

Report:

ISSUES RELATING TO ORGANIC WASTE DISPOSAL – PART 1 – THE SCIENCE OF ORGANIC WASTE DISPOSAL

A REPORT SUPPLIED BY:
R5 Solutions (NZ) Ltd
PO BOX 4442
CHRISTCHURCH
NEW ZEALAND



Table of Contents

1	Executive Summary	1
2	The Science of Organic Waste Recycling and Reuse	2
2.1	The cost of organic waste ‘disposal’	2
2.2	Organic waste strategies	2
2.3	Composting defined	3
2.4	The composting process	3
2.5	Optimising the composting process	4
2.5.1	The microbial environment.....	4
2.5.2	Process engineering	6
3	Composting technologies	6
3.1	Open Windrows.....	6
3.2	Within Building Systems.....	6
3.3	In-vessel Composting Systems.....	6
4	Standards	7
5	Composting feedstock issues	8
6	Product marketing	8
7	Summary	8

1 Executive Summary

The issues of waste, at a philosophical level, arise primarily from the twentieth century view of the product lifespan as being linear from creation, through use, to disposal. In earlier times, in natural systems and in recent shifts towards sustainability, a more cyclical view prevails. There is an emphasis on reuse and recycling together with minimisation of residuals.

This philosophical shift back to recycling has been given momentum by the impact of waste and its disposal on the environment but more particularly by the voting public affected by the impacted environment. The move towards sustainability has been led from Europe. Key drivers in many countries include protection of groundwater and reduction of greenhouse gas emissions.

This report is the first in a series of three and covers the issues of organic waste recycling and reuse. A second report in the series provides an overview of the HotRot composting system and the third report looks at the science behind the operation of the HotRot system. Each report is complete in itself but combined provided a detailed reference tool for those wishing to understand organic waste composting and the HotRot system.

2 The Science of Organic Waste Recycling and Reuse

2.1 The cost of organic waste 'disposal'

In a natural ecosystem most living tissue is recycled within the ecosystem. Carbon is fixed by plants, used for growth, consumed by animals and released through respiration or decay. Other elements are similarly cycled within the ecosystem. While this cycling is not perfect, many ecosystems are relatively stable for extremely long periods of time.

In the current human-manipulated environment these cycles have been largely lost or significantly disrupted with two important consequences. Firstly, essential nutrients are removed from productive land and ultimately disposed of to landfill or sewer. This causes problems of both depleted lands and enriched receiving environments. Secondly, organic matter that is necessary for effective soil function is depleted. This depletion is relatively slow with significant effects taking decades to manifest. Nevertheless, as significant depletion of productive land has been occurring for nearly a century, very significant effects are now realised.

The first cost of landfilling organic waste is thus a loss of productive capacity of the land, a cost that is almost completely ignored. While chemical fertilisers have reduced the impact of this, their long-term use is not a sustainable option, and does not address organic matter depletion; carbon mining.

The practice of landfilling organic waste is problematic because the waste is not stable. The greenhouse gas methane is produced in high quantities (up to 100kg/tonne of waste) and ground water may be impacted by leachate. Appropriate engineering can mitigate these issues at a cost but avoidance is generally more cost effective and is without long-term risk.

Composting removes organic waste from landfill, but more importantly applying the product to land replaces organic matter and restores the carbon cycle. Soil organic matter gives the soil structure and preserves biodiversity. In purely functional terms, it improves water retention, (counter-intuitively) improves drainage, suppresses crop disease and increases productivity. Essentially the natural cycles can be restored even though they may now be discontinuous in both time and space. This is a practical and achievable sustainability solution for modern society.

2.2 Organic waste strategies

In the latter half of the twentieth century, not only has waste per capita increased, but also the individual's direct post-rubbish-bin involvement in its disposal has become almost zero. Collection, transport and disposal systems are generally effective, but unsustainable with an obvious disconnect between the waste generator and the waste disposer.

Education and community ownership of waste is required. On the one hand the *cost* of waste needs to be recognised and the amount of waste reduced. On the other, the *value* of waste must also be appreciated and appropriate systems put in place to ensure that this can be realised. Where waste is inevitably generated, key impediments to reuse, recycling or recovery are a lack of cleanliness, mixing and contamination.

Treatment and reuse of organic waste via composting is an established and effective technique. Despite this, relatively little organic waste is dealt with in this way. The impediments are two-fold. Firstly, organic waste is frequently mixed with inorganic and non-compostable materials, resulting in composting being impractical, or the compost product being of low value. Secondly, the costs of alternative disposal options such as landfill have been low. In recent years landfill charges have risen and composting is now usually a cost-competitive option, but access to clean waste streams remains problematic.

Waste treatment of all types has tended towards large centralised facilities where economies of scale in processing can be realised. This is not without cost however. Transport charges can be significant, and the 'out of sight, out of mind' mentality engendered in the waste producer is unhelpful. We believe that, in many cases, community or business ownership of small composting facilities to deal with organic waste will be a more effective solution. This offers a number of advantages.

- Transport costs and issues are eliminated
- Waste contributors have ownership of the solution. This is beneficial in achieving a clean organic waste stream
- The costs of waste management are internalised within the business or community with advantages for control and management

A number of examples of this approach are in operation around the world. This approach may be less applicable in densely populated areas, but we still argue that decentralised composting, where waste generation and compost utilisation are geographically close, is a sensible option.

Similarly collection of source-separated waste should be a goal. Often it is argued that collection of separate waste streams is more expensive than collection of mixed waste. However, this does not take into account the additional cost (both capital and operating) of a much larger processing plant that needs to not only separate but treat the waste. Again collection of source-separated waste streams is transferring ownership back to the generator, where it realistically belongs.

2.3 Composting defined

The Composting Association, UK, in its 'Large-Scale Composting – a practical manual for the UK', defines composting as: *"The controlled biological decomposition and stabilisation of organic substrates, under conditions that are primarily aerobic and that allow the development of thermophilic temperatures as a result of biologically produced heat. It results in a final product that has been sanitised and stabilised, is high in humic substances and can be beneficially applied to land."*

Or, less formally - composting is a natural process that turns organic waste into a clean and useful product.

This process can be effectively accomplished in the backyard by occasional application of a fork. This option should not be discounted, as home composting can effectively contribute to waste reduction, but for collected waste in commercial or municipal quantities, a rather more engineered solution is required.

2.4 The composting process

Composting is an application of the natural processes of decay. The distinction being that sufficient organic material is gathered so enough energy (food) is available to support a large and active microbial population, which, through respiration, generates sufficient heat to accelerate the process. This also achieves a selective sterilisation of potential pathogens and seeds that is variously known as sanitisation, pasteurisation or disinfection. Recognition of the process goes back to ancient times, and it is readily achieved on a small scale; although often not very efficiently.

Composting is driven by a succession of microbial processes. Broadly the process may be considered as four phases: Heating, thermophilic decomposition, mesophilic decomposition and curing. In the heating phase microbial respiration, in the presence of oxygen, causes the temperature in the compost mass to rise. As this occurs there is a change in the microbial population from those that thrive at ambient temperatures to those that prefer elevated temperatures up to around 55-60°C (thermophiles)¹. While sufficient readily metabolisable material (energy) remains in the waste, the action of the

¹ While it is recognised that compost piles may achieve temperatures higher than this, this is generally associated with poor heat removal and will lead to inhibition of the true composting process.

thermophiles maintains the high temperature. From a practical standpoint this ensures that pathogens and weed seeds are destroyed and results in rapid waste treatment. It is important to note though that temperature is a function of microbial activity and heat removal from the process; a balance must be struck between allowing sufficient heat to accumulate to provide optimal conditions for compost microbes and the elimination of seeds and pathogens and removing sufficient heat to prevent overheating. While very high temperatures can be generated in composts, these are not particularly beneficial as very few organisms are able to function above 65°C; various publications list the optimum temperature for composting as being between 53 and 65°C, with a number indicating that the temperature should not exceed 60°C.

As the readily available sources of energy (nutrients) declines the compost cools (as the rate of microbial respiration slows) and a new population of mesophilic microbes, preferring warm temperatures, becomes established. The compost remains warm and active, and considerable degradation continues. Indeed the mesophilic phase of composting is likely to be the longest and support the greatest numbers and diversity of microbes. Eventually, all the readily degradable material has been utilised, the temperature returns to ambient, and active composting has ceased. At this stage the compost is usually referred to as 'immature'. This is because it contains relatively high levels of ammonia and other compounds that are toxic to plants. Microbes able to oxidise ammonia to nitrate are not able to survive at elevated temperature. During curing these microbes re-colonise and phytotoxic compounds are dissipated and stabilised.

Depending upon the goals of the process and end use of compost the curing stage can often be omitted. Where a compost-rich plant-growing medium is produced, curing (and appropriate validation) is essential. Where compost is spread broadly to land, curing can often be dispensed with.

Good engineering can optimise the composting process, but it must be recognised that the process is driven by the biology of microbial degradation. With a well-engineered system it is possible to generate immature compost in around 20 days. From a processing point of view it may be possible to reduce the time within the composting unit below this, but more active curing mechanisms will be required. Very short residence times of a few days are sometimes used, but these achieve only sanitisation through the thermophilic composting phase, and the resulting material remains highly biologically active and in need of further composting.

2.5 Optimising the composting process

2.5.1 The microbial environment

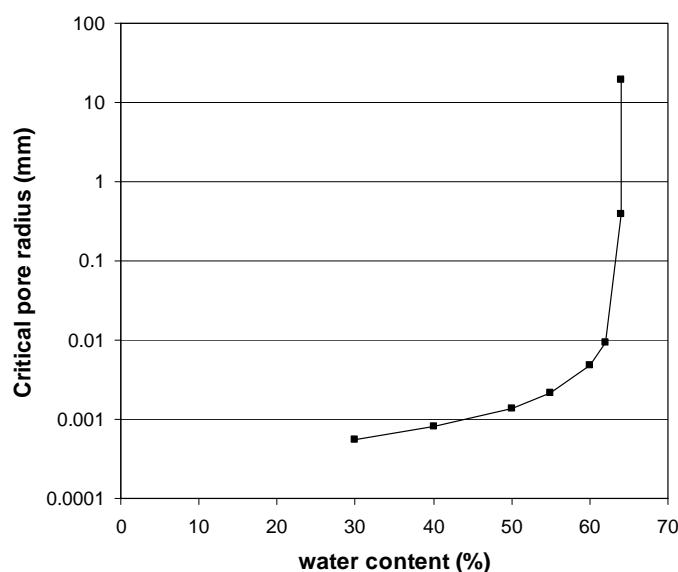
Effective composting requires appropriate feedstock, as this is the 'food' for the microbes that drive the process. A sufficient level of readily degradable carbon is required. This is sometimes expressed as 'volatile solids content' and is essential for rapid microbial growth, which in turn promotes heating. A balance of other nutrients, principally nitrogen is also required. The requirement is often expressed as a C:N ratio. Workable ratios are quite broad – the range 25:1 – 40:1 is often quoted as ideal but lower C:N ratios can be acceptable in well engineered and aerated processes (see Part 3 for more details on C:N ratios and how HotRot deals with low ratio wastes).

Composting is an aerobic process; sufficient oxygen must be supplied to allow the process to proceed. Air must be able to penetrate to all parts of the pile. At the gross level this means mechanisms for turning and air injection is required. At a lower level it also requires that attention be given to particle size, avoidance of accretions or conglomerates, and prevention of preferential air flows (channelling).

Water content is also a critical factor. Moisture needs to be kept at between 40-60%. At higher moisture levels porosity is usually adversely affected (pore spaces become flooded) and it becomes impossible to maintain oxygen levels. The issues underlying air (oxygen) penetration are structure, moisture and heat release. Fast composting requires oxygen delivery to the microbial cells. This is optimal when there is an interlinked network of relatively small often pores. Oxygen movement

through water is around 10,000 times slower than oxygen movement through air. If pores are filled with water, the rate of oxygen transport will be too slow to sustain thermophilic composting. Richard (2000) explains the theoretical relationship between water content and the size of air filled pores (<http://compost.css.cornell.edu/oxygen/capillary.html>).

At any water content below saturation, capillary action within the waste will exert a negative pressure on free water in contact with the waste. This pressure can be related to a 'critical pore radius' the critical pore radius is of great importance, as it describes the size of the waste pores that will be air filled – pores less than the critical radius will be water filled and those above will be air filled. This is shown in the graph below for a model waste. The shape of the curve is expected to be similar for all wastes, although the water levels at which saturation occurs will vary considerably.



The importance of moisture content lies in the shape of the curve and the sudden change in free air space as saturation approaches. In the example above, at 62% water, pores with a radius above 0.01mm are air filled. At 64% water the waste is effectively saturated. This phenomenon illustrates the very sharp cut off between acceptable and unacceptable water levels that is not appreciated by many operators

In addition, moisture is a major heat sink – high moisture levels result in cooler temperatures and insufficient heat for evaporation. At lower moisture levels biological activity is insufficient for the process to proceed.

Not only is the overall moisture content valid but so also is moisture distribution within the pile. As composting proceeds areas will become dry through evaporative losses and simple movement of air and other areas may become excessively wet due to leachate drainage or preferential airflow. Consequentially, areas will also become too hot or too cold. For efficient microbial activity optimal conditions need to be present at the micro level, evenly throughout the mass, rather than as a gross average. Thus mixing of the waste is critical, and the smallest particle size compatible with good aeration should be sought.

While achieving an ideal composting mix may appear intensive, much of this work is done during plant design and commissioning. Where waste streams are reasonably consistent, relatively little effort is required to maintain successful feedstock and microbial environments.

2.5.2 Process engineering

The practical requirements for composting are relatively simple. In addressing large volumes of waste, however, there are problems of hazards, vermin control, odour, leachate, dust and aerosols that need to be addressed. The process needs to be monitored and controlled, and standards met. Any process needs to be cost and energy effective. In large scale composting, therefore, the process is engineered to address the requirements of human society, business and regulation as well as providing appropriate conditions for biological activity. Any system that does not pay attention to all of these factors will not be sustainable (in the broadest sense of the term).

3 Composting technologies

A range of composting-based solutions are available for the treatment of municipal wastes. These are distinguished by the goal of the process and the mechanism for achieving treatment. Two approaches to organic waste are taken: sustainable reuse and waste treatment. In the former, composting is used to produce a useful product that is beneficially reused on land. The wastes processed are separated or selected to ensure that contamination levels are low. In using 'composting' as a waste treatment technology, separation of waste prior to a composting stage is less important and the goals are stabilisation and volume reduction. The final product is of little or no value, and may have to be landfilled. Clearly a sustainable reuse approach is most desirable, but this is only achievable where the means and will for an uncontaminated organic waste stream exist, and where appropriate markets for the composted product can be developed. These issues are discussed further below.

Composting technologies can be split into three broad categories: open windrow, within building and in-vessel.

3.1 Open Windrows

Open windrows are long piles of compost that are turned occasionally by appropriate equipment. There is no containment so odour, dust, leachate and the potential for pathogenic aerosols are uncontrolled. Aeration is limited and turning infrequent, composting generally occurs at very slow rates (composting times are protracted around 120 days). Siting and the range of wastes that can be processed are therefore constraints. Typically open windrow is restricted to green waste composting where there is no requirement for pathogen control. In this application some unevenness of treatment is not problematic. Climatic impacts can be significant but cost is low. In some parts of the world regulatory approval for windrowing is becoming hard to obtain.

3.2 Within Building Systems

In-building systems bring composting inside. The composting process is contained with respect to the environment, but workers and equipment are exposed to potentially damaging aerosols. There is scope for much higher levels of monitoring and process control when compared with windrow composting. In-building systems are generally suited for larger scale installations but are relatively inflexible. The direct processing cost is usually high due to the large amounts of air that need to be moved and treated. Installations are capital intensive and maintenance costs may be significant.

3.3 In-vessel Composting Systems

In-vessel systems are varied but generally offer the following features:

- The compost is retained within some sort of vessel and the environmental and human impacts can therefore be more tightly controlled.
- Most organic wastes can be handled – although only with considerable care in some systems.
- There are opportunities for strict monitoring although this is often miss-directed measuring only parameters such as oxygen, CO₂ or temperature; rather than heat release (see Part 3 of this series).

- The thermal properties of the system generally ensure rapid and sustained heating; although in some cases this is simply a reflection of low-rate composting generating modest levels of heat that is not removed from the process. The equipment appears efficient but is in reality poor.
- Air delivery can be well controlled, although many systems do not including mixing or turning thus channelling resulting in uneven temperature and moisture often results. This can lead to a product that is relatively heterogeneous despite meeting overall process requirements.
- Systems are generally scalable

In-vessel solutions are relatively capital intensive, and total processing costs reflect this, but they offer the most comprehensive control and containment options. Systems are generally suited to small to medium sized installation. However, their modularity and cost advantage when compared to in-building systems means that several satellite plants can be established to serve very large populations. The advantage of satellite plants is that waste and product transportation costs can be minimised.

4 Standards

It will be apparent that with the diversity of feedstocks, and technologies to process them, that the composted product is potentially variable. Standards differ according to their intent, but generally seek to ensure that the products are safe to people who come in contact with it and the environment receiving it. Standards may also have components that indicate quality or fitness for purpose. In many cases a number of compost classes are recognised, and often there may be restrictions on the use to which some of these can be put.

Common components of standards include:

- Heavy metal and chemical contaminants: Heavy metals are ubiquitous in the environment, but may be problematic in composts; particularly those derived from biosolids and processing sludge. However, it must be recognised that it is the overall concentration that is important and even compost containing significant quantities of some elements should be able to be used, as long as application rates are monitored. It should also be recognised that many heavy metals are in fact trace nutrients in agricultural system; chromium for example is critical for wool growth.
- Chemical contaminants such as pesticides are also subject to limits in some standards.
- Human pathogens, typically *Salmonella* and coliforms are given limits. While this requirement can be met by direct testing, it is common to demand specific temperature performance for the composting process. Typically this is 3 days above 55°C or shorter time for higher temperatures; however, as noted temperature measurement alone is not a good indicator of compost performance.
- Weed seeds: The composting process should kill most plant propagules, again this aspect is controlled in some standards.
- Vector attraction reduction (VAR): Putrescible waste is usually attractive to a range of nuisance animals including flies, birds and rodents (vectors). Full composting eliminates the attractiveness of the material by reducing the volatile solids content (converting readily degradable compounds to more stable ones). Legislative requirements are usually based on time at temperature requirements.
- Plant growth inhibitors: As discussed above, uncured compost can be toxic to plants. Herbicide carryover is also an occasional problem. Obviously this is a significant factor where the product use is as a plant growth medium component.
- Physical contaminants: metal, glass, plastic and stones are all potential contaminants of compost and their prevalence will reflect the feedstock.

Not all standards control all variables, as purposes vary. Some, for instance, are relatively unconcerned with product performance and focus on safety, while in others the opposite can be true.

Some significant standards are:

- AS/NZ 4454 (Australian and New Zealand standard – safety and performance)
- USEPA Rule 503 for the safe disposal of biosolids (US. Safety bias)
- Australian state EPA guidelines (these are varied and cover safety and performance and well as plant operations, many are based on AS 4454).
- The Composting Association (UK. Performance bias).
- UK and EU Animal By-Products Regulations (Pathogen elimination)
- Canadian CCME Guidelines (Product stability)

5 Composting feedstock issues

The need for relatively uncontaminated feedstock that is compositionally appropriate for microbial degradation has already been highlighted. In a large community it is likely that various waste streams will be balanced and that the resulting mix will be compostable. Where composting is practiced for industrial wastes, it is possible a number of complementary industries will have to combine wastes to produce a suitable mix. For example, producers of highly putrescible food wastes may need to collaborate with producers of garden, paper or wood wastes to obtain a suitable C:N ratio, structural component and water content. Commercial and industrial businesses are, however, able to control their waste separation to a greater extent than is generally possible for domestic waste. Commercial waste streams are therefore more amenable to treatment by composting within the existing waste handling infrastructure (source separation of domestic wastes can be achieved with community and consumer involvement).

6 Product marketing

While collection, handling and processing of waste are within the purview of local government, disposal of compost is governed to a greater extent by the market. The most sought after outcome of composting is a reduction in organic waste destined to landfill, but as we have discussed, closing the loop and returning organic matter to land is the sustainable solution. Product marketing is the key to this closure, which should also generate beneficial economics for the whole composting process.

Compost has uses in horticulture, agriculture and domestic gardening; land restoration, roadwork restoration and landscaping and erosion control. It is beyond the scope of this document to fully explore marketing issues, but they are highlighted here, as there is a need to consider this aspect in any composting based waste solution.

7 Summary

Removal of organic waste from landfill is a pressing need. Composting is a technically and economically viable treatment option for much of this waste, with added benefits for soil health if the product is suitably used. Compost quality depends on feedstock cleanliness, and the ability to obtain uncontaminated organic waste is often an impediment.