URBAN WASTE MANAGEMENT

Composting and Its Applicability in Developing Countries

8

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EXECUTIVE SUMMARY

Composting has always existed on every field and forest floor, and intuitively it makes sense to compost the organic fraction of the municipal solid waste stream. Composting is a cornerstone of sustainable development, yet it is often neglected within integrated municipal solid waste management programs. This informal paper argues that composting should be a more widespread practice, especially in developing countries. Composting is obviously not a panacea to today's vexing waste management problems, but it should be an important component within most integrated municipal waste management strategies.

Over 50 percent of an average developing country city's municipal solid waste stream could be readily composted. Composting is a simple process where optimization efforts are used to increase the rate of decomposition (thereby reducing costs), minimize nuisance potential, and produce a clean and readily marketable finished product. Composting helps to increase the recovery rate of recyclable materials—household source separation of recyclable paper, metal and glass is already common in many developing countries.

Composting provides many benefits:

- increases overall waste diversion from final disposal, especially since as much as 80% of the waste stream in low- and middle- income countries is compostable
- enhances recycling and incineration operations by removing organic matter from the waste stream
- produces a valuable soil amendment—integral to sustainable agriculture
- flexible for implementation at different levels, from household efforts to large-scale centralized facilities
- can be started with very little capital and operating costs
- addresses significant health effects resulting from organic waste, such as reducing Dengue Fever
- provides an excellent opportunity to improve a city's overall waste collection program
- can integrate existing informal sectors involved in the collection, separation and recycling of wastes

Composting is not more wide-spread for a number of reasons. These include: inadequate attention to the biological process requirements; lack of vision and marketing plans for the final compost product; poor feed stock which yields poor quality finished compost; poor accounting practices which neglect that the economics of composting rely on externalities, such as reduced soil erosion, water contamination, climate change, and avoided disposal costs; sensible preoccupation by municipal authorities to first concentrate on providing adequate waste collection; inadequate pathogen and weed seed suppression; nuisance potential, such as odors and rats; poor marketing experiences; poor integration with the agricultural community; and land requirements are often minimal, but can be a constraint. All of these constraints can be overcome. This paper reviews past composting experiences and provides an outline for municipal managers to use when evaluating composting programs within an integrated municipal waste management system.

INTRODUCTION

■ Composting has always existed on every field and forest floor, and intuitively it makes sense to compost the organic fraction of the municipal solid waste stream. Composting is a natural process which provides several benefits: the process can be inexpensive; it addresses over 50 percent of a city's waste stream; it reduces one of the world's largest contributors to Greenhouse gases; it enhances related recycling and incineration activities; and it can produce a beneficial end product with unlimited marketing potential. It simply recycles organic material back to the topsoil from where it is mined through typical agricultural practices.

Composting is a cornerstone of sustainable development, yet it is often neglected within integrated municipal solid waste management programs. This informal paper argues that composting should be a more widespread practice, especially in developing countries. However, composting can only be part of municipal solid waste programs if adequate recognition is given to the need and costs associated with proper waste disposal; nothing is cheaper than not collecting solid waste.

Composting is obviously not a panacea to today's vexing waste management problems; but it should be an important component within most integrated municipal waste management strategies. This paper views the role of composting from the perspective of a municipal solid waste manager; an equally relevant perspective would be that of the agriculturist.

To identify common themes, examples of both successful and failed initiatives are provided in Annex A. Annex B (Composting Mechanics), Annex C (Composting Processes), and Annex D (Composting Health and Safety), are provided as brief introductions to these issues in the hope of encouraging more evaluation of composting proposals by municipalities.

APPLICABILITY IN DEVELOPING COUNTRIES

Over 50 percent of an average city's municipal solid waste stream in a developing country could be readily composted. Composting is a relatively simple process; the compost operator helps nature take its natural course. Optimization efforts increase the rate of decomposition (thereby reducing costs), minimizes nuisance potential, and promotes a clean and readily marketable finished product. Composting is highly compatible with other types of recycling. Diverting organic material helps to increase the recovery rate of recyclable materials, while at the same time, recycling programs for glass and plastics, which are common Municipal Solid Waste (MSW) compost contaminants, improve the quality of the finished compost. Household source separation of recyclable paper, metal and glass is already common in many developing countries.

Many cities in developing countries are plagued with poor waste collection. While a few, more influential residents may get daily waste collection, others may never have such services. Daily waste collection in wealthy neighborhoods is usually too frequent and contributes to the lack of collection in poorer areas. In more affluent areas of a city, the use of containers and diversion of organic waste for composting is a good way to quickly improve the cities overall waste collection service. Many cities have switched from unreliable daily collection to bi-weekly organic waste collection and weekly non-organic waste collection. Variations of this schedule are easily tailored to each area's individual characteristics. Introducing waste diversion for composting programs provides a city with a unique opportunity to improve its overall waste collection service.

BENEFITS OF COMPOSTING

- increases overall waste diversion from final disposal, especially since as much as 80% of the waste stream in low- and middle- income countries is compostable
- enhances recycling and incineration operations by removing organic matter from the waste stream
- produces a valuable soil amendment—integral to sustainable agriculture
- promotes environmentally sound practices, such as the reduction of methane generation at landfills
- enhances the effectiveness of fertilizer application
- can reduce waste transportation requirements
- flexible for implementation at different levels, from household efforts to large-scale centralized facilities
- can be started with very little capital and operating costs
- the climate of many developing countries is optimum for composting
- addresses significant health effects resulting from organic waste, such as reducing Dengue Fever
- provides an excellent opportunity to improve a city's overall waste collection program
- accommodates seasonal waste fluctuations, such as leaves and crop residue
- can integrate existing informal sectors involved in the collection, separation and recycling of wastes

CONSTRAINTS ON COMPOSTING

- inadequate attention to the biological process requirements
- over-emphasis placed on mechanized processes rather than labor intensive operations
- lack of vision and marketing plans for the final compost product
- poor feed stock which yields poor quality finished compost, for example heavy metal contamination
- poor accounting practices which neglect that the economics of composting rely on externalities, such as reduced soil erosion, water contamination, climate change, and avoided disposal costs
- difficulties in securing finances since the revenue generated from the sale of compost will rarely cover processing, transportation and application costs

- "subsidies" may be required to maintain programs; these reflect the benefits that accrue beyond local governments, and avoided disposal costs are not adequately addressed
- sensible preoccupation by municipal authorities to first concentrate on providing adequate waste collection
- inadequate pathogen and weed seed suppression
- nuisance potential, such as odors and rats
- poor marketing experiences
- poor integration with the agricultural community
- perverse incentives such as fertilizer subsidies or over-emphasis on capital intensive projects
- land requirements are often minimal, but can be a constraint

DESIGN REQUIREMENTS

All organic matter will eventually decompose, however, some materials are more suitable for composting than others. The raw materials which are most appropriate for composting include: vegetable and fruit waste; farm waste such as coconut husks and sugar cane waste; crop residues such as banana skins, corn stalks and husks; yard waste such as leaves, grass and trimmings; sawdust; bark; household kitchen waste; human excreta and animal manure. All of these organic materials are readily found in municipal solid waste generated in developing countries. Animal waste, such as carcasses and fish scraps, can be used as well but they are more likely to attract unwanted vermin and generate odors. Other organic matter such as wood, bones, green coconut shells, paper and leather decompose very slowly and hinder the composting process (Lardinois and van der Klundert, 1993).

Composting occurs whenever there is sufficient oxygen, water and ambient temperatures. Designing a composting system usually involves optimization between: transportation, land, labor, and capital costs, feedstock, and markets. There is never one "right answer" but rather several possible options. For example, combinations of community and large-scale composting facilities should be encouraged to reduce municipal costs.

Residential Composting

Household composting can be a simple way to manage kitchen and garden wastes. This type of composting effectively reduces waste quantities for collection, thereby improving efficiency and reducing operating costs. Residential composting should be promoted when a significant number of homes have individual or collective yards or gardens and there is sufficient space (UNEP, 1996). Composting units can be made out of locally available materials such as wood, bamboo, clay bricks, wire mesh, etc. The design and operation of the composters should not attract rodents, insects, or other scavenging animals. Keeping large quantities of meat, fish and fatty food out of the composter is the best way to keep pests away from the unit.

Public health officials may discourage household composting because of perceived health risks, however, local governments can overcome this concern through public awareness programs, providing subsidies for basic composting units, and promoting education on compost processes, e.g., how to minimize the presence of rodents and flies.

Decentralized Community Composting

Decentralized composting at a neighborhood or community scale provides small groups a way to compost at a relatively low cost. Households, commercial establishments (e.g., small markets or shops), and institutions (e.g., government buildings, schools) in an area generating between five and 50 tonnes of organic waste per day can compost on vacant land, beside community gardens, or in public parks. Local governments can support the project through public education, providing land for the facility, assisting with start-up costs, transporting and disposing of rejects to local landfills, and using the final compost in public parks. To ensure that the composting operation is environmentally and socially acceptable, UNEP (1996) recommends the following requirements for the site:

- the site be accessible to all individuals who want to use it
- the site be clearly designated with signs which all users and non-users can understand
- the site have approval from all surrounding land users
- the site have adequate controls to prevent it from becoming an area for local dumping
- the site have appropriate soil and drainage to accommodate the leachate

Centralized Large-Scale Composting

Centralized composting can range from 10 tonnes per day to more than 500 tonnes per day. Since centralized composting is on a significantly larger scale, environmental, social and technical considerations should be approached in a more formal manner and address the following requirements (UNEP, 1996):

- technical assessment of the area, soil, and geographic characteristics of potential sites
- inclusion of engineering and design professionals in site selection and facility design
- environmental assessment of the site
- formal evaluation and site selection processes that involve all relevant stakeholders
- program to minimize and/or compensate for nuisance effects of traffic, odor, leachate, and noise produced by the composting operations
- separate collection and/or pre-processing system to ensure that unwanted materials do not enter the composting system; special attention paid to the informal sector in pre-processing the waste and recovery of non-compostable materials
- establishment of a marketing strategy for the compost
- enforceable protocols for the quality and composition of the compostable materials delivered to the facility
- formal agreements made between all municipalities within the jurisdiction for siting, design, financing, operations, maintenance, environmental compliance, and billing for services and waste delivery
- designated routes for the delivery of organic materials to the facility

Even though organic decomposition is a natural process, health and safety issues exist for workers and neighboring residents that need to be addressed. Establishing compost standards and taking precautions in the facility design and operations should assist in the mitigation of any negative health and safety impacts. These issues and suggestions are presented in Annex D.

MARKETING COMPOST

Virtually any soil will benefit from the application of compost. Theoretically, there is an unlimited market for good quality compost; the organic matter is simply recycled back to where it came from. However, the cost of production, transportation and application of compost can exceed the benefits. Therefore, good marketing programs, and optimizing the use of compost, needs to be the basis of a successful municipal compost project. The issue of compost marketing is not so much finding a use for the finished compost but rather finding cost-effective applications. The history of many failed composting projects can be attributed to poor marketing strategies and inadequate attention to long-term financing.

The first step in developing a marketing strategy is to assess all existing and potential markets. This requires knowledge of the product, potential uses, limitations on use, and estimating the value of the product to the user. It is also important to adapt the marketing strategy to meet the local requirements by considering soil characteristics, agricultural practices, social customs, climate, transportation costs, seasonal variations, etc. The other critical aspect of a compost marketing strategy is to adequately include avoided collection and disposal costs that would be paid if the organic matter was not composted.

The strategy has to be flexible to accommodate market fluctuations and frequently reviewed to anticipate and make the appropriate adjustments. Marketability of the finished compost is affected by the following factors:

- condition and fertility of local soils
- government policies toward import substitution, such as import restrictions or subsidies on chemical fertilizers
- availability and cost of other soil conditioners, such as animal wastes and crop residues
- transportation costs
- local agricultural and horticultural practices
- reliability and quantity of compost production
- availability and cost of other agricultural inputs, including chemical fertilizers
- seasonal agricultural patterns
- compost quality, such as the nutrients, particle size and maturity
- seasonal variations in the waste stream, particularly in terms of the volume of organic waste and its composition

COMPOST QUALITY

The high organic content in the MSW stream of developing countries is ideal for composting. However, the municipal waste stream also contains increasing quantities of glass, plastics, metals and hazardous materials which can contaminate the finished compost. Separating contaminants from the raw material at the compost site is inefficient since it requires additional effort, space, and time, and it is likely that much of the contamination has already affected the organic fraction. Source separating the waste before collection is usually an environmentally and technically better way to improve the quality of the final compost.

In addition to ensuring a safe product, compost standards provide a valuable marketing tool. The consumer can be satisfied with the knowledge that the product quality is consistent and suitable for the desired application. This is important for commercial and agricultural operations where a relationship exists between predictable results and repeated sales. The supply of compost must also be reliable since inability to meet market commitments affects customer relations and reflects poorly upon the credibility of the program (Albrecht, 1989).

Table 1 presents indicative heavy metal concentrations in different MSW composts and demonstrates that source separated municipal wastes produce a higher quality end product compared to non-source separated municipal solid waste. Source separation simply means putting waste out for collection in separate containers.

Table 1. Concentration of heavy metals in different composts

Heavy metal	Source separated MSW compost: Europe and North America	Source separated MSW compost: Java, Indonesia	Non-source separated MSW compost: Netherlands	**Proposed standards for MSW compost in developing countries**
Arsenic	-	0.5	-	**10**
Cadmium	1.2	0.9	7.3	**3**
Chromium	27.0	20.0	164.0	**50**
Copper	59.0	54.0	608.0	**80**
Lead	86.0	99.0	835.0	**150**
Mercury	0.9	0.9	2.9	**1**
Nickel	17.0	50.0	173.0	**50**
Zinc	287.0	236.0	1567.0	**300**

(World Bank, 1997a)
See Annex D for a discussion on the development of proposed compost standards.

Developing countries should exercise caution if applying industrialized country compost standards because these measures are site specific and may be inappropriate. The compost standards in Table 1 were recommended by the World Bank (1997a) for Indonesia and could be applied to other developing countries.

The proposed compost guidelines for Indonesia were created to meet all environmental regulations throughout the country and to assure the public that the compost is safe for use. The guidelines do not propose a stringent and expensive testing regime, rather they have been developed to encourage "clean" composting that will maximize market development and minimize future process changes. Assumptions and factors used to set high quality compost standards for unlimited applications include:

- heavy metals should be safe for use under all soil conditions
- compost product has to be of quality such that no leaching, or plant uptake, of heavy metals will occur even under acidic soil conditions
- prevent the accumulation of heavy metals even after repeated applications, which could occur on horticultural lands proximate to cities
- guarantee all future land use options with sufficient standards so that site-specific controls, even after many years of application, are unnecessary
- limited to only one class since laboratory testing facilities are usually too limited to ensure the quality of two compost classes
- prevent the gradual pollution of relatively clean lands
- conservative since testing costs tend to reduce testing frequency to an absolute minimum
- sufficiently stringent to promote development of composting procedures and systems design that can be exported to other countries
- encompass all soil amendments, such as worm castings from vermicomposting operations

It is also suggested that the standards be re-evaluated after five years of experience with MSW composting in different communities. If the standards cannot be achieved continuously at different locations, the reasons for exceeding the limits should be identified and, if possible, mitigated. Heavy metal standards may not be needed if the compost is going to be used in non-agricultural land uses, e.g., rehabilitation of mine sites or landfill cover. However, it is prudent to design a waste management system that has the potential to produce good quality compost with unlimited marketing potential. With proper attention to source separation and compost process control, these standards can readily be achieved in most cities.

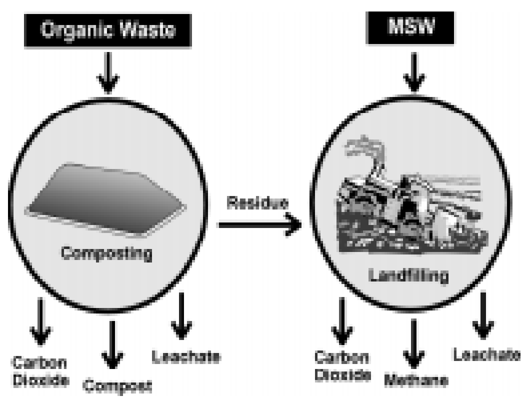
Similar to heavy metal standards, a review of the proposed process is critical for ensuring pathogen and weed-seed suppression. Generally if the compost material has been exposed to temperatures in excess of 55°C for three consecutive days, pathogens will be sufficiently reduced. In developing countries, where reliance on laboratory tests and restrictions on compost use should be minimized, waste management authorities should focus on the provision of a sound compost process, with quality and temperature controls.

ENVIRONMENTAL ISSUES

The emission of landfill gases (LGs) produced by the anaerobic and aerobic decomposition of organic matter is a major source of Greenhouse gases (GHG) which are responsible for global warming and ozone depletion. There is significant variation in the amount of carbon present in different municipal solid waste streams. However, it is reasonable to assume that one million tonnes (Mt) of unsorted MSW contains approximately 0.3 Mt of carbon in various forms. Experimental research and process modeling demonstrate that about 0.2 Mt would be converted to landfill gases (LGs) consisting of 0.09 Mt carbon dioxide and 0.09 Mt methane, and other trace constituents. LG emissions from landfills account for nearly half of the world's total anthropogenic sources of methane. Furthermore, methane is between 19 and 21 times more potent as a GHG than is carbon dioxide.

It is therefore not surprising that eliminating methane emissions from MSW can substantially lower the world's overall GHG emissions. Although beneficial, recovering methane from landfills has proven to be only partially successful since up to 60% of the methane generated escapes through leakage. It is clearly much better to prevent landfilling of organic waste in the first place.

Figure 1. Environmental impact of composting versus landfilling



Composting is one of the simplest ways to prevent emissions of methane because the organic fraction of the waste stream is diverted from landfill. While composting does release carbon dioxide, it is currently considered to be a neutral process since the removal of carbon dioxide from the atmosphere by photosynthesis to produce organic matter is also not considered.

Landfill leachate is created when water percolates through the waste and biological and chemical constituents from the waste is brought into solution. Depending on the landfill design and prevailing weather conditions, composting may not significantly reduce the quantity of landfill leachate, but it will improve the quality of the leachate. This is achieved by reducing the concentrations of biochemical oxygen demand (BOD) and phenols produced as a byproduct from the decomposition of leaves and metals mobilized by the formation of carbonic acid from the decomposing organics. Composting may also produce leachate, potentially high in BOD and phenols, which should not be discharged into water bodies. Collecting and re-circulating the leachate into active compost piles will mitigate any environmental impacts while at the same time enhance the compost process (the composting process is usually a net-water user).

In developing countries, organic matter constitutes a significant portion of municipal solid waste. Diversion of organic materials from landfilling extends the life of the landfill by reducing the amount of waste to be disposed.

Odors are produced when conditions inside the compost pile become anaerobic through a lack of oxygen. A well operated composting facilities should produce minimal objectionable odors.

The final compost product can be beneficially used as a soil amendment. Recycling organic matter back into agricultural applications improves overall soil conditions by:

- developing and maintaining structure
- improving physical properties
- decreasing susceptibility to erosion
- encouraging microbial activity
- providing potentially available plant nutrients (Hesse,1984)

The effects of chemical fertilizers compared to compost are often misunderstood. The main difference between the two is that the nutrients contained in the chemical fertilizer are used rapidly but incompletely, whereas the nutrients supplied by the compost are used slowly and stored in the soil over an extended period (Kumazawa, 1984). Chemical fertilizers are generally preferred over compost because they are easy to handle, store, and apply, and because they often receive economic subsidies from governments. However, a synergistic relationship exists between compost and chemical fertilizers, and greater fertilizer efficiency can be established through the use of compost in conjunction with chemical fertilizers (World Bank, 1997a).

Application of compost to agricultural soils may also help to suppress certain plant pathogens and reduce the incidence of disease. The Institute Pertanian Bogor in Indonesia found that compost significantly reduced the occurrence of certain plant root diseases of economic importance, namely seedling disease of chili peppers, tomatoes, and sweet corn, and wilt disease of soybeans (World Bank, 1997a).

COST OF COMPOSTING

Composting rarely generates profits on its own. However, when viewed as a component of an integrated solid waste management program, composting can provide economic benefits on a much larger scale. The costs of composting includes raw materials, production, marketing, and hidden environmental costs; whereas the benefits involve the market value of the compost, savings from avoided waste disposal costs, as well as various positive environmental impacts.

When considering the large quantities of organic matter generated in developing countries, governments can save money by reducing the amount of waste requiring collection, transport, and disposal. The extent of these savings are dependent on how the waste management system incorporates composting initiatives, including the elimination of temporary dumping sites, rerouting of collection vehicles, and the redirection of labor.

Traditional cost accounting systems usually do not include the hidden costs and benefits of environmental and social externalities since they are difficult to quantify. Table 3 presents some of the environmental costs and benefits of composting which are rarely accounted for.

Table 2. Environmental costs and benefits of composting

Costs	Benefits
■ potential odor emissions ■ improper disposal of rejects	■ reduced landfill space ■ reduced surface and groundwater contamination ■ reduced methane gas emissions ■ more flexible overall waste management system ■ reduced transportation costs ■ enhanced recycling of materials such as paper, metal and glass ■ reduced erosion and improved efficiency of synthetic fertilizers ■ reduced air pollution from burning waste

There are other benefits which may not directly impact the operation of the composting facility but do affect the overall health and well being of society. Water contamination can occur from leachate infiltration or from disposing of waste into open water bodies. Poor water quality has been linked to various human infections and diseases. Each year, according to the World Health Organization (WHO), about 900 million people experience diarrhea or contact diseases such as typhoid and cholera spread by contaminated water. Providing alternative waste treatment options, such as composting, will reduce the quantities of waste blocking rivers, canals and drains, and stagnant water where mosquitoes prefer to breed and potentially transmit diseases, such as malaria and Dengue fever.

Residents often burn their waste, contributing significantly to urban air pollution which can lead to respiratory illnesses such as chronic bronchitis. A 1991 emissions inventory prepared by the Indonesian Environmental Control Agency (BAPEDAL) estimated the share of total air pollutants attributed to solid waste burning. In Jakarta about 8 percent of particulate matter and 8 percent of hydrocarbons originated from solid waste. Bandung experienced even higher levels of 20 and 17 percent, respectively (Kozak and Sudarmo, 1992. Cited in World Bank, 1994).

Applying compost as an amendment to agricultural land for improvement of soil properties and erosion reduction is another benefit which is rarely considered. The costs of soil erosion are not reflected in conventional measures of economic welfare because:

- markets rarely exist for soil resources
- influence of externalities on the true costs of soil erosion
- systems of national accounts are biased to treat natural resources as free goods (Magrath and Arens, 1989)

Box 1: Cost of soil erosion on Java, Indonesia

Soil degradation occurs gradually as soil depth declines by erosion and leaves progressively less topsoil and a lower nutrient supply. Erosion leads to decreased agricultural productivity and profitability, and the deposition of soil at downstream locations reduces the benefits of infrastructure, such as reservoirs and irrigation systems. Magrath and Arens (1989) estimated that for the island of Java, soil erosion costs the economy between $340 and $406 million per year; on-farm losses of productivity account for $315 million and downstream damages cost $25 to $80 million (1989 $ values).

Because of these hidden costs, benefits and savings, MSW composting should not be evaluated solely by the sale of finished compost. The traditional cost accounting approach used by some municipal authorities has resulted in the closure of several compost operations established in the past (Selvam, 1996).

CONCLUSIONS

Composting is all too often implemented for the wrong reasons. It will not make large profits, nor will it solve all solid waste management problems. Incentives, such as the availability of government subsidies and soft loans, are frequently used to set up composting projects which cannot be sustained on a long-term basis. Composting should be considered as part of an integrated solid waste management strategy with appropriate processing technologies selected based on market opportunities, economic feasibility, and social acceptance. Cost effective and sustainable composting is possible within the context of an integrated solid waste management strategy. Participation and cooperation from many stakeholders is required, including national governments, municipalities, local communities, waste generators, and the private sector.

To enhance municipal composting efforts the following are required: (i) improved policies, (ii) capacity building-technical and managerial, (iii) increased public education, (iv) proper full cost accounting, (v) integration with agricultural and horticultural activities, and (vi) more focus on implementation and day-to-day operations.

Governments should support and encourage community based, private sector, and municipal composting initiatives by:

- providing technical assistance on composting techniques
- developing guidelines for the implementation of low-cost facilities
- evaluating loans and other financial support
- allocating land for compost facilities on a long term lease basis
- establishing and enforcing compost quality standards
- regulating and monitoring the performance of compost operations
- promoting the use of compost through public awareness campaigns
- using compost in its own departments, such as public works and agriculture
- reducing subsidies on chemical fertilizers

RECOMMENDATIONS

Composting Do's

- ✔ Source separate compostable materials from the waste stream
- ✔ Encourage small-scale decentralized composting projects
- ✔ Use labor intensive composting processes first
- ✔ Conduct an in-depth market study for the compost end product
- ✔ Study existing and past composting projects
- ✔ Establish compost quality standards
- ✔ Provide incentives to encourage implementation and operation of composting projects
- ✔ Integrate composting within the existing solid waste management system
- ✔ Involve community based and non-governmental organizations
- ✔ Encourage public participation and input
- ✔ Assess public needs and willingness to participate
- ✔ Educate all stakeholders about the benefits of composting

Composting Don'ts

- ✗ Do not compost mixed municipal solid waste
- ✗ Do not initially establish large-scale composting facilities
- ✗ Do not rely on highly mechanized composting processes
- ✗ Do not assume that the compost end product will have an immediate use
- ✗ Do not choose technology which is unreliable and not replicable
- ✗ Do not assume that international compost standards are appropriate for the end use
- ✗ Do not provide funding without monitoring the implementation and performance of the composting project
- ✗ Do not assess composting success solely on a municipal financial basis
- ✗ Do not rely on enzymes or "special" inoculates to enhance the process

REFERENCES

Albrecht, R., 1989. How to Succeed in Compost Marketing. The Biocycle Guide to Composting Municipal Wastes. The JG Press, Inc., Emmaus, Pennsylvania, USA, pp. 118-119.

Alternative Technology Group (GTA), 1992. The SIRDO From Mexico. Los Alamos, San Mateo, Naucalpan, Edo. de Mexico.

Asomani-Boateng, R., Haight, M. and C. Furedy, 1996. Community Composting in West Africa. Biocycle, January. pp. 70-71.

Bennett, C., Bloom, D.E., Bloom, L.R., Robinson, M.S., and M.H. Simpson, 1992. Enterprises For the Recycling and Composting of Municipal Solid Waste in Jakarta, Indonesia. Development Discussion Paper No. 433, Centre for Policy and Implementation Studies, Jakarta, Indonesia, October.

Chesapeake Occupational Health Services, 1991. Health Surveillance Program for Compost Workers: An Epidemiologic Review. WSSC Site II. Silver Spring, Maryland. Cited in Epstein, E., 1996. Protecting Workers at Composting Facilities. Biocycle, September, pp. 69-77.

de Bertoldi, M., 1993. Compost Quality and Standard Specifications: European Perspective. Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects, International Composting Research Symposium, Columbus, Ohio, 1992. Cited in World Bank, 1997. The Use of Compost in Indonesia: Proposed Compost Quality Standards. Infrastructure Operations, Country Department III, East Asia and Pacific Region, June.

de Bertoldi, M., Vallini, G., and A. Pera, 1983. The Biology of Composting: A Review. Waste Management and Research, 1, pp. 157-176.

de Bertoldi, M., Zucconi, F., and M. Civilini, 1988. Temperature, Pathogen Control and Product Quality. Biocycle, February, pp. 43-50.

Economist, 1998. A Survey of Development and the Environment. March 21st.

Epstein, E., 1996. Protecting Workers at Composting Facilities. Biocycle, September, pp. 69-77.

Hesse, P.R., 1984. Potential of Organic Materials for Soil Improvement. Conference paper in Organic Matter and Rice. International Rice Research Institute, Manila, Philippines.

Indian Supreme Court, 1999. Solid Waste Management in Class 1 Cities in India. Report of the Committee Constituted by the Honourable Supreme Court of India.

Johannessen, Lars Mikkel, 1999. Guidance Note on Recuperation of Landfill Gas from Municipal Solid Waste Landfills. The World Bank, Urban and Local Government Working Paper Series, No. 4.

Kozak, J.H. and R.P. Sudarmo, 1992. An Overview of Air Pollution in Jakarta. Report of the EMDI Project, Jakarta, Indonesia. Cited in World Bank, 1994. Indonesia: Environment and Development. Washington, D.C., USA.

Kumazawa, K., 1984. Beneficial Effects of Organic Matter on Rice Growth and Yield in Japan. Conference paper in Organic Matter and Rice. International Rice Research Institute, Manila, Philippines.

Langouche, D.M., 1988. Organic Recycling and Biofertilizers in Agro-Chemicals News in Brief. FADINAP/ARSAP, Agriculture Division, Economic and Social Commission for the Asia and Pacific (ESCAP), United Nations, Bangkok, Thailand, September.

Lardinois, I. and A. van de Klundert, 1993. Organic Waste: Options for Small-Scale Resource Recovery. TOOL, Amsterdam and Waste Consultants, Gouda, The Netherlands.

Lardinois, I. and A. van der Klundert, 1994. Recycling Urban Organics in Asia and Africa. Biocycle, June, pp. 56-58.

Magrath, W. and P. Arens, 1989. The Costs of Soil Erosion on Java: A Natural Resource Accounting Approach. Environment Department Working Paper No. 18, World Bank, Washington. D.C., USA, August.

Malmros, P. and C. Petersen, 1988. The Working Conditions at Danish Sorting Plants. ISWA 88 Proceed ing of the 5th International Solid Waste Conference, 1:487-491, Copenhagen, Denmark. Cited in Epstein, E., 1996. Protecting Workers at Composting Facilities. Biocycle, September, pp. 69-77.

Mazumdar, I., 1992. India. Warmer Bulletin 34, August, p. 3.

Mehta, K., 1992. City Waste Management in India. Warmer Bulletin, May, p. 18.

Obeng, L.A. and F.W. Wright, 1987. The Co-composting of Domestic Solid and Human Wastes. Integrated Resource Recovery. Technical Paper No. 57, World Bank, Washington, D.C., USA.

Pahren, H.R., 1987. Microorganisms in Municipal Solid Waste and Public Health Implications. CRC Critical Reviews in Environmental Control 17 (3), pp. 187-228. Cited in Epstein, E., 1996. Protecting Workers at Composting Facilities. Biocycle, September, pp. 69-77.

Perla, M., 1997. Community Composting in Developing Countries. Biocycle, June, pp. 48-51.

Richard, T., Woodbury, P., Berslin, V. and S. Crawford, 1993. MSW Composts: Impacts of Separation on Trace Metal Contamination. Composting Frontiers, Volume 1, 3, Maplewood. Cited in World Bank, 1997. The Use of Compost in Indonesia: Proposed Compost Quality Standards. Infrastructure Operations, Country Department III, East Asia and Pacific Region, Washington, D.C., USA, June.

Riffaldi, R., Levi-Minzi, R., Pera, A., and M. deBertoldi, 1986. Evaluation of Compost Maturity by Means of Chemical and Microbial Analyses. Waste Management and Research (4), pp. 387-396.

Rylander, R., 1993. A Perspective on Indoor Air Microbiological Contamination. pp. 334-337. Cited in C.B.A.C.C.E. Sterling (ed.). American Society of Heating, Refrigeration and Air Conditioning Engineers. Cited in Epstein, E., 1996. Protecting Workers at Composting Facilities. Biocycle, September, pp. 69-77.

Rynk, R. (ed.), 1992. On-Farm Composting Handbook. Northeast Regional Agricultural Service, Ithaca, New York, USA.

SEEDS, 1984. Community Management of Waste Recycling: The SIRDO-Mexico. Pamphlet No. 8, New York, USA.

SEEDS, 1997. Empowering the Next Generation: Girls of Maqattam Garbage Settlement. Pamphlet No. 19, New York, USA.

Selvam, P., 1996. A Review of Indian Experiences in Composting of Municipal Solid Wastes and a Case Study on Private Sector on Private Sector Participation. Conference of Recycling Waste for Agriculture: The Rural-Urban Connection. Washington, DC, USA, September 23-24.

Solid Waste Management and Resource Mobilization Center, 1988. Instruction Manual for the Operation of the Compost Plant Teku (Production Unit). Kathmandu, Nepal. Cited in Lardinois, I. and A. van de Klundert, 1993. Organic Waste: Options for Small-Scale Resource Recovery. TOOL, Amsterdam and Waste Consultants, Gouda, The Netherlands.

Tchobanoglous, G., Theisen, H. and S. Vigil, 1993. Integrated Solid Waste Management: Engineering Principles and Management Issues. McGraw-Hill, Inc., New York, USA.

United Nations Environment Programme (UNEP) International Environmental Technology Centre (IETC), 1996. International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management. IETC Technical Publication Series, Issue 6.

White, S., 1996. Vermiculture Bioconversion in India. Biocycle. June, pg. 65.

World Bank, 1994. Indonesia: Environment and Development. Washington, D.C., USA.

World Bank, 1997a. The Use of Compost in Indonesia: Proposed Compost Quality Standards. Infrastructure Operations, Country Department III, East Asia and Pacific Region, Washington, D.C., USA, June.

World Bank, 1997b. Brazil: Managing Pollution Problems, The Brown Environmental Agenda, Volume II-Annexes. Natural Resources, Environment and Rural Poverty Division, Country Department 1, Latin America and the Caribbean Region, Washington, D.C., USA.

ANNEX A. REVIEW OF COMPOST PROGRAMS

Composting Projects

Despite the relative simplicity of composting, its suitability for developing countries, and its compelling economic and environmental benefits, several projects initiated over the past decades have failed due to technical, financial, and institutional reasons. Few urban areas have been able to successfully operate composting plants due to a combination of the following:

- inappropriate technology
- poor quality feed stock waste
- lack of operator education and training
- mechanical breakdown
- poor maintenance
- high operating costs
- offensive odor emissions
- poor marketing plans for the end product
- insufficient focus on management
- lack of cooperation from the public and municipal governments

Transfer of solid waste technology, including processes and equipment, is usually from industrialized countries to less developed countries. Often the technology is not directly applicable, as it fails to adequately consider local factors such as the waste characteristics, seasonal variations in climate, lack of technical education and training, cultural attitudes towards solid waste, and the status of waste management in political institutions.

The preference of mechanized composting technology over labor intensive processes is usually inappropriate for developing countries. A lack of trained and educated personnel to control the daily operations results in a low-quality end product and frequent mechanical breakdowns. When a piece of equipment becomes inoperable from misuse or poor maintenance, it is often too expensive and time consuming to purchase and import foreign spare parts.

Many composting facilities are designed to process high-quality waste consisting primarily of organic matter. Often the waste arriving at the plant is mixed municipal solid waste which requires more energy to process, causes mechanical breakdowns, and reduces the quality of the final compost. Source separated organic waste is the preferred feed stock since contamination by plastics, glass, metals, and household hazardous materials is minimized. The principle source of heavy metals in MSW is often common household products: batteries (mercury, cadmium, lead, zinc), leather (chromium), paints (chromium, lead, cadmium), plastics (cadmium, lead, nickel), light bulbs (lead), paper (lead), consumer electronics (lead, cadmium), ceramics (lead, cadmium), cosmetics (cadmium, zinc), and dust from sweeping (de Bertoldi, 1993; Richard, 1993). However, the biggest source of contamination in cooler climates is usually coal-ash (from home heating).

Municipalities often give solid waste management a low priority in terms of financial and institutional support. Lack of coordination between composting facilities and solid waste management authorities, inadequate financial resources, absence of technical guidance, and poor marketing plans are common problems experienced by composting operations in many developing countries. Technical problems and poor management invariably lead to higher production costs and ultimately financial losses. For example, a composting plant operating in Delhi experienced an increase in production costs from Rs. 384 per tonne in 1983 to Rs. 2,091 in 1991. A corresponding increase in the selling price of the compost was only marginal because of low product demand (Selvam, 1996).

Box A1. Vermicomposting in Indonesia

Vermicomposting is a successful method to process organic waste in densely populated, low-income neighborhoods in Indonesia. A pilot group of about 60 Jakarta families use 30 L tubs with 0.5 kg of worms to compost household organic material. After one to two months, a tub can produce 20 kilograms of vermicompost which is used by the family or sold locally to supplement the household income (Perla, 1997).

Box A2. Apartment composting in India

Patna, India has a population of about one million with little door-to-door waste collection nor any composting facilities or sanitary landfills. On average a three person household generates 2.1 kg of food waste each week. Backyard composting is used by some households, but this is not an option for those living in apartments. A composting method was developed for apartment dwellers to use their balconies and window sills. Excess water is drained from the organic waste and placed in clay pots. Soil supplemented with floor sweepings and dried moss from roof tops is added to equal amounts of waste. The compost matures in 3 to 4 months and is used directly for planting without further additions of fertilizer of chemicals. Flowers, ornamental plants, spinach, and tomatoes are successfully grown in the compost (Mazumdar, 1992).

Asomani-Boateng *et al.* (1996) describe how several African countries built sophisticated, highly mechanized MSW composting plants with the aid of foreign capital and assistance during the 1970s and 1980s. Lack of equipment and technical personnel, mechanical breakdowns, and financial restrictions resulted in these facilities becoming largely inoperable.

In 1974, the Government of India began a modified scheme to revive MSW composting by focusing on cities with a population over 300,000. Recognizing the link between waste collection, composting and agriculture, the Ministries of Agriculture and Urban Development each reimbursed percentages of composting capital and operating costs. During a ten year period, eleven mechanical composting facilities, with processing capacities ranging from 150 to 300 tons of MSW per day, were established in cities like Bombay, Delhi, Kanpur, Bangalore, Jaipur, and Calcutta. Today, with the exception of Delhi and Bangalore, all of the plants have been shut down due to poor quality solid waste, wrong choice of equipment, poor maintenance, higher production costs and financial losses, low priority at the top level, and poor marketing efforts (Selvam, 1996).

A 1990 survey conducted in Brazil discovered that 57 municipalities had composting facilities, of which only 18 were operating and 15 were under construction. The other 24 plants were closed as the result of operational or financial failures. Composting was promoted by BNDES, a special fund for recycling or composting plants which was available to municipalities, autonomous agencies, or concessionaires. Funds were channeled to contractors whose technical and marketing assumptions were not always appropriate for municipal needs and specifications. Municipal managers were often frustrated by an erroneous vision of generating a profit on the composting operation or by the inability to produce compost of the quality necessary for the market. Not only did small municipalities experience difficulties with composting, the city of Rio de Janeiro apparently spent US$30 million on a 1,200 tons per day composting plant commissioned in 1993. The plant was shut down one year later because of operational and odor problems, and it remains closed today (World Bank, 1997b).

Box A3. Community composting in Brazil

In Olinda, two neighborhoods have set up composting units on plots of land of about 250 m2. Incoming waste is dumped into a shallow, lined pit and lifted onto a sloped sorting table where rejects and recyclable materials are removed. A team of six individuals can sort one trailer load of waste, weighing approximately 600 kg, in about 45 minutes. The remaining organic matter is weighed and formed into windrows. The composting process is controlled by measuring the temperature on a daily basis and the windrows are turned when the temperature drops or when it rises above 65oC. Pieces of plastic and other reject material that were missed during pre-sorting are removed when the windrows are turned. Stabilized compost is sieved before it is transferred to stockpiles for future use. Regular supervision of the composting process is necessary to ensure proper control (Lardinois and van der Klundert, 1993).

Composting in Sao Paulo, Brazil

Despite the numerous examples of Brazilian composting plants that have failed, the Municipality of Sao Paulo has managed to run a large successful composting operation since the early 1970s. Two materials sorting and composting plants are located in Vila Leopoldina and Sao Mateus. Each plant has been modified and enlarged by the municipality since the installation and currently have capacities of 900 and 600 tons per day, respectively.

A study of the efficiency of the Sao Mateus plant reported that for each ton of waste processed, the output is made up of 53% compost, 4% recyclable material, and 43% rejects that are disposed in sanitary landfills. After taking into consideration the income from compost sales (US$5.80 per ton of compost, or US$3.08 per ton of waste processed) and recyclable sales, the municipality is required to subsidize the operation at a cost of US$10.76/ton of waste processed (World Bank, 1997b).

Box A4. Household source separation in Egypt

Efforts are underway to convince Cairo residents of the benefits of separating their wastes into organic and non-organic fractions. In an experimental project, 600 households are separating their residential wastes into two streams before collection. The health and efficiency of the waste collectors and the quality of the compost are being monitored. The collectors and processors realize numerous benefits from source separation: reduced incidence of worker injuries and waste related diseases, higher selling price of cleaner recyclable materials, less time required to sort the incoming waste materials, and improved compost quality. Municipal waste management authorities also benefit from household source separation because less waste has to be collected resulting in lower transportation and disposal costs (Lardinois and van der Klundert, 1993).

Composting in Cairo, Egypt

Settlements of landless family groups, known as the Zabbaleen, located on the outskirts of Cairo rely on the collection and sorting of urban solid waste as a source of income. Maqattam is the largest of the Zabbaleen settlements with a population of seventeen thousand people. In the early 1980's, a community composting operation began at a former quarry in the Maqattam settlement to compost garbage from which recyclables have been removed and pig manure from the zeribas. Lardinois and van der Klundert (1993) report that the waste is dumped by a mechanical front-end loader through a grid onto a conveyor belt, which transfers the organic material to a hopper and finally to a rotating, cylindrical drum, where the material is sieved. The composting time varies from only six to fifteen days since the waste has already undergone partial decomposition. Mechanical parts for the plant can be purchased in Egypt, but some electrical parts have to be imported.

The final compost is sold to local farmers to improve the quality of existing agricultural soils. Even though the overall quality of the compost appears to be good, small pieces of glass and plastics and significant quantities of heavy metals have been observed in the final product. According to SEEDS (1997), the total cubic metric tonnage of compost produced and sold has steadily increased since 1988. The resulting profits cover the operating costs of the plant and supports staff from the Association for the Protection of the Environment (APE) who oversee social development components of the project (functional literacy, health, and income generating initiatives).

Community Composting in Jakarta, Indonesia

Cipinang Besar, a neighborhood in East Jakarta, decided to implement a community composting program to properly dispose of household wastes being dumped into the Cipinang River. Indiscriminate dumping clogged the river and canal and caused flooding during the rainy season. Financial assistance from the United Nations Development Program (UNDP) and the government of New Zealand helped the community to establish its own composting business in 1992. The facility was built from recycled scrap steel, currently employs 12 people, and produces 3 tons of compost per month. Control of the composting business empowers the community and addresses their specific social and environmental needs (Perla, 1997).

The Watam community composting project began in 1990 with support from the Indonesian Center for Policy and Implementation Studies (CPIS) and the local municipality. The project is located on a rent free site adjacent to the municipal transfer station which serves 3,000 families, a park and a market. The facility consists of a cement pad constructed for windrows, curing, screening and storage; a roof shelter to protect the process from rain; and four foot high enclosing walls. A year prior to operation, managers were educated and trained in compost technology, environmental controls, health issues, and business management. Workers also completed a 3 month training program on the composting process and related health risks. Compost produced by the Watam facility was marketed to a nursery chain selling plants and fertilizer to middle- and high-income households and a golf course for landscaping. The project lost its distributor and is now running at half capacity because it is unable to sell the compost (Perla, 1997).

CPIS initially conducted heavy metal tests on the final compost produced by projects it was funding. The results did not show high levels of metals and the compost met 1991 U.S. Environmental Protection Agency (EPA) standards. Untreated compost leachate draining into the Ciliwung River was found to actually contain less pollutants than the river water. Worker health has also been monitored and no adverse effects have been reported (Perla, 1997).

Vermicomposting in India

Founded in 1981, the Bhawalkar Earthworm Research Institute (BERI) has established six large-scale vermicomposting projects and motivated almost 5,000 farmers to use vermicomposting applications. A system implemented by BERI at the Indian Aluminum Co. Ltd. (Indal) site uses worms to treat solid waste and sewage from a colony of 500 homes and to filter the company's canteen greywater so that it can be reused in the cooling tower. Venkateshwara Hatcheries Ltd. applies BERI vermiculture to process almost 4 tonnes per day of poultry residues and manure. The end product is marketed as "Biogold" and sold at a much higher price than conventional compost. A vermiculture facility is successfully operated by Orient Vegetexpo Ltd. to digest 4.5 tonnes of onion residuals per day during a ten month processing season. The adsorptive properties of vermicomposting is able to dissipate the smell of onions within a few hours of feeding (White, 1996).

Composting in Mexico: SIRDO

In response to a lack of proper sanitation leading to the spread of water-borne diseases, the Alternative Technology Group (GTA) developed the Integral System for Recycling Organic Wastes (SIRDO) to treat household wastewater, human excreta and organic matter in rural and urban environments. The end product can be used beneficially within the community, or it can be marketed for application to agricultural soils. SIRDO technology is appropriate for the conditions of developing countries because the units:

- provide decentralized waste treatment
- encourage household source separation and waste recycling
- reduce waste collection, transportation and disposal requirements
- prevent contamination of surface and ground waters
- reduce infrastructure requirements (piping, pumping)
- adapt to both rural and urban environments
- create a beneficial end product
- do not require mechanization or water

A dry SIRDO unit can be built with one or two chambers and takes approximately 6 months to fill one chamber with human excreta and organic matter, which is then kept closed for an additional 6 months. Solar energy is used to enhance the natural aerobic decomposition of the organic wastes. Sufficiently high temperatures should be achieved within the chamber during the final 6 months to eliminate most pathogens from the final compost (GTA, 1992).

SIRDO technology has been refined over the years and is able to treat human and organic wastes. However, examples of SIRDO being implemented in urban communities of Merida and the Valley of Mexico illustrate how political, social, and administrative problems can detract from its successful operation. Strong opposition was experienced at both sites when the system was first introduced. A community-based project like SIRDO worries some government officials that urban populations will become less dependent on state support, thereby leading to more political independence. Many local residents initially did not accept the SIRDO units because they faced a new technology that they did not understand and were required to modify some of their daily habits. A local cooperative was formed in Merida to operate and maintain the units, provide education to community members, and market the final product. The cooperative was initially successful; however, financial conflicts arose which stopped the production of fertilizer and related income-generating activities in the community (SEEDS, 1984).

Private Sector Participation in India

A Bombay based agrochemical manufacturing industry, Excel Industries Ltd., is implementing semi-mechanical MSW composting facilities in various Indian cities. In the past 4 years, five plants have been set up in Bombay, Ahmdabad, Gwalior, Bhopal, and Vijayawada; the largest plant located in Bombay with an installed capacity of 500 tons per day. Excel Industries usually runs its plants on a build, own, operate basis and encourages local partners to take over and operate the plant for a fee.

The final compost product is marketed to farmers under the name of Celrich bio-organic soil enricher. The compost has a lower nutrient value and is more expensive than government subsidized chemical fertilizers; however, farmers understand the benefits of applying compost to their crops. Excel Industries has a nation-wide distribution and sales network for its agrochemicals which provides a marketing and circulating advantage for its Celrich compost to agricultural regions. According to Excel Industries Ltd., approximately 95 percent of their compost is purchased by farmers for growing sugarcane, grapes, bananas, etc. that has resulted in a 25 percent decrease in chemical fertilizer use among these farmers.

According to Excel Industries estimates, a 500 ton per day composting plant requires a capital investment of Rs. 60 million, or US$1.7 million at January 1996 price level, excluding the cost of land. This estimate includes a 5 percent turnkey know-how fee and commissioning charges and about 8 to 10 percent for working capital. The overall production cost of the compost is about Rs. 1,200 to 1,400 per ton. The selling price ranges between Rs. 1,600 to 2,000 per ton of compost subject to transportation distances and other local overheads (Selvam, 1996).

ANNEX B. COMPOSTING MECHANICS

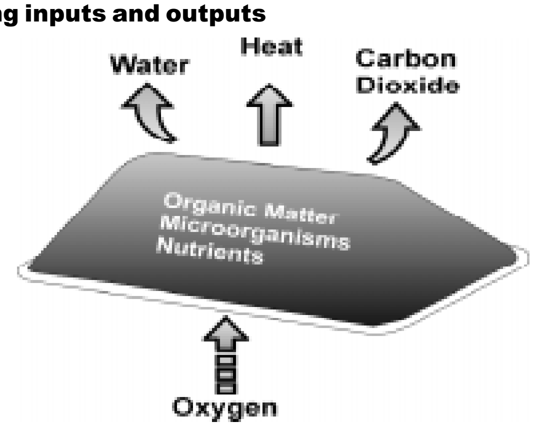
Biological Conversion Process

All life is dependent on nutrient cycling since growth needs decay. Composting is simply the enhancement of the natural biological degradation of organic matter. Microorganisms convert the organic matter into a humus-like material; the end product being more commonly known as compost. The following general formula and Figure B1 illustrate the inputs and outputs for the conversion of organic matter in the presence of oxygen:

$$\text{organic matter} + O_2 + \text{nutrients} \xrightarrow{\text{bacteria}} \text{new cells} + \text{resistant organic matter} + CO_2 + H_2O + NH_3 + SO_4^{2-} + ... + \text{heat}$$

(Tchobanoglous *et al*., 1993)

Figure B1. Composting inputs and outputs



Oxygen

Composting is an aerobic process that by definition requires oxygen. The consumption of oxygen is greatest during the early stages and gradually decreases as the process continues to maturity. Limiting the oxygen supply to the organic materials slows down the composting process, creating anaerobic conditions and potential odors. Different anaerobic reactions by microorganisms form intermediate decomposition compounds such as methane, hydrogen sulfide, and organic acids.

Physically turning the compost or providing forced aeration maintains aerobic conditions and limits odors. Excessive temperatures also indicate that the materials are not receiving adequate airflow. The turning frequency is dependent on the type of system and the length of time to make compost, as shown in Table B1.

Table B1: Turning frequency based on system intensity

System Intensity	Height of Pile (meters)	Width of Pile (meters)	Turning Frequency	Time to Create Final Product (months)
Minimal	3.0-3.7	6.1-7.3	1 time per year	24-36
Low	1.5-2.1	3.7-4.3	3-5 times per year	14-18
Intermediate	1.5-2.4	3.7-5.5	Weekly	4-6
High	2.4-3.0	4.9-6.1	Aerated static pile [a]	3-4

[a] Forced aeration is used for a period of 2 to 10 weeks, after which the piles are occasionally turned.
(Tchobanoglous *et al.*, 1993)

Moisture

Moisture dissipates heat and serves as a medium to transport critical nutrients. Moisture content varies with the particle size and physical characteristics of the raw materials; the preferred moisture content for composting is between 50 and 60 percent. A low moisture content, usually below 40 percent, will slow the composting process whereas a high moisture content, usually above 65 percent, will restrict air movement through the pore spaces and result in anaerobic conditions (Lardinois and van der Klundert, 1993). Excess leachate may also be produced if the moisture content is too high. Moisture levels should be maintained so that materials are thoroughly wetted without being waterlogged. Generally, the materials are too wet if water can be squeezed out of a handful and too dry if the handful does not feel moist (Rynk, 1992).

Nutrients

The primary nutrients required for microorganism growth are carbon, nitrogen, phosphorous, and potassium. Bacteria also need trace amounts of sulfur, sodium, calcium, magnesium, and iron which are usually present in adequate quantities in the organic material.

Of the primary nutrients, carbon and nitrogen play the most important role in the composting process. Carbon is used by microorganisms for energy and growth whereas nitrogen is needed for protein and reproduction. The amounts of carbon and nitrogen relative to one another are referred to as the carbon-to-nitrogen ratio (C/N ratio). A C/N ratio ranging from 20/1 to 25/1 is optimum for composting organic wastes, but higher ratios may be possible. Table B2 indicates various C/N ratios of compostable materials. The optimum C/N ratio can be attained by combining various organic wastes. For example, leaves (high in carbon, low in nitrogen) can be blended with food waste (high in nitrogen) to balance the C/N ratio.

Table B2. Nitrogen content and C/N ratios of compostable materials (dry basis)

Material	Percent N	C/N Ratio[1]
Food processing wastes		
Fruit wastes	1.52	34.8
Mixed slaughterhouse waste	7.0-10.0	2.0
Potato tops	1.5	25.0
Manures		
Cow manure	1.7	18.0
Horse manure	2.3	25.0
Pig manure	3.75	20.0
Poultry manure	6.3	15.0
Sheep manure	3.75	22.0
Sludges		
Digested activated sludge	1.88	15.7
Raw activated sludge	5.6	6.3
Wood and straw		
Lumber mill wastes	0.13	170.0
Oat straw	1.05	48.0
Sawdust	0.1	200.0-500.0
Wheat straw	0.3	128.0
Wood (pine)	0.07	723.0
Yard wastes		
Grass clippings	2.15	20.1
Leaves (freshly fallen)	0.5-1.0	40.0-80.0
Biomass		
Water hyacinth	1.96	20.9
Bermuda grass	1.96	24.0

[1]C/N ratio is based on total dry weights.
(Tchobanoglous *et al.*, 1993)

Generally, all of the organic nitrogen present in organic compounds will biodegrade, whereas only a portion of the organic carbon may biodegrade. For this reason, the C/N ratio should be based on the total dry bio-available weights of carbon and nitrogen.

Microorganisms

Microorganisms are an essential component of the composting process since they are responsible for the biological conversion of the organic matter. The primary microorganisms involved are bacteria, fungi, and actinomycetes and can be further classified according to the temperature ranges described in Table B3.

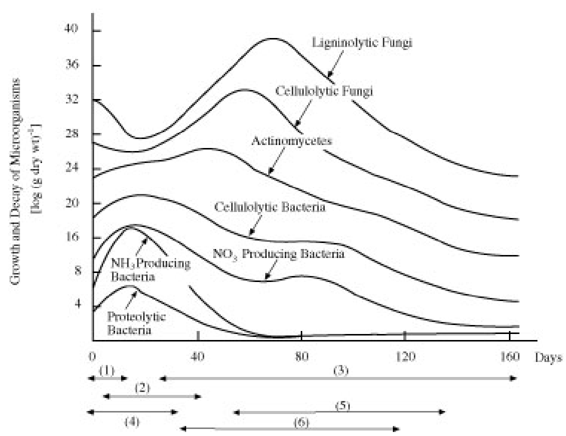
Table B3. Typical temperature classifications for microorganisms

Type	Temperature (°C)	
	Range	**Optimum**
Psychrophilic	-10-30	15
Mesophilic	20-50	35
Thermophilic	45-75	55

(adapted from Tchobanoglous *et al.*, 1993)

Different microorganisms contribute to the decomposition of organics at various stages in the composting process. Microorganism growth and decay over the composting period is shown in

Figure B2. Microorganism growth profile during composting process



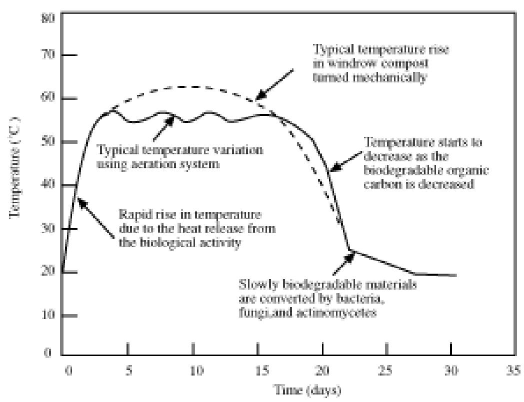
(Riffaldi et al., 1986 and de Bertoldi *et al.*, 1983)
(1) Mesophilic microorganisms break down simple sugars
(2) Thermophilic microorganisms break down proteins and more complex carbohydrates
(3) Mesophilic bacteria, fungi, and actinomycetes attack complex compounds (e.g. cellulose and lignin); C/N, temperature and moisture decline
(4) Phytotoxic
(5) Peak activity for nitrogen fixing bacteria
(6) Humification of organic matter by actinomycetes

Occasionally "innoculums" or special additives are touted as ways to speed up the composting process. Almost always these claims are false. There is sufficient background bacteria to start the composting process, especially if a small portion of finished compost is initially added to the organic matter. The availability of oxygen, C/N ratios, moisture content, and temperature are the principal determinants of the process rate.

Temperature

Microorganism activity releases energy in the form of heat which is dissipated by water evaporation. The temperature rapidly rises in the initial composting stages and eventually decreases as the biodegradable organic carbon is consumed. As illustrated in Figure B3, the temperature profile varies between the windrow and aerated static pile processes in the thermophilic phase.

Figure B3: Temperature variation during composting process



(Tchobanoglous *et al*., 1993)

Optimum composting generally occurs in the mesophilic and thermophilic temperature ranges. Higher temperatures are required to kill pathogens, weed seeds, and fly larvae within the compost. However, excessive temperatures will slow the composting process by causing many of the composting microorganisms to become dormant or die off. Table B4 indicates the temperature exposures required to eliminate certain pathogens and parasites from the compost.

Table B4. Thermal kill of pathogens and parasites

Microorganism	Observations
Salmonella typhosa	Growth ends at 46°C; death within 30 minutes at 55-60°C and within 20 minutes at 60°C
Salmonella sp.	Death within 1 hour at 55°C and within 15-20 minutes at 60°C
Escherichia coli	Most die within 1 hour at 55°C and within 15-20 minutes at 60°C
Entamoeba histolytica cysts	Death within a few minutes at 45°C and within a few seconds at 55°C
Taenia saginata	Death within a few minutes at 55°C
Trichinella spiralis larvae	Quickly killed at 55°C; instantly killed at 60°C
Brucella abortus or Br. Suis	Death within 3 minutes at 62-63°C and within 1 hour at 55°C
Micrococcus pyogenes var. aureus	Death within 10 minutes at 50°C
Streptococcus pyogenes	Death within 10 minutes at 54°C
Mycobacterium tuberculosis var. hominis	Death within 15-20 minutes at 66°C or after momentary heating at 67°C
Corynebacterium diphtheriae	Death within 45 minutes at 55°C
Necator americanus	Death within 50 minutes at 45°C
Ascaris lumbricoides eggs	Death in less than 1 hour at temperatures over 50°C

(Tchobanoglous *et al.*, 1993)

An effective compost operator is able to balance the need for higher temperatures to suppress pathogens with the potential to over-heat the composting mass, thereby slowing the process. A general "rule of thumb" for pathogen suppression is to maintain the compost process at 55 to 65°C for 3 consecutive days.

Level of pH

Composting can occur over a broad pH range due to the variety of microorganisms involved; however, the preferred pH level is between 6 and 8. Fluctuations in pH result from the formation of organic acidic compounds or the production of ammonia. Regardless of the initial pH and fluctuations, the final end product will have a stable pH around 7.

Material Conditioning

Porosity, structure, texture, and particle size all influence the composting process. Porosity is a measure of the air spaces within the pile and affects airflow; structure refers to the rigidity of the particles and the ability to prevent settling and compaction; and texture describes the available surface area for microbial activity (Rynk, 1992).

The optimum particle size is dependent upon the raw material, although a smaller particle size will increase the rate of aerobic decomposition since the available surface area is increased. Depending on the composition of the raw material, size reduction can be achieved by manual and mechanical methods such as screening, grinding, or chopping. Typical particle sizes should be approximately 1 cm for forced aeration composting and 5 cm for passive aeration and windrow composting (Obeng and Wright, 1987).

Bulking agents can be added to the raw material if it lacks the structure to maintain adequate porosity within the compost pile. Wood chips, recycled compost, peat moss, corn cobs, crop residues, bark, leaves, shellfish shells, waste paper, and shredded tires are all examples of good bulking agents. Most of these materials are recovered from the final compost by screening and recycled.

Curing

Curing is an often neglected stage in the composting process. This final stage prevents the use of immature compost by allowing the compost to mature until stable. Curing occurs at lower temperatures, consumes less oxygen, generates less heat, and reduces moisture evaporation. This stage continues the aerobic decomposition of resistant compounds, organic acids and large particles, increases the concentration of humus, and allows the compost to gain disease suppression qualities (Rynk, 1992). Immature compost is an undesirable end product because it continues to consume oxygen, contains high levels of organic acids, possesses a high C/N ratio, competes for nitrogen, and can damage plant growth when used for agricultural applications.

The curing stage does not have a distinct beginning or end. In the windrow process, curing starts when the temperature does not re-heat after turning and begins in forced aeration systems after the temperature decreases to the mesophilic range. The compost becomes mature as the temperature approaches ambient conditions.

Mature compost should meet the following parameters to ensure that it is stable:
- should have a C/N ratio of less than 22 to be safe for agricultural use
- should not re-heat over 20^{o}C upon standing
- should reduce volume of raw organic material by at least 60 percent

Final Conditioning

Conditioning improves the final quality and appearance of the mature compost. Manual or mechanical screening is an effective way to remove unwanted objects, recover bulking agents, and separate organics that are not completely decomposed. Screening also provides different "grades" of compost based on the particle size; coarse compost is usually returned back to the process to be further refined.

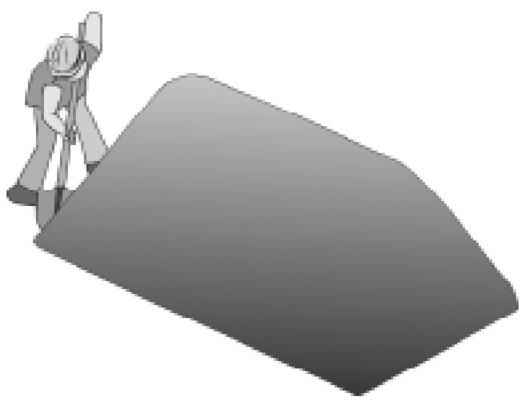
ANNEX C: COMPOSTING PROCESSES

Windrow Composting

Windrow composting is a simple and versatile method where organic matter is built into large piles and physically turned on a regular basis. Regular turning of the windrows helps oxygenate the pile; breaks up particles to increase surface area; improves the porosity to prevent settling and compaction; and allows trapped heat, water vapor, and gases to escape. A turning schedule should be established based on the rate of decomposition, moisture content, porosity of the material, and the desired composting time (often a function of land availability). The frequency of turning the windrow should be adjusted as the rate of decomposition decreases with time.

The size, shape, and spacing of the windrows depends on the equipment used for turning. For example, bucket loaders are used to build high windrows whereas turning machines create low and wide windrows. Manual labor is also used for windrows of a smaller scale when the additional cost and use of machinery is not feasible.

Figure C1. Individual turning a windrow



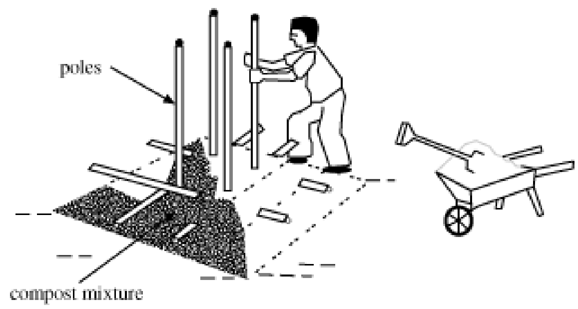
The porosity of the raw material affects the air flow within the windrow. Dense materials, such as manure, require smaller windrows to minimize anaerobic zones, whereas more porous and lighter materials, such as leaves, can be built into larger windrows. A balance needs to be achieved between proper aeration and temperature requirements since small windrows tend to dissipate heat quickly and may not reach adequate temperatures to kill pathogens and weed seeds (Rynk, 1992).

Passively Aerated Windrows

This method is very similar to windrow composting except that turning is not required for aeration. 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 flow through the pipes. A porous base is built out of peat, compost, straw, or grass . The organic material is thoroughly mixed before being place on top of the base to ensure proper air distribution and prevent uneven composting. A covering of peat or compost is layered on top of the material to provide insulation, prevent flies from breeding, and reduce moisture losses and odor emissions (Rynk, 1992).

The Chinese covered pile system uses a grid of vertical and horizontal bamboo poles to provide aeration to the decomposing organic material, as illustrated in Figure C2. A cover of clay mixed with straw is placed on top of the pile to prevent heat and moisture losses. When the clay dries, air ducts are created within the pile by removing the bamboo (Lardinois and van der Klundert, 1993).

Figure C2. Chinese covered pile method



Aerated Static Pile

The aerated static pile method combines techniques from passive aerated windrows with more advanced technology. This method also builds the material into a pile on top of a porous base and then covers it with a layer of peat or compost, but it also uses a blower and pipe network to force air through the material. Bulking agents and amendments are used to create good structure and maintain porosity. Pile heights can vary from 1.5 to 2.5 meters depending on the aeration system used. Good initial mixing of the organics is required to prevent air channeling and anaerobic areas in the pile.

The aeration system is usually operated by a programmed timer or a temperature sensor which can adjust the airflow rates to produce the desired temperature profile. Timers tend to be a simple way to regulate the air flows, but they do not maintain optimum process temperatures. Temperature sensors are better for controlling the composting system; however this method requires greater airflow rates, larger blowers, higher costs and an overall more sophisticated control system (Rynk, 1992; Finstein, 1986).

In-Vessel Composting

In-vessel composting occurs inside an enclosed container or vessel and relies on various methods of aeration and mechanical turning to control the process. These mechanical systems are designed to minimize odors and process time by controlling air flow, temperature, and oxygen concentration. In-vessel composting systems can be divided into two major categories: plug flow and dynamic. A plug flow system operates on the first-in, first-out principle, whereas a dynamic system mixes the material mechanically throughout the process. Bin composting and silos are representative of plug flow systems, while rectangular agitated beds and rotating drums which are characteristic of dynamic systems.

Vermicomposting

Vermicomposting, also known as vermiculture, is a simple technology using the natural digestion process of redworms and earthworms to break down organic material. From the moment it hatches, a worm can consume daily its body weight in organic matter such as vegetables, fruit, leaves, grass, meat, fish, sludge, cardboard, and paper. The waste is continuously turned and mixed as the worms burrow through the medium. Worms multiply fast; under optimum conditions eight worms can produce 1,500 new worms within six months.

Worm castings contain high concentrations of nitrates, potassium, calcium, phosphorous, and magnesium and can be applied instead of chemical fertilizers in some agricultural practices. Castings also contain many worm eggs which continue to enrich the soil when it is applied. The actual worms are also high in protein and are often sold as fish bait or used to supplement animal feed. Worms can be housed in any ventilated container with a lid providing drainage holes or a layer of gravel at the bottom to allow the removal of liquid created in the process. Even though vermiculture is a relatively basic operation, some problems can arise with the most common complaints being:

- process is relatively slow
- difficult to remove the castings
- presence of fruit flies in the warmer months
- need to maintain the temperature between 13 and 25^{o}C to enhance worm activity

Langouche (1988) reports that heavy metal accumulation can occur in earthworm tissue, and pathogens may survive in the worm castings since high process temperatures are not achieved to kill pathogenic microorganisms. Source separating the organic material from the waste stream before being fed to the worms can reduce the heavy metal contamination.

Selecting the Most Appropriate Process

The most appropriate composting system has to be selected based on its technological feasibility, economic costs, and social and environmental impacts. Composting is site specific; a facility that operates in rural North America may not be successfully replicated in rural Asia. Table C1 compares the main technological differences among the previously described composting processes.

Table C1. Comparison of composting processes

Item	Windrow	Aerated static pile	In-vessel with forced aeration
Capital costs	Generally low	Generally low in small systems, can become high in large systems	Generally high
Operating costs	Generally low	High (in sludge systems	Generally low where bulking agents are used)
Land requirements	High	High	Low, can increase if windrow drying or curing is required
Control of air	Limited unless forced aeration is used	Complete	Complete
Operational control	Turning frequency, amendment, or compost recycle addition	Airflow rate	Airflow rate, agitation (dynamic), amendment, or compost recycle addition
Sensitivity to cold or wet weather	Sensitive unless in housing	Demonstrated in cold and wet climates	Demonstrated in cold and wet climates
Control of odors	Depends on feedstock, potential large area source	May be a large area source but can be controlled	Potentially good
Potential operating problems	Susceptible to adverse weather	Control of air supply is critical, potential for channeling or short circuiting of air supply	Potential for short circuiting of air supply (plug flow), system may be mechanically complex

Lardinois and van der Klundert (1993) describe a study conducted in a Karachi, Pakistan neighborhood to determine the effectiveness of three different composting systems: the Chinese covered pile system, the windrow system and the forced aeration static pile system. The Chinese covered pile system placed the organic waste up to almost 1 meter in height and covered with a layer of mixed clay and straw. On a bed of grass, bamboo poles were arranged 1 meter apart to create a grid and later removed to create air ducts. In the windrow system, long open piles of waste were constructed and turned every fifth day of the process. The forced aeration static pile system built piles similar to the windrows on top of a grid of pipes laid on a thick bed of dry grass. Using a timer and a horse-powered air blower, air was blown for 15 minutes every 45 minutes.

The windrow system was the simplest to implement and operate, but the high temperatures were associated with some nitrogen loss. The temperatures could be better controlled by increasing the turning frequency, requiring more manual labor. The Chinese covered pile system was the best form of non-mechanized process control, however using clay as a covering layer increases the steps to build the system. The forced aeration static pile system was suitable for dealing with large quantities of waste but had the disadvantage of requiring a power supply. Even though all of the systems produced good quality compost in three to four weeks, the windrow method was selected as the most appropriate for this neighborhood due to its overall simplicity.

Vermicomposting is also a suitable technology for developing countries, especially at the household and community level in urban centers, because it does not require sophisticated machinery, high capital investment, continuous process monitoring, or extensive administrative support (Mehta, 1992). Source separating the organic matter from other household wastes should reduce heavy metal accumulations in the worms. Caution should also be exercised when using the worm castings because pathogens may have survived the decomposition process.

A Brief Discussion on Centralized Composting Processes

Background. Scientific generalization about the biological phase of a composting enterprise is possible because certain well-understood, predictable, cause-and-effect relationships govern system behavior. Moreover, interactions among the key factors can be variously manipulated to serve different circumstances. This accounts for the process' flexibility and potential for low capital and operating costs. The internal workings of the composting process are briefly summarized below.

Organic wastes invariably carry a variety of benign, beneficial, microbes (mainly bacteria and fungi) fully capable of initiating and carrying through to completion a composting cycle. Therefore, given at least minimal porosity for gas exchange, forming waste into a sizable mass initiates a composting cycle. This is because the mass is thermally self-insulating, hence metabolic heat generated through microbial attack on the waste is retained and the temperature increases. That is, the pile self-heats. Oxygen (O_2) is consumed and, in addition to heat, carbon dioxide (CO_2) and water (H_2O) are generated. Water (and heat) leave the system through evaporation, while the passive diffusion of gases, or forced aeration if deemed necessary, removes CO_2 and replenishes O_2. The result is a more-or-less intensive, controlled, transformation of waste to stabilized process residue (compost).

In devising a composting process management strategy appropriate to circumstance, the key issue can be expressed in a single word—rate. This refers to the speed at which the waste is transformed to compost. Depending on the level of technology employed, the rate can differ by orders of magnitude. Moreover, rate affects the potential for nuisance odor and how this can be prevented. Whatever the approach taken, it is understood that nuisances such as malodor are not acceptable.

A few other remarks are indicated at this point. As already noted, competent microbes are invariably present in the waste, hence composting is a self-inoculating process. No benefit can be expected by adding commercial inoculums, starter cultures, or ‘bioaccelerants’ by whatever-the-name. In a similar vein, any suggestion that a building is needed to enclose the composting material should be viewed skeptically. A canopy to divert intensive rainfall might be considered. The composting area should have a firm surface, whether hard ground or pavement.

Given sufficient area to hold a large inventory of slowly composting material over a lengthy processing cycle, little technological intervention is needed. The opposite extreme, when only a limited area is available, calls for (demonstrably) high-rate composting. This is realizable through relatively simple, carefully selected, technology based on forced aeration and temperature feedback. An intermediate situation with respect to the area available can be satisfied through well-timed mechanical agitation (turning) of the composting material. Matching technological level, which may be equated to transformation rate, to circumstance represents the main problem to be solved.

Three possible approaches to match technology to circumstance. For illustration, three hypothetical scenarios are developed. These are suggestive of numerous possible operational configurations. All would require adjustment, based on practical results as informed by an appreciation of the internal workings of the composting system. Details to be adjusted include pile width and height, waste/compost ratios, and processing time.

Except where indicated, for all three scenarios we provisionally take pile dimensions to be 5 x 2 meters (width x height), with elongation lengthwise into ‘windrows’ for an indeterminate distance. Since the potential for unpleasant odors is greatest at the outset, and well-stabilized compost is a good odor absorbent, the fresh waste is mixed with old compost. A volumetric ratio of perhaps 90% waste and 10% compost is provisionally suggested. Similarly, the newly formed pile is blanketed with 20 cm of compost.

Scenario 1: A large area for the full scale operation is available. In this circumstance, decomposition may be allowed to proceed ‘at its own pace’ without little intervention.

Soon after formation, the interior of the pile (or windrow) becomes depleted of O_2 (anoxic), giving rise to gaseous, malodorous, fermentation products (e.g., volatile organic acids). However, because the material is not disturbed, and because such products are readily biodegraded, malodors are not vented. Rather, the noxious gases, on diffusing outward, encounter O_2 diffusing inward from the pile edge. At the anoxic/oxic (oxygenated) interface the gases are destroyed by common aerobic (O_2-dependent) microbes.

The oxygenated front gradually penetrates inward, leaving in its wake spent, less O_2-consumptive, material. When the front reaches the pile’s interior, the transformation from waste to compost is essentially complete throughout. At that point the pile can be physically disturbed without venting odors. Meanwhile, the windrow has shrunk to perhaps half its original volume and weight.

In judging the progress of decomposition over time, as part of a pilot trial, samples at different distances from the edge are removed periodically. The status of the material is best judged by odor, followed by color, texture, and the intactness of original material (e.g., recognizable banana peels). Measurement of temperature and O_2 would be helpful, but not essential. Tactile evaluation of moisture content is adequate. The material should be moist, but not dripping wet. (Remember—porosity is needed for gas exchange.) Visual comparison of in-progress samples to both fresh MSW and finished compost would be informative. The process may take 5 to 10 months to complete the transformation from waste to compost.

Scenario 2: The available area is somewhat limited. This calls for an intermediate level of intervention, through turning, to speed decomposition.

Smaller windrows are formed initially, perhaps 3 x 1.5 meters (w x h). With a shorter diffusion path-length for O_2 penetration, a partially stabilized state is reached throughout the material relatively quickly. At some point (about 1-2 months) the pile can be disturbed without venting malodors. Then, two or more windrows are combined, using a front-end loader if available. Piling one windrow on top of another is to be avoided. Rather, both (or three) windrows are mechanically disturbed and mixed together into a single larger one.

This larger windrow is itself turned periodically, lack of odor venting potential permitting. The more frequent the turning, the faster the stabilization. If a large facility is contemplated, the purchase of a special turning machine (windrow, or turning, machine) might be justified. It might take 2 to 6 months to reach a well-stabilized state.

Scenario 3: The available area is small. This situation requires a high rate of decomposition. This can be accomplished using forced pressure aeration (air blown up through composting matrix) in conjunction with temperature feedback control. [Caution: vacuum-induced aeration (air sucked down through matrix) is not effective in controlling the process.] Although development of a facility based on Scenario 3 involves a degree of sophistication, routine operation would not be complicated. A rough estimate of total time to completion is 2-3 months.

The aeration system has three basic elements:

- Blowers having a capacity to meet peak demand for heat removal, as exerted time-variably via temperature feedback control. As a conservative estimate, peak demand could be as much as 2 m^3/tonne-minute. This value needs refinement in a pilot trial. Radial blade blowers, which are economical to buy and operate, may be used, as only a low backpressure is anticipated
- Ductwork conveying air from the blowers to the bottom of the windrow, with reasonable uniformity and distributional loss. One approach is to use perforated pipe surrounded by old compost to serve as a plenum.
- Integrated timer/temperature feedback control of the blowers. The timer serves to schedule aeration events to avoid anoxia during the temperature come-up stage. Heat is removed on demand,

so that air exiting from the top of the windrow does not exceed 55-60ºC. Owing to composting system dynamics, this process control strategy automatically provides biologically favorable temperatures and thorough oxygenation of the matrix.

A rough estimate of total time to completion is 2-3 months. However, the material would be kept under forced aeration only until demand for air dwindled and aeration events returned to being solely as scheduled by timer (demand via feedback control ceased). This “active” stage lasts perhaps 2-3 weeks. It might end prematurely, however, because of excessive dryness (the main mechanism of heat removal is the vaporization of water). This may necessitate a re-wetting step. Regardless, the partially stabilized material is moved to a curing stage. This involves passive aeration, with occasional turning being optional.

ANNEX D: COMPOSTING HEALTH AND SAFETY

Pathogens, toxic chemicals, dust and heavy metals are the main health and safety concerns for both waste workers and the general public. Compost workers tend to be more exposed since they are directly handling the waste for an extended period of time.

Health risks are influenced by the composting technology and the raw organic materials used as feed stock. Table D1 compares the health hazards of various materials commonly composted.

Table D1. Relative health hazards of various compostable materials

Raw Material	Pathogens	Bioaerosols	Toxic Organics	Heavy Metals	Dust
Sludge	High	High	Low	Very low	Medium
MSW	High	High	Low to medium	Very low	Medium to high
Yard waste	Medium	High	Low	Very low	Medium to high
Food waste	Low	High	Very low	Very low	Low to medium
Animal waste	Medium to high	High	Very low	Very low	Low to medium
Predominant exposure routes	Oral	Respiratory	Dermal, respiratory respiratory	Oral	Respiratory

(Epstein, 1996)

As shown in Table D1, most compostable wastes contain low levels of toxic organics. MSW may have higher levels due to disposal of household hazardous wastes, pesticides, and other chemicals. Once again, household source separation of the waste before it is brought to the composting facility is recommended to reduce worker injury and compost contamination.

Pathogens

There are two classifications of pathogens; primary and secondary. Primary pathogens can infect healthy individuals, whereas secondary pathogens usually infect individuals with weakened immune systems. Bacteria, protozoan, helminths and viruses are primary pathogens, and fungi and actinomycetes are secondary pathogens.

Human excreta and animal manure contain pathogens which are found in MSW from the disposal of sludge, diapers, and yard trimmings containing domestic animal waste. Table D2 shows that MSW can contain the same or even higher orders of magnitude of indicator pathogenic organisms as sludge and hospital wastes. Open dumping of municipal wastes in urban areas attracts rats, flies, and other insects which can transmit these pathogens to humans.

Table D2. Indicator pathogenic organisms and pathogens in biosolids, hospital waste, and MSW

Microorganism	Biosolids	Hospital Waste	MSW
	number of microorganisms per gram		
Total coliforms	2.8×10^8	9.0×10^8	7.7×10^8
Fecal coliforms	2.4×10^8	9.0×10^8	4.7×10^8
Fecal streptococci	3.3×10^7	8.6×10^8	2.5×10^9

(Pahren, 1987. Cited in Epstein, 1996)

Bioaerosols can contain secondary pathogens such as the fungus Aspergillus fumigatus. This fungus naturally exists in decomposing organic matter and is commonly present in homes, attics, libraries, air conditioning units, building ventilation systems, soil, and compost. According to Epstein (1996), it is the fourth most common mold in households and is present in all seasons. A. fumigatus usually infects only those with weakened or suppressed immune systems. It has been found that healthy individuals who inhale large quantities of A. fumigatus spores do not succumb to infection. In addition to people with weakened immune systems, pregnant women should avoid exposure to secondary pathogens.

Endotoxins found in common gram-negative bacteria and organic dusts can cause mucous membrane irritation (MMI). Repeated exposure to organic dusts can result in itching and watering eyes and nose and throat irritation (Rylander, 1993. Cited in Epstein, 1996).

Danish studies have shown that workers in MSW composting facilities reported flu-like symptoms, eye and skin irritations, and respiratory problems (Malmros and Petersen, 1988. Cited in Epstein, 1996). Improvement in the ventilation systems and rebuilding the plant significantly improved the worker conditions.

In contrast to the Danish facilities, studies to determine the health of workers at biosolids compost facilities in the United States found no detrimental health effects. A five-year study conducted at the Washington Suburban Sanitary Commission Site II biosolids facility in Maryland by Chesapeake Occupational Health Services (Cited in Epstein, 1996) concluded that there was no evidence of adverse health effects related to A. fumigatus; lung air capacities essentially remained unchanged; physical examination findings were stable; chest X-ray results were unremarkable; and employee health concerns decreased. Routine employee examinations at biosolids composting facilities in Columbus, Ohio and Fairfax County, Virginia also reported no adverse health affects related to employment.

It is virtually impossible to eliminate all pathogens from the compost end product. Mature compost will always contain some pathogens, just as natural soil contains pathogens. The composting process should reduce to a safe level all pathogens which are not indigenous to natural soil and can pose a danger of contamination at sufficiently high concentrations. However, setting this minimum level is difficult because it varies among organisms. Fecal coliforms and fecal streptococci are often used as indicator organisms to determine if compost is safe for application, but it is usually too expensive and impractical to regularly test for and control these organisms. Another way to ensure that compost is safe of pathogens is to define and control the composting process (World Bank, 1997a). According to de Bertoldi *et al*. (1988), the most important parameters to produce a safe end product are:

- entire compost mass must be maintained at a minimum of 65°C for 2-3 consecutive days
- material must be mature and biologically stable so as to prevent pathogen regrowth

Heavy Metals

Heavy metals, such as cadmium, lead, and mercury, are found in MSW because of discarded objects like batteries, lighting fixtures, paints, and inks. As seen above in Table D2, heavy metals in compost pose very little health threats to workers. However, a public health hazard exists when poor quality compost is used for agricultural purposes because heavy metals can accumulate in soils and enter the food chain through plant uptake. Source separation of municipal wastes into compostable and non-compostable fractions is an effective way of reducing compost heavy metal concentrations.

Establishing and enforcing heavy metal standards is an effective way to ensure appropriate compost use. As indicated in Table D3, most industrialized countries who consider composting to be part of an integrated solid waste management plan have developed regulations and guidelines concerned with its ultimate use. It should be realized that these regulations and guidelines were established after several years of research and that different scientific approaches results in a wide range of standards between industrialized countries.

Table D3. Global compost standards as of April 1996

Country	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
	(mg/kg dried matter)							
USA (S)	41	39	1200	1500	300	17	420	2800
Canada (MO)	13	2.6	210	128	83	0.83	32	315
Ontario (SSMO)	10	3	50	60	150	0.15	60	500
Austria (MO)	-	4	150	400	500	4	100	1000
Belgium (SSMO)	-	1	70	90	120	0.7	20	280
Denmark	-	1.2	-	-	120	1.2	45	-
France (MO)	-	8	-	-	800	8	200	-
Germany	-	1	100	75	100	1	50	300
Switzerland	-	3	150	150	150	3	50	-
Spain	-	40	750	1750	1200	25	400	4000
Indonesia (proposed)	10	3	50	80	150	1	50	300

(S) refers to sewage sludge
(MO) refers to mixed organics
(SSMO) refers to source separated mixed organics
(proposed) refers to standards proposed by the World Bank-suggested for all developing countries as a good starting point.
(World Bank, 1997a)

Developing countries should exercise caution if applying industrialized country compost standards because the standards are site specific and may be inappropriate. The following factors for setting high quality compost standards were recommended by the World Bank (1997a) for Indonesia and can be applied to other developing countries:

- heavy metals concentrations should be safe for use under all soil conditions
- compost has to be of a quality such that no leaching, or plant uptake, of heavy metals will occur even under acidic soil conditions
- prevent the accumulation of heavy metals even after repeated applications, which might occur on lands near cities
- guarantee all future land use options with standards set sufficiently low so that site-specific controls, even after many years of application, are unnecessary
- limited to only one class since laboratory testing facilities are usually too limited to ensure the quality of two compost classes
- prevent the gradual pollution of relatively clean lands
- conservative since testing costs tend to reduce testing frequency to an absolute minimum
- sufficiently stringent to promote development of composting procedures and systems design that can be exported to other countries
- encompass all soil amendments, such as worm castings from vermicomposting operations

It is also suggested that the standards be re-evaluated after five years of experience with MSW composting in different communities. If the standards cannot be achieved continuously at different locations, the reasons for exceeding the limits should be identified and, if possible, mitigated (World Bank, 1997a). The World Bank's (1997a) proposed standards are for unrestricted application. There may be cases where compost of poorer quality could be used in limited applications such as mine tailings reclamation and daily landfill cover.

Design Precautions

Precautions to mitigate environmental and public health effects can be implemented in the design and siting phases of the composting project. The following criteria are recommended by Bennett *et al.* (1992) for siting a composting facility in Jakarta, Indonesia, but could be applied to other developing countries:

- locate away from wetlands or flood plains
- meet quality standards, such as waste sources low in toxic compounds and heavy metals, and not extremely saline
- avoid densely populated neighborhoods and areas where adjacent land users may find the operations inappropriate, such as hospitals, religious facilities, schools
- locate in accordance with urban plans and zoning regulations
- avoid locating on top of sites which have wastes beneath them, or where toxic waste has been previously disposed
- plan sites to have buffer zones separating the facility from the surroundings, such as hills, trees, fences
- distance from the surface of the facility to groundwater/clay layers/bedrock should be a minimum of 1 to 1.5 meters

- avoid impermeable or overly permeable soils
- locate downwind from residential areas to avoid possible odor complaints

Facility Operation Precautions

There are several ways to reduce worker exposure and minimize health hazards from the composting process. Education is one of the best ways to prevent problems; workers and facility managers should receive ongoing training and education about health and safety issues. Children, the elderly, pregnant women, and immuno-suppressed individuals should not work in composting facilities since they are the most susceptible to infection by pathogenic diseases. The compostable materials should also be source separated to eliminate hazardous wastes, metals, and glass which can cause worker injury.

Obeng and Wright (1987) suggest the additional precautions to be implemented in all composting facilities:

- workers should be encouraged to maintain high standards of personal hygiene
- during hot, dry weather the composting area should be periodically sprinkled with water to reduce dust
- workers should protect themselves by wearing gloves, masks and boots during processes such as sieving or turning, when the spores can be dispersed
- during adverse weather conditions, workers should be encouraged to wear masks, respirators or some other material to cover the mouth and nose in order to avoid dust inhalation