsequent to tipping that causes many of the contamination problems of non source separated material. Composts made from organic materials that are separated from mixed domestic waste after collection tend to contain a four to ten times higher concentration of toxic contaminants than compost made from source separated organic. However, many of these can be caught in initial screening before the active composting.

3.3.2 Sorting during collection

This approach makes the collection workers responsible for sorting the materials, which the households have mixed together. This system can work well and they are fewer to train in regards to what should be separated out for composting. It also works well when the workers then have the right to sell the materials for their own benefit. It also can be efficient when the waste stream itself has only a few categories of waste, or when there has been a partial separation by the household, so that, for example, wet organic garbage is in one container, and dry components, including packaging materials, are in another. Sorting during collection slows the collection process, but it can make it more efficient to transport the materials.

3.3.3 Separation at source

Asking generators to separate the materials at source can work well, but requires a focused and on-going communication programme or campaign, so that people know exactly which materials should be held apart, and how they should be stored and handled. Planning for **source separation** requires intimate knowledge of how households work, so that what people are asked to do is consistent with religious and cultural restrictions and practices. The effort is worth it because source separation is seen as environmentally and technically better and it improves overall economics of the system as well as the quality of the final compost.

Photo 1. Source separated organic waste in Argentina

Photo: ©WASTE, Inge Lardinois

Even with the best of intentions, contamination can not be avoided, thus some sort of quality control which may include front or back-end screening may be necessary in most situations and of course, this is also driven by the end-use.

These three different approaches are compared in Table 3. Note that in all cases, some final sorting for quality control will be necessary at the site itself.

	Advantages	Disadvantages
Separation at source by households + quality control at the composting site	• Low probability to have heavy metals in the composition of the compost • Low probability to have plastics • High probability to increase the organic matter content	• Addition of structural material necessary • Need for post process screening may be avoided
Separation at source by collectors + quality control at the composting site	• Low probability to have heavy metals in the composition of the compost • Low probability to have plastics • High probability to increase the organic matter content	• Addition of structural material necessary • Post-process screening may be necessary • Higher cost of collection
Sorting at the composting site	• Compost contains inert and structural materials, which can aid in passive aeration of composting mass • Collection cost low	• Compost can be toxic for the plant or the roots by the presence of heavy metals • Compost does not look like soil earth material by the presence of plastic

Table 3. Comparison of source separation alternatives

Photo 2. Separated organic and non-organic waste is disposed in composting rooms, Guatemala
Photo: ©WASTE, Jeroen IJgosse

Photo 3. Workers at delivery site of source seperated organic waste, Argentina
Photo: ©WASTE, Inge Lardinois

Composting in Burkina Faso
In Wogodogo community, Burkina Faso, collectors sort during collection; they put separately organic material, in a rice bag and put aside the remaining waste which will be temporarily disposed at a transfer station. They also collect green waste and animal waste from houses.The three materials are then composted in a small lot within the neighbourhood. This way they avoid to incorporate dust and inert compounds in the compost mixture. The analysis of nutrients has shown that percentage of nitrogen, phosphorus, potassium and organic matter are very satisfactory. The C/N ratio is about 22%.

Composting on the Pacific Islands
In the Philippines, solid wastes are segregated by the vendors and market employees. In Indonesia, household solid wastes and market wastes are sorted by hand into recyclables, compostables and residues.

Photo 4. Workers are sorting out non-organic waste at compost site, Brazil
Photo: ©WASTE, Inge Lardinois

Photo 5. Sieve trommel in Accra, Ghana
Photo: ©WASTE, Arnold van de Klundert

3.4 The co-composting option: options for inclusion of human excreta in composting systems

A key decision in the development of a composting system is whether to design the system for co-composting of domestic waste with a waste stream consisting of human excreta in some form. Domestic waste in the South is normally quite likely to have some level of animal or human faecal matter in it – from livestock in the household compound, from open defecation, and the like. This waste cannot be avoided. However, since it is present in relatively small quantities, it does not affect the overall waste management system.

Beyond this, though, the decision to include a faecal waste stream does introduce important questions about collection, design, operations, and the type of compost that you are seeking to produce. There are similar choices to be made, with similar implications, about the option to incorporate grey or black water from water from households, or discharge water from food or wine processing or a distillery. They can be generated by industrial processes or by domestic activities.

The choice to use excreta means that certain operational decisions have to follow. For example, turning has to be optimised to assure pathogen kill. The application of supplemental fertilisers may need to be reduced, since the nutrient content is higher. When human excreta is included, the resulting compost can be best used for growing trees, food grains, and cereals and on crops with high market value. Table 4 shows the pros and cons of this option.

Advantages	Disadvantages
• Addition of excreta improves the moisture content. • Addition of excreta improves the nutrient content of the compost, especially its nitrogen content, making it more like fertiliser. • With good management, composting can disinfect excreta without any use of chemical compounds.	• It has been observed that vegetables grown with composted excreta are underdeveloped. • Pathogens may be present in the soil and on the crops after spray or application of compost containing human excreta.

Table 4. Advantages and disadvantages of including human excreta

3.5 The raw waste option: landspreading of organic materials without treatment

There is a basic decision to be made about whether to 'bother' with composting, or to simply spread raw waste on cereal or other crops that require large quantities of organic nutrients. In the landspreading option, there is no process of composting, and no compost is produced. The raw, uncomposted waste from transfer stations or collection vehicles is directly discharged onto the field. Table 5 lists the pros and the cons of raw waste landspreading[3].

Pros	Cons
• The organic matter content is higher than in mature compost. • Being untreated, the costs of acquiring such waste in comparison to treated product are relatively low. • On arid soil, the improvement of the soil is more evident in soils amended with fresh residues than in those with compost due to a higher mineralised rate of carbon fraction.	• Such waste products likely contain some level of pathogens and the same restrictions applied for the case of excreta. • Transporting bulky materials – contaminated with non-organic items and materials – is expensive. • There is great variation in the nutrient content of untreated urban solid waste, which may include undecomposed materials that can damage plants. • Land application of non stable organic material can rob the soil of available micro-nutrients necessary for plant growth.

Table 5. Pros and cons of landspreading raw materials

[3] Landspreading:

1. Restrictions required when landspreading raw materials, are summarized below.
2. Raw waste should be applied only on the surface because the pathogens injected into the soil surface may survive longer than the normal survival period.
3. Raw waste should be applied on isolated crop, in low density or remote areas to restrict the public from potentially coming into contact with the pathogens.
4. The waiting period between the time of application of raw waste and the period of harvesting the crops should be not less than one month.
5. Crops with harvested parts below the soil should have a longer waiting period than crops that do not contact the soil or that are not consumed before processing and not distributed as a food crop.

Chapter 4. **Steps in the Process of Composting**

4.1 Design considerations

Before composting begins, some basic decisions have to be made. These include finding and configuring a site, selecting materials to be composted, deciding how to combine them in recipes, and designing the process based on the maximum volume the site can handle.

4.1.1 Candidate materials for composting

Candidate materials for composting in the South include organic materials that:

- Are not currently being extracted or recovered.
- Are generated in large quantities in one place or in many adjacent places.
- Are generated close to the composting facility to reduce costs of transport.
- Are consistently generated, either throughout the year or on a predictable cycle, so that their availability, volume, and physical and chemical characteristics can be predicted.
- Are as raw (unprocessed) as possible, to allow optimum biological degradation.
- Do not have a recognised value added, so that they are available for low or no cost or even are deposited with a paid tipping fee.

In solid waste management, the availability of a material, or its presence in the waste stream, may be more important than its specific qualities.

4.1.2 Potential problem materials

Sand, dust and inert materials

The amount of these mineral fractions varies strongly depending on the waste generation patterns, the collection system, the collection area, the soil conditions in the region, and the relationship of waste collection to street sweeping activities.

Usually the mineral particles do not disturb the composting process, but they can be problematic for other reasons. First, they increase collection cost by adding weight to the collected materials. Secondly, they can damage parts of equipment or collection vehicles.

Salt

Soluble salts are not necessarily a problem in compost. The point at which salt concentration is considered excessive depends on its planned use and whether it will be blended with soil or other materials prior to spreading. If necessary, the following actions will inhibit any potential risk of salt concentration:

- Apply compost to fields at lower rates but more frequently.
- Apply compost to fields well before planting.
- Leach excess salts with irrigation water after compost is applied.
- Design into the process flow a storage time to allow natural precipitation to leach out salt before distribution.

Pathogens

Pathogens may be present in the waste before composting begins, especially if the waste includes excreta. If thermophilic temperatures are maintained, composting will kill pathogens and enteric parasites.

Heavy metals

Analysis in the North has shown that there may be high concentrations of heavy metals in compost made from mixed municipal solid waste. This has the potential to increase the concentration of heavy metals in the soil, so that leafy vegetables and root crops can uptake heavy metals too.

Once metals are present in compost, they are difficult to remove, so the preferred method of solving this problem is to work on prevention. Important strategies are:

- Implement source separation and separate collection.
- Promptly remove undesirable materials during all stages of composting.
- Use mature, well-cured compost.

4.1.3 Composting recipes

Once available materials have been identified, it will be necessary to decide on recipes: that is, how the materials will be combined to achieve optimal carbon-nitrogen ratios. There are two approaches to the selection of the best mixture. **The scientific approach**, based on calculations (shown in Table 6 and Table 7), and the following considerations:

- The quantity of nitrogen should be sufficient.
- The C/N of the mixture should be in the range of 25:1 - 30:1.
- The initial moisture content should be between 40% and 60%.

Column 1				Column 2			
Wet organic nitrogen rich materials, C/N, %Moisture (M) and %N				Dry organic materials with high carbon content, C/N, %Moisture (M) and %N			
	C/N	%M	%N		C/N	%M	%N
Mixed manure	16 to 25	60	2.15	Cereal and crop residues	50-120	20	1
Grass clippings	17	80	2-6	Straw	40-150	15	.5-1
Leaves	50	40	.5- 1.5	Sawdust	400	40	0.2
Slaughterhouse residues	3	40	2	Wood chips	400	30	0.1
Fish processing waste	3-5	76	7-10	Cardboard	560	8	0.2
Seaweed plants	5-27	70	1-2	Newsprint	400-850	20	0.1
Water hyacinth	20-30	70	2				
Sewage sludge	5-16	70	2-7				
Household excreta	6-20	70	5-6				
Pit latrines	20	60	6				
Vegetable residue	14-16	70	2-3				
Mixed municipal waste	34-80	30-80	0.6-1.5				

Table 6. List of materials and features

The field approach is based on the principle of mixing rapidly decomposing materials with slowly decomposing materials in the ratio of two to one by volume. Table 8 classifies the materials, and Table 9 shows some typical and commonly successful recipes.

Material	XX	YY	ZZ	Mix of XX + YY + ZZ
Fill A, B, C and calculate Q				
Weight kg	A	B	C	Q= A+B+C
Look at respective % Humidity (Table 6) and fill D, E, F				
% Humidity, moisture content	D	E	F	
Calculate X, Y, Z and M				
Weight of water (kg)	=A*D=X	=B*E=Y	=C*F=Z	M=X+Y+Z
Calculate U, V, W and AA				
Weight of dry material kg	U=A*(1-D)	V=B*(1-E)	W=C*(1-F)	AA=U+V+W
Select G, H, I from Table 6				
% Nitrogen	G	H	I	HH=BB/Q
Select J, K, L (between 30 and 50) from Table 6				
C/N	J	K	L	GG=FF/BB
Calculate R, S, T, HH				
% Carbon	R=G* J	S=H*K	T=I*L	
Calculate N, O, P, BB, CC, DD, EE, GG				
Weight of nitrogen kg	N=U*G	O=V*H	P=W*I	BB=N+O+P
Weight of carbon kg	CC=J*N	DD=K*O	EE=P*L	FF=CC+DD+EE
% Final moisture content	Choose II between 40 to 60%			II
Water to be added (litre)	Calculate JJ: The quantity of water (JJ) to add to the mix depends upon the desired moisture content (II), the total mass (Q) and the weight of water from each material			JJ=II/(1-II)*(Q-M)-M

Table 7. Calculation framework

Rapidly decomposing materials (high nitrogen)	Slowly decomposing materials (high carbon)
Vegetables produce	Wheat straw
Waste from the kitchen	Leaves from banana trees, mango trees, palm trees, peanuts
Manure	Paper, cardboard
Fish residues	Rice hulls, corn cobs
Grass clippings	Wood chips and sawdust

Table 8. Classification of materials by speed of decomposition

Organic materials	Proportions by volume
Organic materials from markets + animal manure + rice hulls / sawdust	1/1/1
Mixed domestic waste[4] + cow dung slurry	1/1 to 4/1
Vegetables market waste + press mud from sugar mills + slurry waste + water hyacinth	5/1/1/1
Municipal solid waste	1
Mixed waste from markets (fruit, vegetables, packaging materials, non organic refuse)	1
Institutional organic waste (composed by vegetable residual, dust and ashes, paper, grass packing)	1
Green waste + animal manure	1/1
Household organic waste + cow dung slurry	10/1 to 6/1

Table 9. Typical successful mixtures

[4] 60% organic and 40% plastic, glass, paper, iron.

4.1.4 Potential use of additives, inoculums, compost starter, effective micro-organism (EM) or accelerator

In addition to the waste materials themselves, composting always requires two additional feedstocks: water and oxygen. As long as these are present, composting will normally occur on its own, based on the micro-organisms available from the raw materials.

In case the quality of the mixture is not sufficient or in case it is necessary to accelerate the decomposition rate, to reduce the odours, control the flies and the rodents, inoculation or additives can be added. What to add (mature compost, earth, manure, blood meal, bones, micro-organisms) when to add (start, middle or end of the process) and how much to introduce depend upon analysing the deficiency.

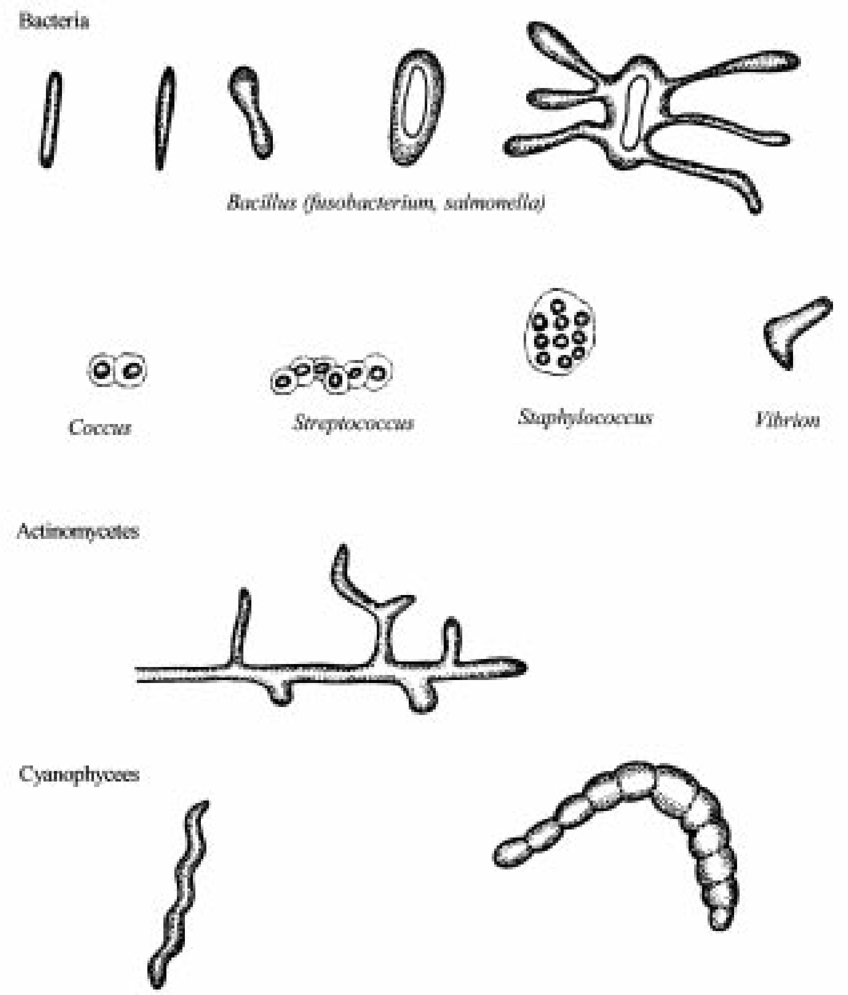

Figure 3. Existing micro-organisms in the compost pile

Source: Le Compost, 1987

4.1.5 Land availability

Land availability is one of the main design constraints on composting. The space required is proportional to the daily volume, the windrow/pile dimensions and volumes, the number of windrows/piles and the duration of the activities. In some urban and peri-urban areas, selection of a composting site is becoming a great challenge because public land is not always available and private owners are not willing to rent their properties for something ‘dirty’. Where land is scarce, the design should include:

- Increased turning to speed up the active composting phase, or the use of static pile composting with forced aeration.
- Larger curing piles to make better use of the space.
- Source separation to decrease the amount of organic materials arriving at the site.
- Where financial resources are sufficient, use of a vessel for more intensive composting.

Flexible compost management in Oagadougou, Burkina Faso
In Ouagadougou, one small enterprise has demonstrated great flexibility to adjust to a new situation when it lost its access to a composting site, and had to move to a spot 20 times smaller. After some technical and organisational adjustment, the enterprise is producing the same amount of compost as before. To allow space for processing and curing, they shifted to sorting by the collectors themselves at the point of collection. This way, they can do without their area for waste sorting and removal.

4.1.6 Size and configuration of composting pad

The layout of a composting site includes three main areas for active composting, maturation and storage. Size and configuration of the composting pad depends partly upon the quantity of materials to be processed. The duration of activities, including active composting, curing, and storage, is also important. In general, the higher the volume of materials, the more space that will be required for open composting. Using a vessel can reduce the space needed, but it greatly increases the cost.

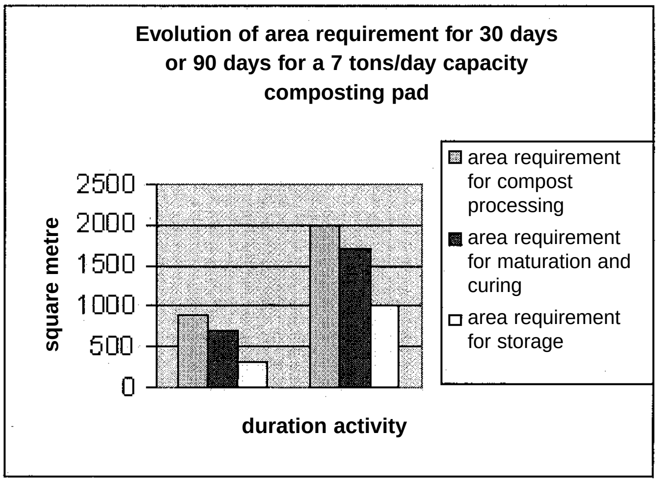

Figure 4. Sizing of composting area according to duration of activities

Typical duration for composting is 45 to 60 days, curing or maturation requires 30 to 120 days, and storage is dependent on the amount of time until the product can be marketed or removed for use.

A good site for composting is a piece of land that is nearly flat, with a good distance from ground or surface water. A 2% to 4% grade is ideal for composting: the windrows should go with the grade, not across it.

Additional criteria for selecting a composting site include:
- It is close to the area where the waste is generated and collected.
- The distance to the compost users (the market) is compatible with the equipment used for transporting the compost, such as hand- or animal-drawn carts, tractor with trailer, dump truck.
- Vehicles have reliable and easy access to the composting pad.

Some typical lay-outs are presented in Figures 5, 6 and 7.

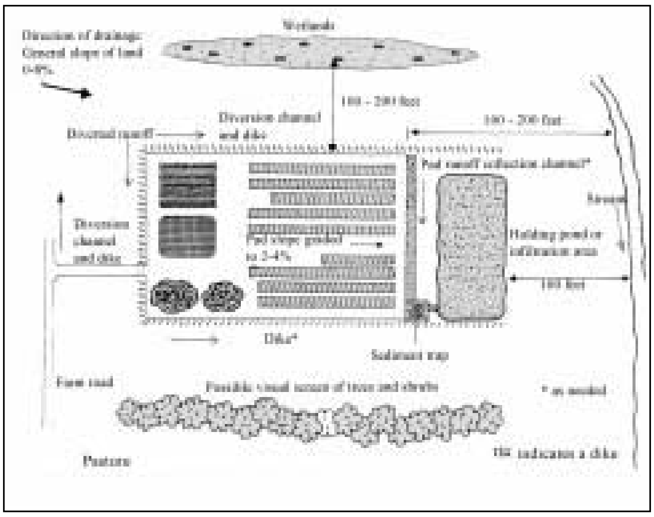

Figure 5. General site layout example 1, in feet. (3.3 Imperial feet = 1 metre)
Source: On-Farm Composting Handbook, NRAES-54, June 1992

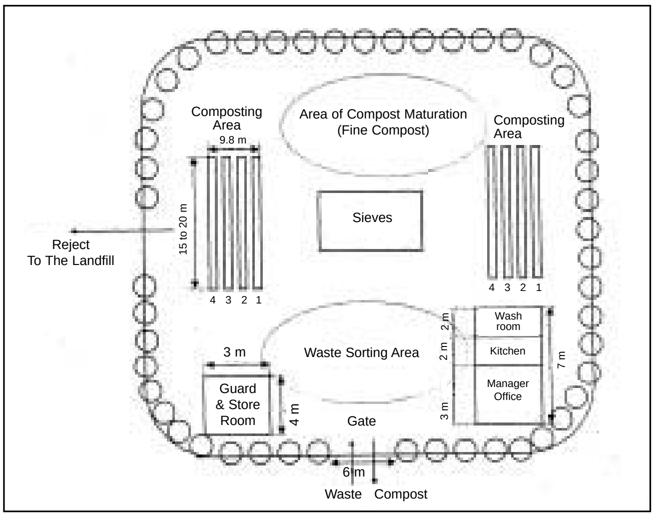

Figure 6. General site layout example 2
Source: WASTE 1998

Figure 7 presents a different, recently implemented design, called the half-circular layout. The conception of the new design is based on the juxtaposition of the turning and moving section in order that piled materials are transferred from one section to another until the pile reach the screening/storage location. This layout benefits to the operators and the management since motion time is decreased, allowing for a more efficient and functional management.

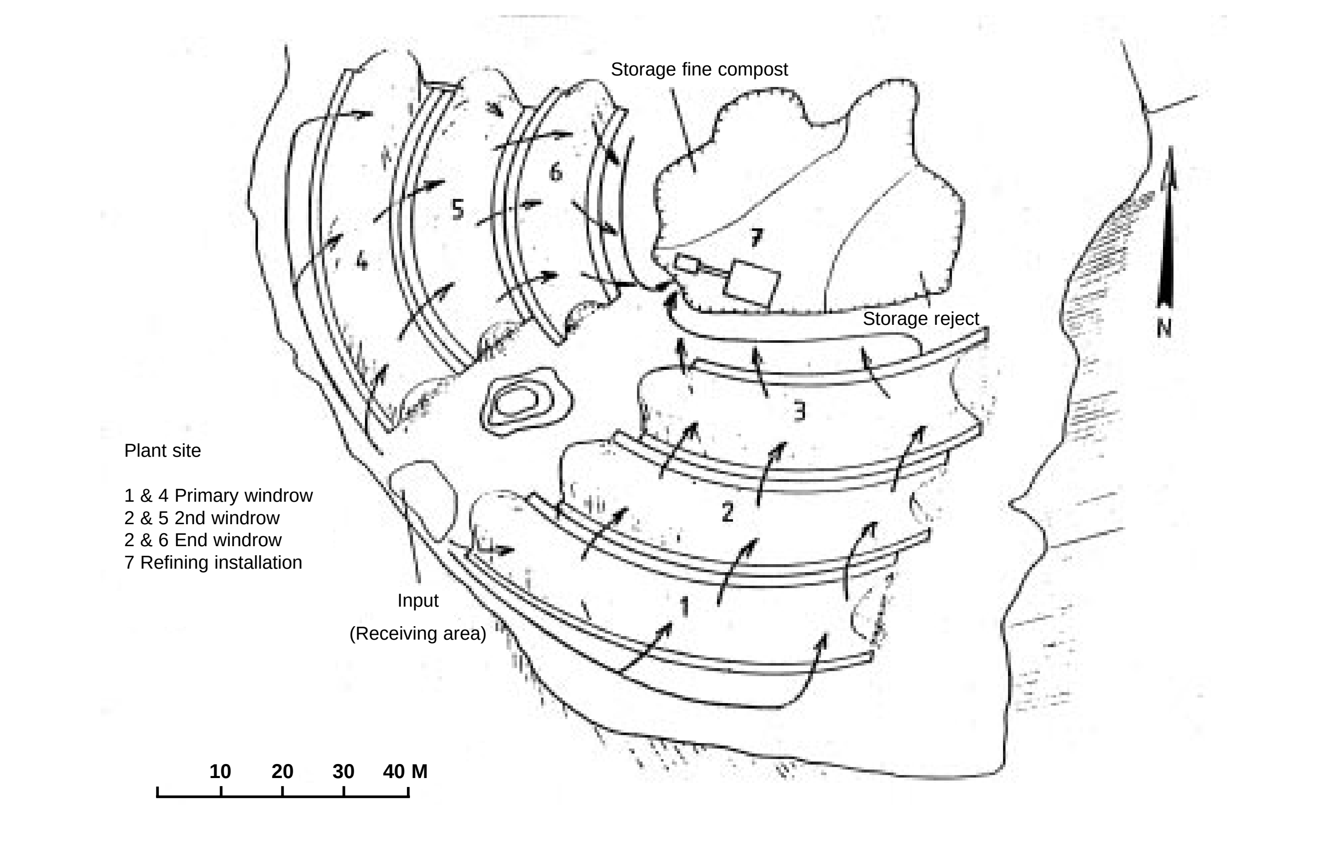

Figure 7. Half circular layout

Source: WASTE, 1998

4.2 Pilot composting operations

It is often wise to start a composting programme with the establishment of a pilot phase having low initial capacity. In this way, the willingness of households to source separate can be tested, and the composting operation can be built up from a small operation, which can be expanded or duplicated at other suitable sites.

Some design considerations for a composting pilot unit include:

- A pilot project in a large city should serve at least 10,000 households. This level is necessary to understand economies of scale.
- Intermediate implementation should follow after eighteen months to two years, the time needed to evaluate the evolution of the level of production in comparison to the demand and the associated operations expenses. This time span is also needed to design the full-scale operation. On a regional scale the intermediate step may also require to set up replicas of the initial pilot.
- This time span also allows for institutional support to be developed so that issues as land permits, credit, operator training and market development can begin to be established.

4.3 Process steps

Once the design process is complete, composting requires a series of distinct, but inter-related operations:

1. Receiving, including sorting and size reduction
2. Mixing
3. Pile and windrow formation

4. Watering
5. Active composting and turning
6. Curing/screening
7. Storage and marketing

4.3.1 Receiving, sorting, size reduction

Any compost site needs an area for receiving the incoming loads. In this same area, or next to it, the incoming materials can be sorted if necessary.

When a compost company sells equipment, a large part of what they are selling consists of specialised equipment for sorting and size reduction[5]. It is important to understand that there are many different ways to accomplish these operations, and no particular piece of equipment is absolutely essential.

In some cases, such as when the materials consist of large branches or cardboard, size reduction will also be necessary. Size reduction is likely to be necessary because composting occurs on surfaces. The more surfaces available, the more the compost bacteria can decompose the waste. Size reduction technology is almost always one of three types: a hammer mill, which beats the material to reduce it in size; a shredder, which uses rotating knives to cut the waste into strips; or a chipper, which has rapidly whirling blades to produce small flat particles. Hand cutting is also an option.

4.3.2 Mixing

If the materials will not be layered, they need to be mixed before the pile is constructed. Mixing can take place on compacted and dry natural ground or on a paved pad. Hand mixing requires a cart or wheelbarrow, with shovels, rakes, or pitchforks. Mechanical mixing works well with a wheel loader with front smooth bucket or tractor fitted with an earth-tilling device. Bulldozers are NOT appropriate, as they compress the materials and inhibit composting.

4.3.3 Pile and windrow construction

The construction of a compost pile is in first instance determined by the type of equipment available and the type of organic materials. To avoid odour problems, raw materials should be moved to the windrow within 24 to 48 hours of arriving at the site. In some cases, one pile or windrow is designed to take the materials that arrive at the site in a single day or in a single week.
Other considerations include climate – important in determining pile width and height, with cold and wet climates requiring larger piles to insulate the materials or prevent excess rain infiltration -; and the radius of action of the equipment and, where turning is manual, the accessibility to workers and equipment. These are critical in determining width and height of windrows and width of corridors.

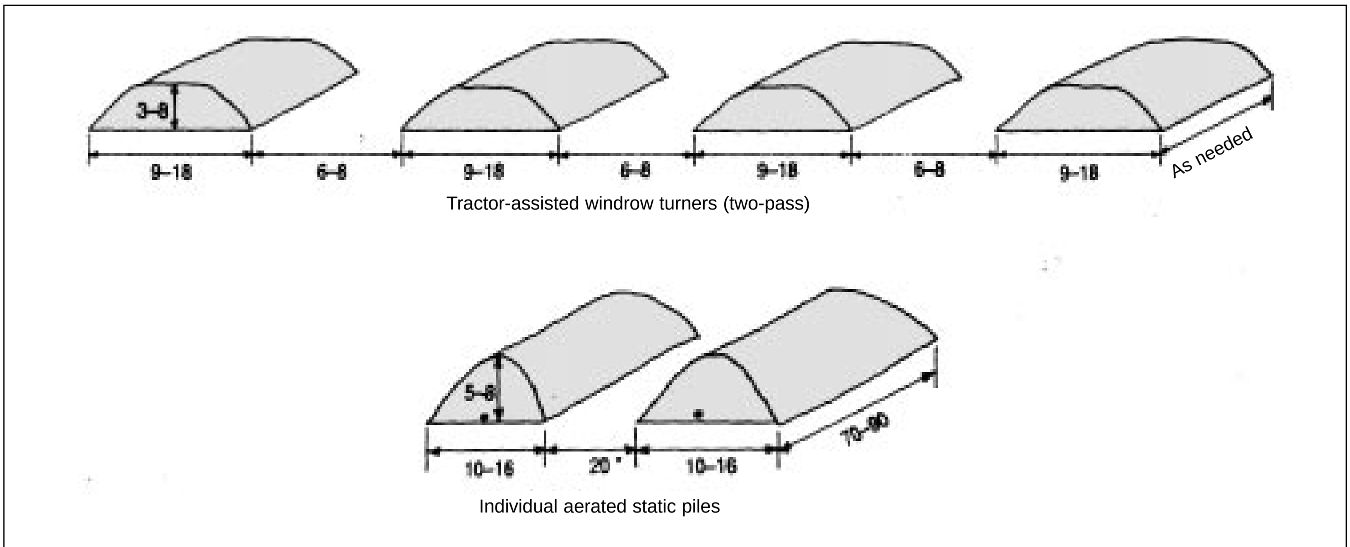

Figure 8. Pile shapes and spacing for windrows and piles, in feet (imperial measurement system: 3.3 feet = 1 metre).
Source: NRAES-54, 1992

[5] Size reduction is a very expensive operation if executed by drum shredders - mixers or hammer mills, because (1) they are capital-intensive; (2) they consume relatively large amounts of energy, and (3) maintenance costs – replacing or sharpening the rotating cutting disks or stationary knives – are high. In addition, there are strong indications that hammer mills increase contamination in the mix since all materials are cut no matter what. However, if they have to be used, the machinery should be made locally and should be mobile.

Photo 6. Direct discharge of organic waste from hand vehicle into windrows, Yemen.
Photo: ©WASTE, Arnold van de Klundert

Protection of the piles: by covers, roof, natural materials (banana leaves).
In tropical climates, piles and windrows may need covering to protect the composting materials from excessive rain or sun. Experience indicates that woven fabric and polypropylene are suitable cover materials. In the Philippines, plastic sheets with a useful lifetime of one year are used, but are considered to be expensive. Alternative solutions include removable covers made out of bamboo or local roofing materials. Coverings need to be: angled to shed water; easily disassembled and reassembled to allow for turning the pile (or be high enough to provide equipment clearance); and approximately 50-150 mm higher than the pile to allow for natural ventilation.

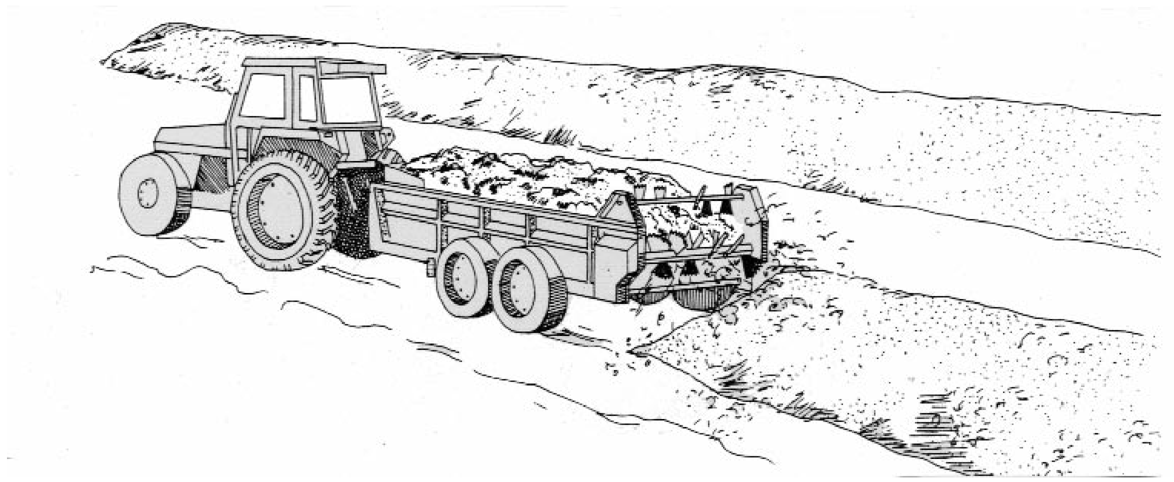

Figure 9. Pile construction of compost with tractor equipped with a spreader
Source: NRAES-54, 1992

4.3.4 Pile construction techniques
Every compost site operator has a favourite pile construction technique. Some of these techniques are designed to reduce the need for mixing. One approach is to discharge the materials directly into a windrow. The most suitable equipment for this is a tractor equipped with either horizontal or vertical rear discharge manure spreader and a smooth bucket attachment in the front. Since the compost is discharged backwards, the manure spreader can be modified by attaching two sheets of steel that will guide the manure into a windrow form.

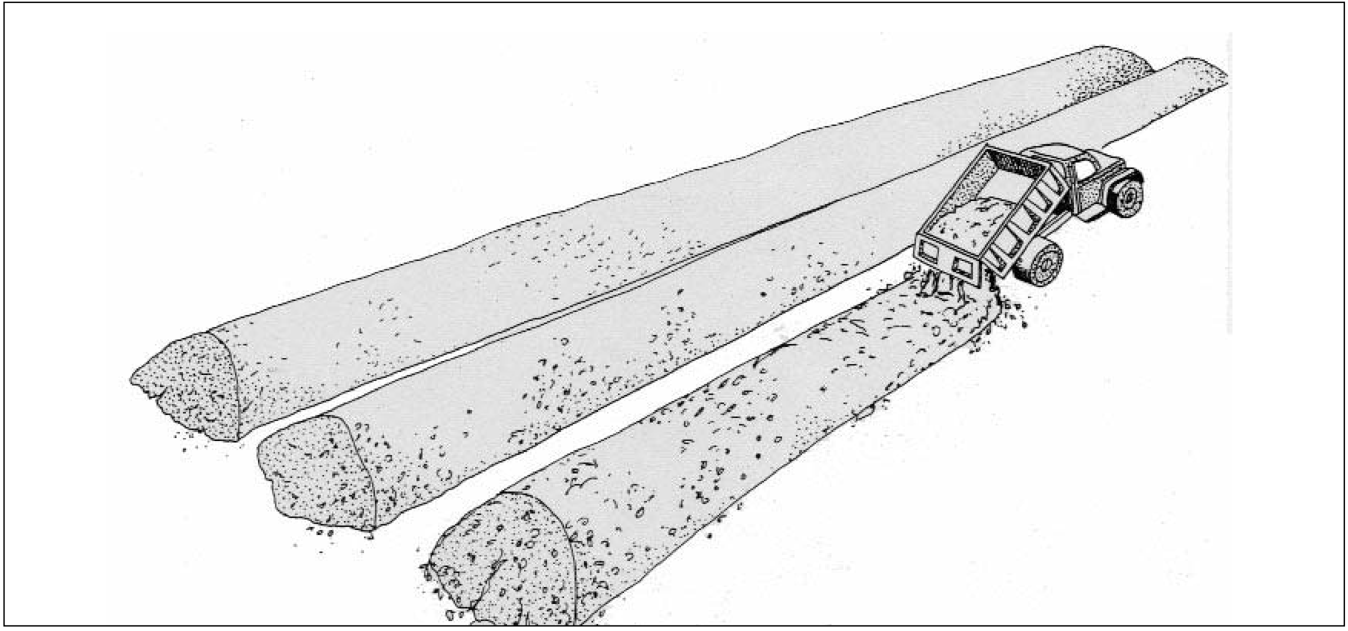

Figure 10. Windrow formation with direct discharge into windrows by dump vehicle

Source: NRAES-54, 1992

Another approach is to deposit the various materials in a succession of horizontal layers whenever the site is large enough. It is usual to start at the bottom with a layer of high carbon, sawdust, branches, etc. The larger pieces allow air flow from beneath. This is followed by layers of high nitrogen materials, which are denser and wetter, alternating with more carbon. Sometimes this pile technique reduces the need for turning, reducing labour and energy. Figure 11 shows this layering technique.

Layering in the Philippines

In the Philippines, the materials are deposited into layers, applying a layer of thickness of around 10-15 cm. The layers are separated by an aeration system made out of poles. High carbon materials are added on top of high nitrogen materials. This configuration is very efficient in absorbing moisture content and reducing odours. Aeration is improved when the bottom layer consists of wood chips or sawdust.

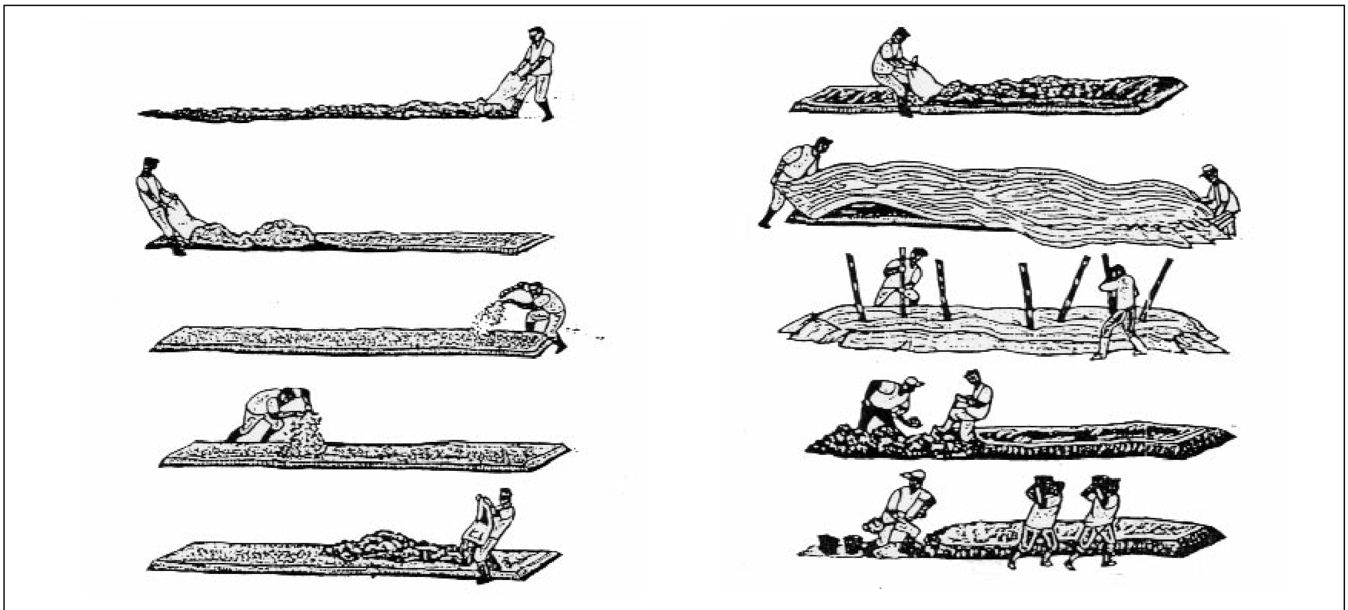

Figure 11. Composting by layers in the Philippines

Source: UWEP, the Philippines

4.3.5 Turning and aeration

Aerobic composting needs large amount of oxygen because if the supply of oxygen is limited, the composting process will slow down and the temperature will decrease. Turning allows oxygen to enter the windrows. This aids the bacteria in maintaining **thermophilic** temperatures inside the windrow. Turning sequences are shown in Figure 12.

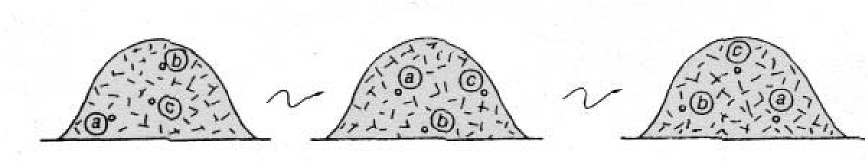

Figure 12. Sequence of turning (a, b, c)

Source: Le Compost, 1987

Selection of turning equipment

Turning can be manual – with shovels - or mechanical, using a wide variety of machines. A turning machine – some of which are manufactured in the South – allows for the production of a more uniform compost. However, this machine will increase the capital cost and increase the pile spacing requirements. Combining manual with mechanical turning can work if the piles are not too high.

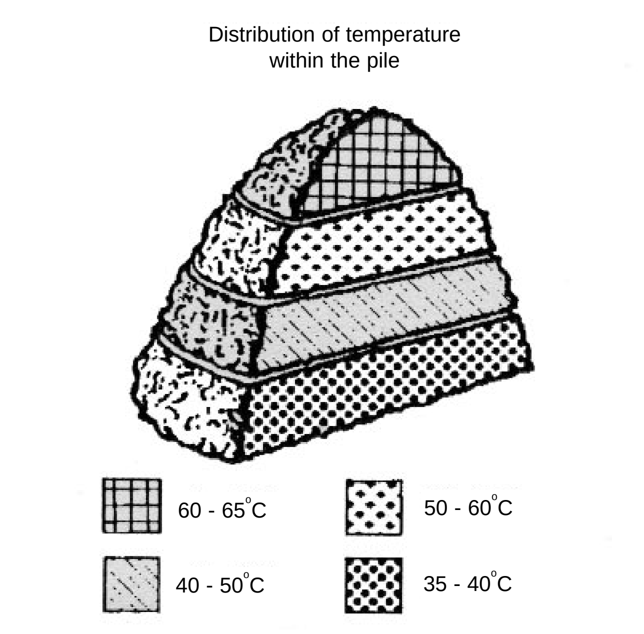

Figure 13. Temperature distribution inside a compost pile

Number of turnings is important

The number of turnings influences the temperature in the pile, and therefore the rate of pathogen suppression. Most compost regulations require maintaining the temperature of the compost process at 55 to 65°C for three consecutive days, in order to achieve pathogen suppression. The average frequency of turning is once per week for 5 weeks. The distribution of the mass heated after each turning is represented in the following table.

% Mass over 55 degree Celsius	Number of turnings
50%	First turn
76%	Second turn
88%	Third turn
94%	Fourth turn
100%	Fifth turn

Table 10. Mass of materials reaching the optimal temperature for each successive turning

Chinese passively aerated windrow method
Air is supplied to the organic material through perforated pipes embedded in the pile. The chimney effect created by the warm gases rising out of the windrow causes air to blow through the pipes. The base of the windrow should be porous and made out of straw, compost or grass. A grid of vertical and horizontal bamboo poles can be added as well as a cover on top of the pile to prevent heat and moisture losses.

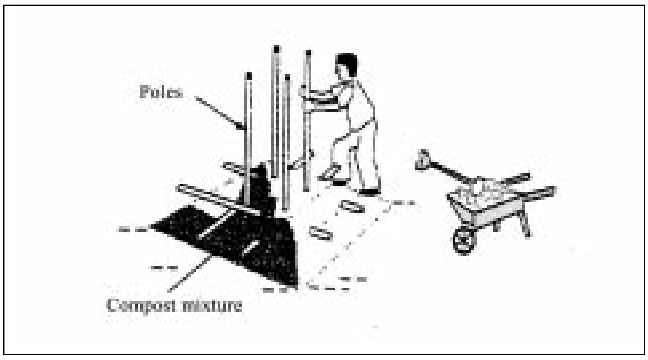

Figure 14. The Chinese model
Source: UMP, World Bank

Forced aeration composting process
This method combines techniques from passive aerated windrows with more advanced technology. The aeration system is usually operated by a programmer timer or a temperature sensor that can adjust the airflow rates to produce the desired temperature profile. It is a costly and complicated technique.

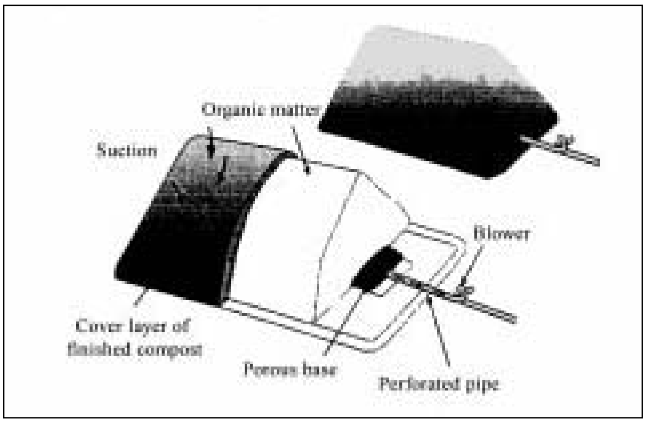

Figure 15. Forced aerated process
Source: UMP, World Bank

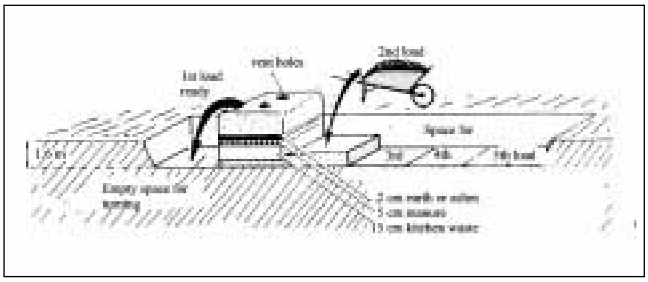

Figure 16. Composting in ditches
Source: Le Compost, 1987

4.3.6 Watering

Water is required for all composting processes. Water is necessary to activate the micro-organisms during the active composting stage. Access to water is an important criterion for site selection. During composting, on average, 34% of the water will be discharged as water vapour, and will need to be replaced.

In areas where there is regular rainfall, piles can be watered by turning the piles during rainfall. Rain can also be caught and used to water the piles. Or liquid waste streams can be used to raise the moisture content.

Moisture content should be kept between 40% and 60%. Where water is scarce, 40% moisture content is usually adequate. Although then the rate of decomposting may be reduced, which impacts site sizing. Composting in ditches reduces water use, but can be a problem for aeration. An example is shown in Figure 16.

4.3.7 Monitoring and troubleshooting

Although composting is a simple, natural process, problems can occur if the conditions are not right. For this reason, monitoring - especially when nightsoils or sludges are part of the mix - is important. The most important tool for monitoring the composting process is a long-stemmed thermometer. Temperature is a good indication of biological activity, and is therefore key to identifying the problems. Much can also be learned by taking a handful of composting material and squeezing it, to see if it feels dry or spongy, and to see whether liquid can easily be squeezed out.

The following table gives guidelines on monitoring. Table 12 lists some typical problems, and suggests strategies for fixing them.

Parameters	What to monitor	When to monitor	Condition/Procedure
Moisture content	Aeration	Every time after turning	Hand squeeze method: take handful of product, close fist, when open fist, ball formed slightly expands and palm of hand is slightly moist: 50% moisture. A handful that is squeezed should produce small droplets of water.
Temperature	Sufficient aeration	Every day	Temperature at 1 metre deep is not exceeding 6°C lower than at 0.3 metre deep.
	Composting activity	Every day during the active composting period	Use of a wood or metal bar, place inside the pile for 15 minutes. A stake of metal or wood about 300-600 mm into the heap and leave it for 15 minutes. Afterwards the portion of stake that was in the pile should feel very hot, but not too hot to hold and it should also appear moist. Use of alcohol thermometer versus mercury thermometer
Ammonia	Sufficient aeration	During composting operation	Detection of an ammonia based odour. Sulphur based compounds and other odours associated with a "putrescible" smell in the early stages of composting indicate an initial failure of the system to heat up properly and can be confirmed with the thermometer.
Pathogens	Log of temperature	Every other day	4 days at 65°C or 15 days consecutive at 55°C[6]
	Management of feedstock and compost	During handling operation	Use separate equipment, clean tools.
Volume	Fermentation grade	During the active composting period	If the volume is decreasing, this means that the fermentation is occurring.
Flies	Composting activities	During the beginning of the active composting period	Fly larvae can be apparent in the colder areas of the compost and on the surface at the beginning.
Colour	Decomposition of organic matter	During the composting process	Yellow/brown: not decomposed. Dark brown: partly decomposed. Black dark brown: decomposed organic matter.
Stability of compost	Log of temperature	During the curing period	Temperature within the composting mass decreases to near ambient levels.

Table 11. Low cost monitoring procedures

[6] The regulatory formula is $D=131,700,00 / 10^{01.4}t$ - where D = days, T = temperature C°
Depending on the composting methodology employed determines the minimum: Windrow – 55°C 15 consecutive days with 5 turnings within that period; Static aerated pile - 3 days at 55°C as long as system is blanketed; In-vessel is a direct calculation based on formula.

4.4 Curing and screening

The curing stage begins when the temperature no longer increases to 55°C after the last turning and all other parameters are met, moisture, oxygen level etc. At this point, windrows can be left, or they can be combined into larger piles and moved out of the active composting area. Curing continues until the temperature falls to near ambient temperatures (within a range of approximately 5°C) and the compost smells like rich soil.

Screening is not essential to the use of compost, but it makes the compost more uniform and easier to use. Therefore the type of screen and target particle size usually depend on the needs of the landscapers, gardeners and farmers.

In the South, most screening is done with an inclined manual screen, which is inexpensive and easy to build by hand. Screening works best when the moisture content is below 45%. Conversely, too dry material (< 30%) can lead to dust problems and loss of product especially in situations where prevailing winds are present.

Condition/situation	Possible source/reason	Indicators	Action
Piles fail to heat	Materials too dry	Very difficult to squeeze water from the material	Add water or turn in the rain.
	Materials too wet, moisture content > 60%	Material feels soggy, liquid squeezes out	Add dry amendments and high-carbon ingredients like straw, rice hulls, leaves, or shredded paper.
	Not enough nitrogen	Large amount of woody materials	Add high nitrogen ingredients, urinate on piles, or, if no nitrogenous materials are available, add water.
	Poor structure	Few large particles, not excessively wet	Add bulking agent, that is, materials in large chunks that maintain air space.
	Small size pile	Pile height less than 1.1 metre	Combine piles.
	pH too low	pH measures less than 5.5	Add lime or wood ash.
Temperature falling	Low oxygen	Temperature declines gradually then sharply	Turn or aerate the pile.
	Low moisture	Cannot squeeze water from the material	Add water and remix.
	Composting nearing completion; C:N ratio less than 20:1	Pile does not re-heat after turning or watering	None required.
Pile overheating	Insufficient aeration	Pile is hot	Turn the pile.
	Moderate to low moisture	Pile feels damp	Add water.
	Pile is too large	Pile height greater than 2.5 metre	Split the piles or spread them out.
Odours generated ammonia, (rotten-egg or putrid odours)	Anaerobic conditions: materials too wet, poor structure, pile compacted, insufficient aeration	Low temperatures, odours	First, turn the piles. If odour persists, then consider adding sawdust, other dry amendment, rock phosphate, or other bulking agent. Then remix, and turn piles again.
	Anaerobic conditions: pile too large	High temperatures	Split the pile or decrease its size.
	Odorous raw materials	High temperatures	Cover the piles with a thin layer of sawdust or leaves to act as an air filter. Turn and mix the materials, add bulking materials, handle raw materials promptly.
High levels of flies, mosquitos	Flies breeding in the compost piles	Fresh manure or food material at pile surface	Turn piles every 4 to 7 days. Cover static piles with 10 cm of matured compost, or with sawdust or leaves. If no cover, remove the outer 150 mm of material before turning and using it in the core of the new pile so that breeding cycle be interrupted. Allowing chicken and fowl to eat the larva helps control the fly population.
	Flies breeding in raw materials	Wet raw materials stored on site more than 4 days	Handle raw materials promptly.

Table 12. Troubleshooting and helpful actions to solve problems

Photo 7. Inclined manual screen in use in Dhamar, Yemen
Photo: ©WASTE, Arnold van de Klundert

Photo 8. Trommel screen in use in Bangalore, India
Photo: ©WASTE, Esha Shah

4.4.1 Useful indicators

Composting is a very active process where the mass and the volume of the feedstock fluctuate day after day, week after week. An initial volume of feedstock will lose between 20 to 60% of its content, depending on its compaction level, the period of activity of the micro-organisms (beginning, end of thermophilic) and the weather, as shown in Figure 17 and Table 13.

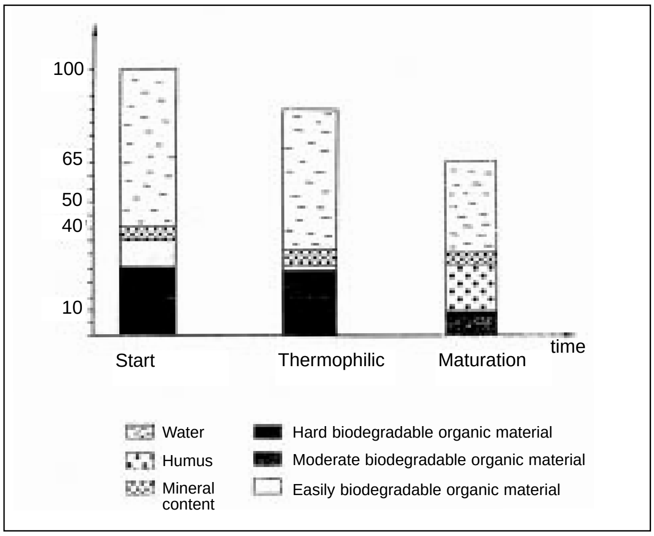

Figure 17. Evolution of the mass of the organic material
Source: Le Compost, 1987

	Density (kg/m³)
Raw materials	350
Materials after 6 to 30 days	450
Mature compost	630

Table 13. Average density during composting

4.5 Marketing

A good marketing strategy is established in advance, when the needs of the users can influence the type and quality of the finished product. The marketing strategy has two important objectives:

1. To find a 'home' for all the compost, so that nothing that is produced has to be disposed of as waste.
2. To identify and receive purchase commitments from a range of potential customers that can pay for compost.

Some markets require fine compost, delivered in small quantities, and will pay well for a good product. Other markets will always accept compost no matter what quality and quantity; these have to be investigated as well, so that municipal managers will never have to pay to get rid of the compost produced.

In terms of planning and management, the marketing strategy will also influence:
- The dimensions of the storage surface area.
- Maintenance of quality and minimising of potential deterioration of the compost during curing and storage.
- Technical adjustments or modifications in the composting process to respond dynamically to end-user demands.

Some marketing instruments available to the municipal manager are presented below according to the following aspects: product, price, promotion and packing.

Question to raise	Context to identify the answers	Examples
COMPOST PRODUCT DESIGN & FORECAST OF MARKET DEMAND		
Who are the customers?	Groups of homogeneous customers	• Municipal and public agencies • Green industries: nurseries • Agricultural markets • Land restoration • Co-operatives and bulk wholesalers
What is the volume of potential demand for compost?	Size of potential area in conjunction with depth and frequency of application	• Hectares of vegetable farms • Hectares of cereal culture • Surface areas of cemeteries • Municipal parks • Green belt • National monuments • Golf resort • Surface area of the landfill site
What is the annual marketing cycle?	Time of application and frequency of yield	• Once a year • Intermittently • Several times a year
What are the types of compost that can be marketed, and for what uses?	Type of crops or activities	• Horticulture and ornamental plants • Leaf vegetable • Non-leaf vegetable • Extensive culture • Intensive culture
PRICE		
What products will compost replace? What price are potential customers willing to pay per type of compost? How much money, chemicals, natural resources are conserved when using compost versus chemical fertiliser?	Comparison with the cost for chemical fertiliser, manure and other products, based on application rates and nutrient value	• Competition with other products in use and evaluation of compost equivalent in the long-term application (3 years). • Farmers with high value crops are more willing to pay for compost. • Potential saving from using pesticides, herbicides when using compost.
PROMOTION		
What channels can be used to create or expand the demand for compost? What are the strategies to inform potential customers about compost?	Analysis of existing communication channels and the flow of information in the social groups	• Outdoor presentation • Leaflet • Exhibition • Trials • Certification
PACKING		
Forecast of packing strategy: How to sell the compost and where?	Screening options relating to the physical characteristics: bag versus bulk sales, pickup versus delivery; pricing by weight or by volume.	• Users usually prefer small to medium volume size bag: 25 to 50 kilos that can be carried by two people. • Majority of vegetable farmers prefer to buy one to four cubic metres at one time. • Bag has to protect the compost against rain and sun.

Table 14. Marketing instruments and strategies

4.5.1 Demand cycles

Demand for compost is related to agricultural cycles. Experience in the South indicates that there will be a lively demand for compost during the winter season. During the winter season, it is estimated that the stock desired by month can amount to 10 to 15% of the annual compost production.

4.5.2 Distribution approach

Marketing is most reliable when existing distribution channels (wholesale and retail) can be convinced to handle the compost product. The following figure represents a schematic interaction between compost producer and users.

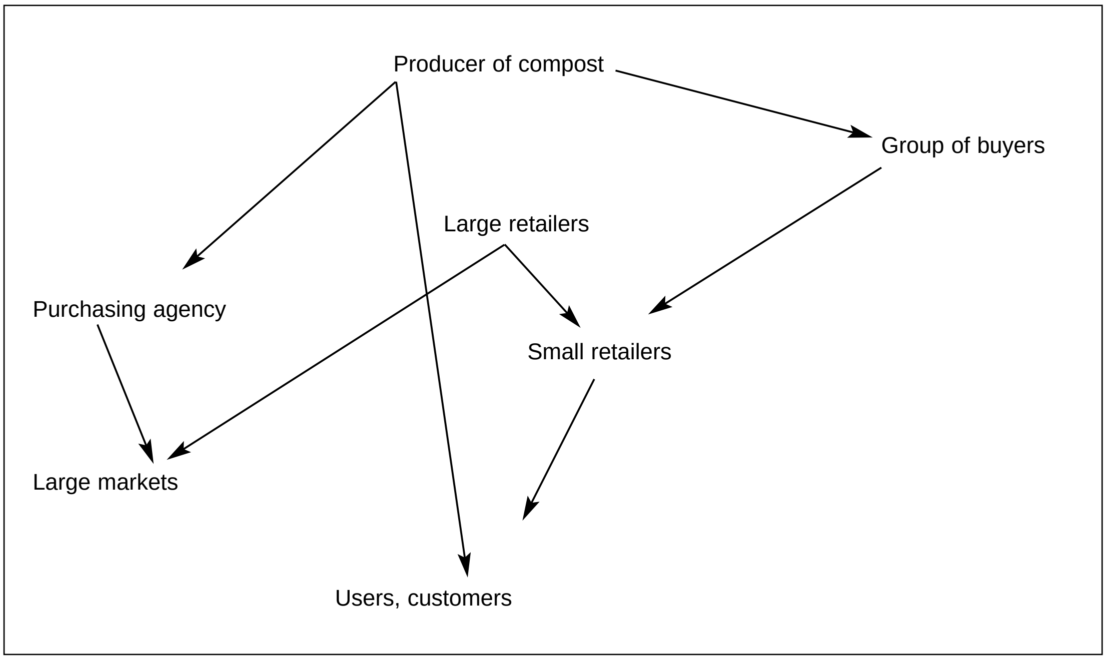

Figure 18. Marketing distribution scheme

Analysing marketing performance in Bhaktapur, Nepal.
Analysis of the annual sale flows at the composting site in Bhaktapur, Nepal showed the sales to be very weak. Analysis of the existing distribution channels pointed to lack of any structure able to play the role of a profit centre within the boundary of the composting unit. As a result, there was no institutional basis for marketing and commercial initiatives.

4.5.3 Market development

Compost can be difficult to market, since in most places it is not a recognised product, and it has no established market value. As a result, part of the process of initiating compost production is developing the market. This includes several types of activities:

- Giving compost away to high-profile users or well-respected farmers and gardeners, whose experiences will be believed and whose opinion will have influence with their peers.
- Promoting or advertising compost through other community or citizen environmental sanitation or recycling education campaigns.
- Using compost in municipal parks, to landscape national monuments or cemeteries and to green roads and public spaces - with some signs to identify that this is where the product is being applied.
- Convincing high-prestige businesses, such as hotels and resorts, to use compost on lawns and gardens.
- If available, partnering with an agricultural education institution to test the compost on specific end-uses and then having this information available for similar end-users in the marketplace. Of particular value here is side by side plots with different application rates of compost in conjunction with varying rates of synthetic fertiliser addition.

Market development is an iterative process. A 'first round' to possible users cannot usually accomplish more than establishing openness and a willingness to experiment, as well as finding out what the user preferences are for the final product. On this basis, the first experimental batches of compost can be produced. Then in the 'second round', compost is given away to users who will experiment with it and promote the results, if successful. On the basis of this experience, it is often possible to set prices for compost, so that the next batches can be sold.

4.5.4 Compost yield trials and comparison with traditional products (fertiliser, topsoil, mulch)

The technical backup to market development is a series of formally monitored compost yield trials. The municipal manager needs to support compost trial implementation and establish strong links with the local agricultural sector, since these are the main clients for the compost product.

Compost yield trials establish the effect of compost on cultivation of plants. They are necessary because the beneficial effects of using the kind of compost produced from the organic waste stream is not familiar to most gardeners or farmers -- each of whom is a potential user and client.

The contacts and alliances that are made during yield trials may also serve to develop effective and operational linkages between the waste management and the agriculture sectors so that the organic waste composted can be applied in agricultural production. Once farmers use compost, they frequently prefer it to other fertilisers. Then, when interviewed, farmers who are using compost acknowledge its benefits, explaining that compost is not ruining the texture of the soil as chemical fertilisers do, that it enhances and improves the soil structure and retains moisture over the medium and long term. Some farmers may prefer to continue to use chemical fertiliser (e.g. urea) in combination with compost, for the 'burst of growth' effect. With compost, only one fourth of the quantity of chemicals on average is needed.

Compost yield trials in Bhaktapur, Nepal

A compost yield trial was conducted in Bhaktapur on two crops, potato and onion, to see the effect on the yield of crop condition and condition of soil. The experiment was planned with four application experiments and 5 treatments: (1) chemical fertilisers, (2) application of compost with a ratio of 1500 kg/ropani[1], (3) application of compost with a ratio of 750 kg/ropani, (4) application of compost and chemical fertiliser. Five plots of 3 by 3 metres were implemented. The output under various replications showed that the best results were obtained when chemical fertilisers alone or chemical fertiliser along with compost were used. For the sake of determining benefit cost ratio, comparisons were made on the basis of production along with total cost of farming. The best results were obtained when chemical fertiliser is used followed by chemical fertiliser and compost combined together.

1) Ropani = 500 m^2

The following figure shows the sequence of actions in a normal growth or yield trial.

2 to 3 growing seasons

duration: ↓ max 18 months

2 identical plots of land

one trial plot ↓ one reference plot

Monitoring of:

- Yield production
- Moisture retention
- Duration of farming operation (weeding, ploughing, dressing, irrigation, digging)
- Expenses per activity
- Use of pesticide and herbicide
- Disease suppression
- Quality of crop, i.e. shelf life, protein content (grains), nutrient content, etc.

Figure 19. Yield trials for composting

Photo 9 . Test plot for compost use on vegetables, Ghana
Photo: ©WASTE, Arnold van de Klundert

Results of compost yield trials in Asia
In Calcutta, India, comparative study of utilisation of labour showed that the average input of labour is lower with the use of compost because compost aerates the soil so that less labour is necessary for ploughing and digging.

In South East Asia where farmers are applying compost to rice fields, cost monitoring has shown that using compost reduces the cost of purchasing and applying pesticides and herbicides as compared to the application of chemical fertilisers, which require a high application rate of pesticides and herbicides.

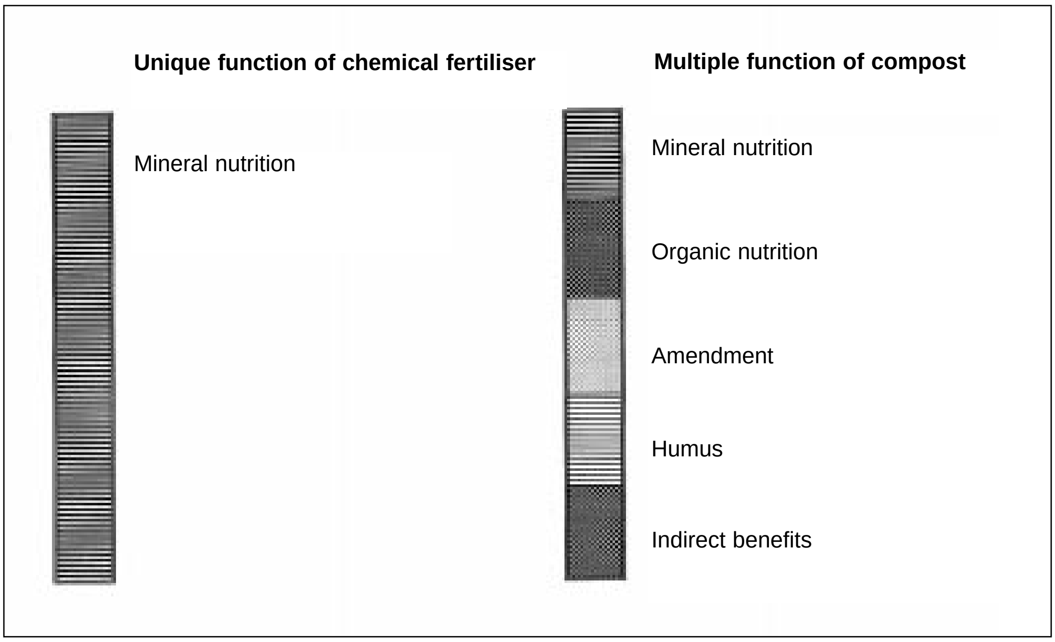

Figure 20. Comparative functions and agronomic values of chemicals and compost

Chapter 5. **Economics**

The economics of composting is complex and has a great deal to do with environmental externalities. The reader is referred to the financial and economic document in this series for a more detailed discussion.

5.1 Costs

The cost of composting includes costs of design and costs of production. The cost of production includes:

1. Planning, feasibility study, design and siting costs
2. Investment costs (capital costs of sites, buildings, machinery, vehicles)
3. Raw materials, additive and feedstock costs, including costs of transportation
4. Production costs, including costs of supervision, energy, water, environmental management, and other kinds of industrial inputs
5. Overhead and administration costs
6. Hidden costs
7. Environmental, social and political externalities such as the cost of air and water pollution, including odour, caused by the waste processing system and improper disposal
8. Marketing costs
9. Residue disposal costs

The most expensive items are (by decreasing order): labour[7] or energy, capital recovery, management and administration, supply of organic materials/additives, amendment/bulking agent, space, packing, and disposal of residue.

5.2 Key insights from UWEP experience

- The cost to purchase input materials can be very high depending on the season and the competition for organic materials. Therefore the availability of organic materials should largely determine the optimal composting mix and the ultimate scale of the enterprise.
- Using an existing or closed landfill site for composting will reduce land costs, but such a site may be far from both generators and users. Using a transfer site is also suitable.
- The cost to purchase bags or other packaging for finished compost raises the price of the finished product. This is probably only worth it for the highest paying markets, and should be avoided it possible. Bulk sales are in general more sustainable.
- Capital costs for buildings, vehicles and machinery need to be depreciated each year, in order for the price of the product to reflect replacement costs of that equipment. In developed countries, the life span of buildings is normally 10 to 15 years, 7 years for vehicles and 5 years for machinery.
- If the composting unit has a building area or if the unit has some vehicles and equipment, then the costs for depreciation are high. Among fixed assets, vehicles (trucks, tractors, vans) are the most expensive items; then comes heavy machinery (loaders, vibrators, rotating screening) and small machinery made locally (mobile shredder, shifter, grinder). Imported parts are very expensive. They are lower when the equipment or machinery is made locally and spare parts are available on the national market.
- Preventive maintenance and repair costs are additional.

Table 15 presents ranges of production costs and administrative expenses for different composting plants.

[7] Labour is the most expensive item in a system where capital costs are low and the energy used is mechanical. Energy costs and capital recovery are the highest costs in in-vessel systems or systems depending on motorised vehicles.

Item	% of total costs in average	Measures to reduce costs
PRODUCTION COSTS		
Raw materials and additives (manure, ash)	Free to 25%	Search for free raw material and store it if necessary.
Plastic sheet and equivalent to cover the windrows during composting	6%	Use coverings made out of local resources or indigenous roofing materials (bamboo, rice bags).
Packing, bags	7%	Market in bulk.
Transportation of organic materials for composting	10%	Reduce frequency of collection to once or two times a week.
Disposal of residue	5%	Disposal of dry materials instead of wet materials, particularly when distances are large or disposal fees are charged on a weight basis. Implement separation at source.
Direct labour (operation)	15 to 58%	Involve workers in improving efficiency, and introduce incentives.
Rent	Free to 60%	Use public land where available.
Consumables, repair and maintenance	1 to 12%	Require frequent and regular preventive maintenance and repairs.
ADMINISTRATIVE COSTS		
Staff (management)	0 to 14%	Calculate effective time spent on composting management only excluding other activities related to the rest of the waste stream.
Insurance, telephone, office supplies	0 to 10%	
CAPITAL COSTS	3 to 24%	Select suitable equipment made locally according to the field and train local garage to do the maintenance.
HIDDEN COSTS		Analyse operations carefully, and implement integrated accounting system.
EXTERNALITIES		
MARKETING COSTS (promotion)	7%	It is not advisable to reduce this expense but to optimise it with for example the participation of unpaid staff (students, retired people).

Table 15. Guidelines for estimation of total composting cost and measures to reduce the costs

5.3 Revenues

Potential sources of revenues include:

- Revenues from handling waste. These can come in the form of tipping fees (paid by the generators or collectors to take the waste) and in the form of diversion credits (paid by the municipality in order to support a reduction in the amount of waste requiring disposal in a landfill).
- Revenues from compost sales. These belong to two complementary types of markets: the high value - low volume market and the low value - high volume market.

Two complementary kinds of markets
A high value - low volume market is available when compost is replacing another kind of fertiliser which also has a high and quantifiable value, used potting flowers or fruits or vegetables for a high-quality market. In this circumstance, customers are willing to pay a high price to have a good quality. This compost is generally finely screened and free of impurities.
A low value - high volume market provides a ‘home’ for any compost, whether or not it is screened. Volume markets include public works, urban or roadside planting and mine- or other land restoration. Customers may take the compost without paying for it, or may be willing to pay a low price.

- Subsidy is another form of revenue, usually related to public environmental or health policy. The form of subsidy depends on the institutional set up of the composting unit: for example national government can subsidise the actual production (per metric ton produced), international donors or agencies can provide machinery. Subsidy can also aim to fill the gap between revenues from sales and actual price (cost for production and profit margin).

Table 16 presents the share of production cost to revenues for different composting plants for a determinate period of time.

Location and Currency	Total revenue	Production cost	Profit
1998 Petamburan/ UDPK Capacity 18 tons/months Rupees	4,050,000,000 (67%)	5,955,000,000 (100%)	(1,905,000,000)
1997 Bhaktapur Capacity[8] 17 tons/months Rupees	282,000 (44%)	634,155 (100%)	(352,155)
1997 KCDC Bangalore Capacity 8 tons/months Rupees	9,649,217 (64%)	151,000,000 (100%)	(5,450,783)
1996 Santa Maria Capacity 4,5 tons/day Pesos	7,294,858 (198 %)	3,668,197 (100%)	3,626,666
1992 Jakarta/ ERCP Capacity 8 tons/months Rupees	19,320,359 (99.9%)	19,344,000 (100%)	0

Table 16. Profit (loss) in five compost plants

These data, and experience in many other composting operations, indicates that revenues do not usually cover the costs of production, packing and delivery. Partly this is because of market limitations on prices: even when the compost is of high quality and quantity, compost prices have to compete with subsidised chemical fertiliser prices.

As a result, composting is profitable *as a manufacturing activity* only in certain circumstances. Usually, the involvement of the public sector, either in regulating or paying for waste management, is necessary for a composting operation to be economically sustainable.

It is as a waste management activity or integrated waste system component that composting has the most potential to be sustainable. Even where operations are privatised, in the end waste management remains a public responsibility, which is paid for from public means. Composting provides an alternative to disposal, so the cost of producing compost, including labour and depreciation of equipment or infrastructure, should in fact be considered as cost for elimination. The justification for costs also includes positive environmental externalities, sometimes called hidden or ‘shadow’ benefits, such as preserving organic materials and avoiding energy-intensive transportation. And of course the avoided cost of landfilling or other disposal of the organic and inert materials is the main benefit to the public sector. Figure 21 shows how the different actors relate to one another.

[8] Capacity of compost production.

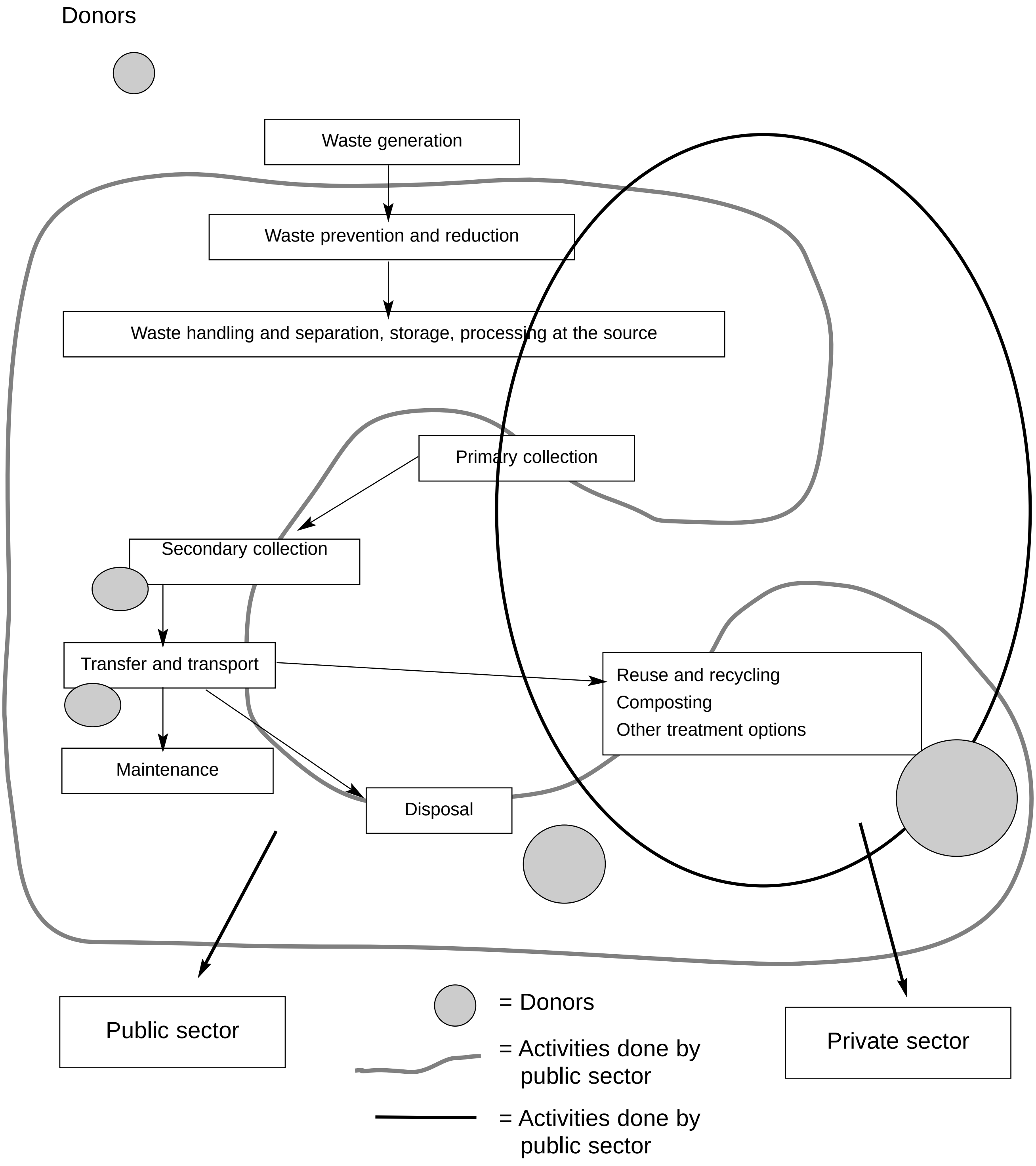

Figure 21. System elements in waste management

1. **Private sector:** Clients of the waste collection service are willing to pay for removal of waste. Customers will pay the purchase price of products that in their new form have value to them, i.e. compost or recycled material. Private cleaning, collection or treatment businesses provide services based on a service fee. Commodities businesses buy, upgrade, and sell recoverable materials.
2. **Public sector:** Government authorities are responsible for waste collection and disposal. They are the payers of last resort in these elements of waste management. They also invest in or subsidise primary collection as well as the different ways of waste recovery. It is worthwhile for them to invest in these sectors, because they reduce the amount of waste that has to be disposed, and the costs associated with disposal, which is their responsibility.
3. **Donors:** Donors are governments or other agencies from the North donating to countries in the South. Donors are likely to subsidise projects consistent with their national policies, or donate equipment made by their companies. They may also donate second-hand vehicles, which are past their useful life expectancy in their home country. They may also finance consultants to offer their services in planning a waste management system. Donations are usually limited and frequently conditional, or driven by external interests rather than local needs.

5.4 Economy of scale

The principal of *economy of scale* is important to ensure cost efficiency of a composting plant. Economy of scale is based on the capacity of different parts of the system. Economy of scale is reached when different parts of the system all operate at their optimal capacity. For example, if the system includes a sorting line that can sort one ton per hour, it does not make sense to have a shredder that can process 10 tons per hour, and that stands idle for nine hours out of 10. There are a number of variables that determine economy of scale:

- The productivity of labour in different operations.
- The type and design capacity of the vehicle or equipment (collection vehicle, loader, tractor, tractor with manure spreader).
- The rate of use of each piece equipment (100%, 60%, 30%).
- The amount of raw materials to be processed, and, ultimately, the volume of compost to produced.

Activity	Productivity of one employee
Manual sorting	1.5 – 2 m^3/hour
Turning with shovel	1.8 – 2.2 m^3/hour
Watering and re-mixing	1 – 1.5 m^3/hour
Screening	0.5 – 0.8 m^3/hour

Table 17. Average productivity for labour in composting

The next table shows the costs for different scenarios.

Scenario	Number of staff	Cost for staff	Cost for maintenance and operation (% use)	Cost for depreciation	Total cost/ton of compost produced
1a: mechanised material handling with a loader	6 to 16	11,000 to 32,000	1,800 to 3,500 (42% capacity)	10,000	6 to 11
1b: mechanised material handling with a tractor	6 to 16	11,000 to 32,000	900 to 3,200	5,700	6 to 9
2: manual processing	9 to 34	18,000 to 67,000	-	-	6 to 9

Table 18. Comparison of mechanical and manual composting operations at throughput of 5 to 30 tons/day in US$

Table 19 is a sample comparison of the total annual production costs according to the capacity of usage of two different vehicles.

% Capacity of usage	100%	60%	40%	25%
Using a loader Reference: 100% = 300 m^3/day	300 m^3/day	180 m^3/day	120 m^3/day	75 m^3/day
	US $ 38,000	US $ 36,000	US $ 35,000	US $ 34,000
Using a tractor Reference: 100% = 180 m^3/day	180 m^3/day	108 m^3/day	72 m^3/day	45 m^3/day
	US $ 31,500	US $ 29,400	US $ 28,400	US $ 28,100

Table 19. Annual costs based on capacity of vehicles

In conclusion, sensitivity analysis of composting gives the following benchmarks:

- Manually operated windrow plants are cost effective up to 30 tons per day.
- Mechanisation reduces staff number by 30% to 50% only.
- There is always a minimum expense when using a vehicle and the lower the throughput, the higher the expense per amount of

compost. Therefore, vehicles are only appropriate for relatively high capacity operations.

- Sophisticated equipment requires trained or experienced operators, and has relatively higher costs of maintenance and repair. If the equipment is imported, the costs of spare parts can exceed the capital cost of the equipment itself.
- While it may sometimes be possible to get a customs duty waiver for the equipment itself, parts will probably not have an exemption, and will almost certainly be taxed. Furthermore, it may be difficult to get the parts through customs.
- The best sources of equipment are local. If no specialised composting machines are available in your region, you may select and adapt appropriate, locally available agricultural machinery –corn choppers, rock pickers, augers, conveyors or harvesting machines. Parts are also locally available, there is local knowledge about maintaining them, and in general they are easy to use and to maintain.
- Another alternative is to upgrade or rebuild existing equipment, rather than investing in a new vehicle or a machine that is unknown to you. Renting new equipment gives you the opportunity to test it before committing yourself. It also reduces maintenance requirements and has the advantage of allowing you to change equipment.

Using a two-stroke engine to mechanise a manual screening drum
The use of a screening drum results in higher compost yields and improves the quality of the compost. The screening drum was originally working with pedal power and eight people were needed per day to turn the drum. This proved to be a too heavy task and a two-stroke engine was installed. As a result only one worker operates the screening drum.

Table 20 indicates the average production cost per ton of compost produced, according to several case studies. On average, mechanical equipment will triple the production cost.

Location	Production capacity (tons/day)	Type of equipment	Total number of staff	Cost per ton in US $
Bhakthapur, Nepal	6	Chopper, conveyor belt, tractor, static sieves	20	50
Bangalore, India		Wheel loader vehicle, vibrator screen, sieving drums, electrical trommel	25	20
Armstrong, Argentina	2	Manual sieving		82
Santa Maria, Philippines	4	Segregation of organic waste at source, mechanical shredder, wheel barrow, mechanical sifter, mechanical hammer mill	15	120
Mechanical composting method in India	more than 30	Mechanical turning	-	10 to 15
Manual composting method in India	less than 30	-	-	1 to 5
Composting in low income country		-	-	5 to 20
Mali	2	Locally manual screens, spade, shovel, pushcart	3	4

Table 20. Range of production costs

5.5 Conclusion

Organic waste constitutes the major fraction of domestic waste in the South, so making optimal use of this resource from the waste stream is a good choice for many municipalities. Composting has the most potential to be sustainable when it is integrated with the waste management system. Major challenges lie in the need to develop a stable and reliable market for the compost, based on external demand; to develop internal markets or uses for the compost at the quality and quantity it is produced; and, finally, to secure a certain quality and quantity of the organic waste flow.

Irrespective of contract arrangements or privatisation decisions, waste management remains a public responsibility, which is paid for by public means. Composting is interesting to the extent that it provides an alternative to disposal, so the cost of securing the waste flow and producing compost should in fact be considered as one of the means to reduce disposal costs. In general, composting will be economically feasible to the extent that economic factors related to landfills, markets and material recovery approximate real financial and environmental costs. For example, when landfilling or dumping is controlled and regionalised, it will usually be sufficiently expensive to make the moderate cost of composting competitive with the cost of landfilling. Calculation of costs related to composting should also take into account positive environmental externalities, such as preserving organic materials and avoiding energy-intensive transportation, which normally are not earmarked as financial savings.

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Organisations and their website addresses

Compost Resource website - www.oldgrowth.org/compost

Compost Resource website - www.vegweb.com/composting/

Compost Resource website - www.mastercomposter.com

ENDA Urban Popular Environmental Economy Programme - www.globenet.org/preceup/

European Organic Membership Organisation - www.hdra.org.uk

Health Impact Assessment – University of Liverpool - www.liv.acuk/~mhb

Natural Resource, Agriculture, and Engineering Service - www.nraes.org

Rodale Institute - www.rodaleinstitute.org

SANDEC - www.sandec.ch

WASTE Advisers on urban environment and development - www.waste.nl

WELL - Water and Environmental Health at London and Loughborough - www.lboro.ac.uk/well

The Organic Waste Flow in Integrated Sustainable Waste Management offers an invitation to identify and understand the role that composting can play in integrated waste management systems. It also explains how the treatment of organic waste, still the major waste stream in the South, can contribute to the sustainability of a city's waste management system.

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- Community Partnerships in Integrated Sustainable Waste Management
- Micro- and Small Enterprises in Integrated Sustainable Waste Management
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