Introduction to Composting Science and Management for Industry Training

An overview of the scientific principles of the composting process

2007
Acknowledgements

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Actinomycetes
A group of microorganisms, intermediate between bacteria and true fungi, that usually produce a characteristic branched mycelium. The organisms are responsible for the earthy smell of compost.

Aerated Static Pile (ASP)
Forced aeration method of composting in which a free standing pile is aerated by a blower moving air through perforated pipes located beneath the pile.

Aerobic
In the presence of, or requiring oxygen.

Anaerobic
In the absence of oxygen, or not requiring oxygen. Composting systems subject to anaerobic conditions often produce odorous compounds and other metabolites that are partly responsible for the temporary phytotoxic properties of compost. Anaerobic conditions are important for anaerobic digestion systems.

Ammonia (NH3)
A gaseous compound comprised of nitrogen and hydrogen. Ammonia, which has a (sharp) pungent odour, is commonly formed from organic nitrogen compounds during composting.

Bacteria
A group of microorganisms having single-celled or non-cellular bodies. Bacteria usually appear as spheroid, rod-like, or curved entities but occasionally appear as sheets, chains, or branched filaments. Bacteria mostly break down organic materials in composting systems. It is bacteria that generate the heat associated with thermophilic composting systems. Bacteria have different temperature optima and are grouped accordingly: psychrophiles (<20°C); mesophiles (20-45°C), and thermophiles (>45°C).

Biosolids
Organic solids or semi-solids produced by municipal sewage treatment processes. Solids become biosolids when they come out of an anaerobic digester or other treatment process and can be beneficially used. Until such solids are suitable for beneficial use they are defined as waste-water solids. The solids content in biosolids should be equal to or greater than 0.5% weight by volume (w/v). Biosolids are commonly co-composted with garden organics and/or residual wood and timber to produce range of recycled organics products.

Bulking Agent
An ingredient in a mixture of composting raw materials included to improve the structure and porosity of the mix. Bulking agents are usually rigid and dry and often have large particles (for example, straw or wood chips). The terms “bulking agent” and “amendment” are often used interchangeably.

Cellulose
A long chain of tightly bound sugar molecules that constitutes the chief part of the cell walls of plants.

Carbon to Nitrogen (C:N) Ratio
The ratio of the weight of organic carbon (C) to that of total nitrogen (N) in an organic material.

Curing
Final stage of composting in which stabilisation of the compost continues but the rate of decomposition has slowed to a point where turning or forced aeration is no longer necessary. Curing generally occurs at lower, mesophilic temperatures. See stability.

Enzymes
Any of numerous complex proteins produced by living cells to catalyse specific biochemical reactions.
Feedstock
Organic materials used for composting or related biological treatment systems. Different feedstocks have different nutrient concentrations, moisture, structure and contamination levels (physical, chemical and biological).

Food Organics
Food Organics includes organics generated by any one of the following activities: the manufacturing, preparation or consumption of food (including beverages); the processing of meat, poultry or fish, and the manufacturing of edible grocery products. Such materials may be derived from domestic or commercial and industrial sources. The definition does not include grease trap waste. Food organics is one of the primary components of the compostable organics stream.

Forced Aeration
Means of supplying air to a composting pile or vessel which relies on blowers to move air through the composting materials.

Fungi
Singular - fungus. A group of simple microorganisms that lack a photosynthetic pigment. The individual cells have a nucleus surrounded by a membrane, and they may be linked together in long filaments called hyphae. The individual hyphae can grow together to form a visible body. See also bacteria.

Garden Organics
Any garden derived organic (plant) materials generated by domestic, C&D and C&I sources. Garden Organics is defined by its component materials including: putrescible garden organics (grass clippings); non-woody garden organics; woody garden organics; trees and limbs, and stumps and rootballs. Garden organics is one of the primary components of the compostable organics stream.

In-vessel
System of composting involving the use of an enclosed chamber or vessel in which (in most cases) the composting process is controlled by regulating the rate of mechanical aeration. Aeration assists in heat removal, temperature control and oxygenation of the mass. Aeration is provided to the chamber by a blower fan which can work in a positive (blowing) and/or negative (sucking) mode. Rate of aeration can be controlled with temperature, oxygen or carbon dioxide feedback signals.

Lignin
A substance that, together with cellulose, forms the woody cell walls of plants and the cementing material between them. Lignin is resistant to decomposition.

Maturation
Final stage of composting where temperatures remain steady below 45°C, and the compost becomes safe to use with plants due to the absence of toxins.

Manure
The fecal and urinary excretion of livestock and poultry. Sometimes referred to as livestock waste. This material may also contain bedding, spilled feed, water or soil.

Mesophilic
A temperature range of 20-45°C. Mesophilic microorganisms grow well at these temperatures and are also important for decomposition during the cool-down or maturation stage of composting. Most pathogenic microorganisms grow in this temperature range, and are thus destroyed under high temperature (thermophilic) conditions during composting.

Moisture Content
The fraction or percentage of a substrate comprised of water. Moisture content equals the weight of the water portion divided by the total weight (water plus dry matter portion).
Passively Aerated Windrow
A composting method in which windrows are constructed over a series of perforated plastic pipes, which serve as air ducts for passive aeration. Windrows are not turned.

Pasteurisation
The process whereby organic materials are treated to kill plant and animal pathogens and weed propagules.

Pathogen
Microorganisms capable of producing disease or infection in plants or animals. Pathogens can be killed by heat produced during thermophilic composting.

pH
A measure of the concentration of hydrogen ions in a solution. pH is expressed as a negative exponent. Material that has a pH of 8 has ten times fewer hydrogen ions than a material with a pH of 7. The lower the pH, the more hydrogen ions are present, and the more acidic the material is. The higher the pH, the fewer hydrogen ions present, and the more basic it is. A pH of 7 is considered neutral.

Phytotoxic
Toxic to plants. Partially decomposed organic materials or immature composts are often phytotoxic, but this usually decreases with time. Such products may be phytotoxic due to a number of factors, including: low nutrient content; high oxygen consumption; presence of fatty acid or alcohol metabolites formed by microorganisms under anaerobic conditions; or due to excessive concentrations of salts, heavy metals and other organic compounds.

Process Control
Stringent and documented monitoring of all critical control points in a composting operation so as to minimise defects and make products which can be guaranteed to customers.

Source Separation
Separation of recyclable materials from other waste at the point and time the waste is generated (ie. at its source). This includes separation of recyclable material into its component categories (e.g. paper, glass, aluminium), and may include further separation within each category (e.g. paper into computer paper, office whites and newsprint).

Thermophilic
Temperatures above 45°C. Used to describe a stage of composting in which high temperatures are sustained resulting in high rates of decomposition and pasteurisation of the organic material. Heat tolerant microorganisms survive well in these conditions.

Turning
A composting operation which mixes and agitates material in a windrow pile or vessel. Its main aeration effect is to increase the porosity of the windrow to enhance passive aeration. It can be accomplished with front-end loaders or specially designed turning machines.

Windrow (with or without aeration)
System of composting involving the aeration of horizontally extended piles formed by a front-end loader or windrow turner. Extended piles are generally 1.5 to 3 m in height, and length is limited by the size of the composting pad. Aeration can be achieved by mechanical turning and/or the delivery of air from the base of the windrow (see aerated static pile).
1. Purpose

Supporting Compost Producers & NZS4454

The key purpose in developing this Introduction to ‘Composting Science for Industry’ learning module is to provide background knowledge and support for Compost producers who are seeking to adopt and achieve ‘best practice’ as outlined in Appendix K of the New Zealand Standard for Compost, Soil Conditioners and Mulches (NZS4454:2005). Such products are often made from, (but not exclusively), recycled organic waste materials.

The beneficial reuse of such wastes (hence avoidance of the negative environmental impacts associated with landfills) is a key target of the New Zealand Waste Strategy (2002) entitled ‘Towards Zero Waste and a Sustainable New Zealand’. The NZS4454 provides a quality assurance framework which will assist in ensuring customers’ satisfaction and the overarching growth of profitable markets and hence, sustainable industry development.

Composting Science and Management

This ‘Composting Science for Industry’ module has been developed in association with the NZS4454 tool-kit which is designed to assist compost producers in understanding the NZS4454 and in applying this as a business development tool. This module draws heavily upon educational resources, generously made available by the Recycled Organics Unit (ROU) (www.recycledorganics.com). This module, (as are the NZS4454 tool-kit and the Standard itself) is designed to be utilised in conjunction with a range of complementary resources, in particular the ‘New Zealand Biosolids Guidelines’ and the ‘Recycled Organics Terms and Definitions’ (ROU 2002).

Interrelated Goals

Broadly speaking the NZS4454 focuses upon the interrelated goals of: end-product quality parameters (outlined in Table 3.1), quality management of the compost production process (outlined in Appendix K), general requirements (outlined in Chapter 2) and product information for customers (outlined in Chapter 3).
Appendix K: Best Practice Guidelines for Composting Systems

Appendix K, entitled ‘Best Practice Guidelines for Composting Systems’, is directed at four commonly recognised composting systems:

- Turned Pile.
- Aerated Static Pile.
- Windrow.
- In-vessel

For each of these four types of compost system, Appendix K outlines a suite of parameter guidelines, which are to be followed (normative). These parameters (namely Ingredients, Shredding or chipping Initial mixing, Dimensions, Turning Moisture content, Temperature, Oxygenation, Duration, Screening and Blending), are all covered within the scope of this ‘Composting Science for Industry’ learning module. As such this module is designed to support and expand the knowledge requirements contained in Appendix K of the NZS4454.

Appendix K: General Outline

Whilst Appendix K describes parameter criteria specific to each of the four compost system types, for the purposes of simplicity, this learning module will focus upon those criteria related to ‘Windrow Composting’ which is the most commonly utilised system type in the New Zealand context. The following provides a general outline of Appendix K:

K1.1 This Appendix outlines ‘best practice’ guidelines for compost processing to ensure minimum contamination of the end-product by pathogens (including human, animal and plant), plant propagules, chemical residues and inorganic matter. This Appendix has been based upon Appendix N from AS 4454 and has been modified to reflect best practice for New Zealand. Best practice guidelines are aimed firstly at the compost facility operator, by outlining the requirement to consider factors such as ingredients, type of compost processing, care with mixing, dimensions of the composting mass, composting duration, moisture content, temperature and oxygenation throughout the composting process. Secondly, these guidelines are designed to assist others in monitoring and assessing composting operations and composted end-products.

K1.2 Odour production shall be considered by both compost manufacturers and monitoring personnel which could affect nearby residents. Odours can be minimised by correct compost processing as indicated in these best practice guidelines.

K1.3 It must be noted that the requirement for composting to achieve pathogen reduction tends not to favour an optimum rate of composting. Time-temperature requirements for sanitation are generally that, the whole of the composting mass must reach at least 55 °C for a minimum of three consecutive days, but operators may opt for higher maximum temperatures to ensure that cooler zones in the compost mass where temperature gradients exist, reach the required 55 °C for the prescribed time. Care must be exercised to ensure that appropriate moisture levels are maintained otherwise there is potential for self-combustion. Alternatively, other temperature and time-related options may be adopted depending upon the technology being used. For example, for in-vessel systems composting animal products and catering waste, it is recommended in the United Kingdom Defra BSE Division Guidelines (K.1) that processing takes place at 60 °C for 2 days or 70 °C for 1 hour. It has been demonstrated that temperatures in the range of 40 – 50 °C produce a stable compost more rapidly than do higher temperatures. Microbiological populations will be affected by ranges in temperature.

K1.4 Compost facility operators shall make individual judgements on their compost system of choice and the processing regime to achieve both a safe, hygienic product and a good quality compost which meets the physical, chemical and microbiological requirements of this Standard.

K1.5 Each facility will need to consider site-specific conditions for health and safety, noise, fire, dust, odour, leachate, vermin and security.
2. Introduction to Composting Science and Management

Inside This Sheet

- 2.1 Aerobic Composting
- 2.2 NZS4454 Quality Standards
- 2.3 Fundamentals of Composting
- 2.4 Feedstocks processed in composting systems
- 2.5 Quality linked to Profitability

Aerobic Composting

In the context of waste management the term aerobic composting is applied to controlled biological processing (governed by the activity of naturally occurring micro-organisms) of ‘source separated’ organic material derived from animal and vegetative residues. The initial most basic goal of composting is transformative, turning waste into stabilised value added product.

The marketability of these end products is determined by the value criteria (such as quality and performance) of end users. Increasingly the sale of end products determines the viability of the business unit undertaking the production process. Consequently the focus of the ‘recycled organics industry’ has shifted from ‘waste processing’, to a ‘market orientation’ developing products which are ‘fit for purpose’ across a variety of growing systems.

NZS4454 Quality Standards

The New Zealand Standard for Composts Soil Conditioners and Mulches (NZS4454:2005) establishes the chemical, physical and biological quality standards for the end products from composting processes. In addition NZS4454 outlines the pathway (general requirements and operational best practices) via which producers can achieve these standards.

The end-product of an NZS4454 certified composting process is sanitised, stable, friable organic material, which is highly beneficial to the physical, chemical and biological properties of agricultural and garden soils. Due to environmental and public health concerns...

Figure 1. Process diagram for composting systems. All composting processes are based on the same principles. O2, oxygen; CO2, carbon dioxide. Modified from Rynk et al., (1992).

the term compost is not considered appropriate to describe the material produced as a result of mechanical sorting and treatment of mixed municipal solid waste (MSW).

**Fundamentals of Composting**

Understanding the fundamentals of composting enables operators to manage various process controls to maximise the rate of decomposition of the organic material and meet other economic, environmental and quality specifications.

The means to control composting conditions differ from site to site depending on the type of technology employed, the types of materials being processed, environmental considerations, the desired end-product and the preference and experience of the site operator.

Like all living things, including ourselves, the aerobic micro-organisms responsible for composting need adequate living conditions to grow and multiply. These conditions relate to the availability of:

- Oxygen (air contains 21% oxygen)
- Water
- Food – carbon, nitrogen and other nutrients and
- Suitable environmental conditions (including mainly warmth or heat).

Heat energy is produced in decomposition as

**Table 1.** The five major categories of source separated compostable organics most commonly processed in composting operations (Recycled Organic Unit, 2002).

<table>
<thead>
<tr>
<th>Compostable Organic Material Class</th>
<th>Material Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garden organics</td>
<td>Any garden derived organic (plant) materials generated by domestic, construction &amp; demolition and commercial &amp; industrial sources. Garden organics is defined by its component materials including: putrescible garden organics (grass clippings); non-woody garden organics; woody garden organics; trees and limbs, and stumps and rootballs.</td>
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</tr>
<tr>
<td>Wood and timber</td>
<td>Any untreated, uncontaminated wood waste material produced by domestic, construction &amp; demolition and commercial &amp; industrial sources, including: off-cuts; crates; pallets and packaging; saw dust and timber shavings.</td>
</tr>
<tr>
<td>Agricultural organics (including forestry residuals)</td>
<td>Any residual organic materials produced as by-products of agricultural and forestry operations, including: weeds (woody and non-woody); animals (processing residuals, stock mortalities, pests), and crop residuals (woody and non-woody), and manures.</td>
</tr>
<tr>
<td>Biosolids</td>
<td>Organic solids or semi-solids produced by municipal sewage treatment processes. Solids become biosolids when they come out of an anaerobic digester or other treatment process and can be beneficially used. Until such solids are suitable for beneficial use they are defined as waste-water solids. The solids content in biosolids should be equal to or greater than 0.5% weight by volume (w/v). Biosolids are commonly co-composted with garden organics and/or residual wood and timber to produce a range of recycled organics products.</td>
</tr>
</tbody>
</table>
a by-product of microbial activity breaking the biochemical bonds in the organic matter. Diverse microbial communities synergise and alternate through the phases of the decomposition process. Decomposition is a dynamic and evolutionary process. For example, some micro-organisms feed on the metabolic by-products of others.

Populations of organisms evolve through the two sequential phases (variably known as phase 1- decomposition / high-rate / thermophilic followed by phase 2- maturation / mesophilic / stabilisation) of the composting process. Each species of organism (predominantly Bacteria, Fungi Actinomycetes, Yeasts Algae, Protozoa and Nematodes) is adapted to the digestion of differing constituent elements (sugars/ carbohydrates, protein, fats, hemi-cellulose, lignin and mineral matter) of organic matter.

Heat is both a function of, and factor affecting, the rate of microbial decomposition. For example, temperature, beyond the targetted optimum of 55°C is lethal to many desirable thermophilic micro-organisms and will resulting in slower process rate. Heat is critical for eliminating pathogens and plant propagules (i.e. weed seeds). Measuring temperature is perhaps the simplest way to monitor what is happening within a composting process.

Feedstocks processed in composting systems

A range of organic materials can be processed in composting systems. Commercial composting operations use ‘source separated’ organic materials as raw material, or feedstock. Successful integration of this material into an hygienic and efficient production system relies upon understanding the service requirements of clients and the needs of host communities and culminates in the development of a quality management system (QMS).

As an established worldwide industry, recycled organics processors can now draw upon a considerable knowledge base from biological science and environmental engineering, to achieve process control and quality management. The five major categories of compostable organic materials are shown in Table 1 below.

Quality linked to Profitability

The financial viability of composting operations is related to a number of key factors such as scale, location, tipping fees, capitalisation, staffing, technology and the knowledge and experience of management. etc. Importantly though as the recycled organics industry embraces a future-focused market orientation, economic viability depends upon the conversion of quality, source separated organics into quality composted products that meet market requirements.

This is not to say that there is not still a role for composting and compost in waste treatment processes. Bio-remediation of some hazardous waste and contaminated soils draws upon composting technology and is environmentally positive. There is also an important role for low value composts, which are unsuitable for agricultural application in the remediation of marginal lands, for example, former mine sites. Unfortunately in many EU member countries the compost produced from mixed MSW now ends up in landfill.

Clearly quality from start to finish (or gate to garden) is a winning strategy. A good understanding of the composting process is essential to produce high-value quality products. The successful marketing and sale of these products rely upon an understanding of the needs and issues of end-users, many of whom manage sophisticated high value, soil-based growing systems.

This resource, Basic Composting Science and Management, is intended to provide an introduction to the scientific principals underwriting compost management and the application of Appendix K from the NZS4454.

“If knowledge can create problems, it is not through ignorance that we can solve them” - Isaac Asmov.
3. Overview of Composting Process and Technologies

At least eight different forms of composting systems are available for processing a wide range of organic materials. Turned windrow systems have been the predominant form of composting in Australia and New Zealand, particularly for garden organics, which are the simplest and least problematic inputs to process.

It is important to realise that the composting system is an integrated management process. The following graphic provides a basic outline of this.

The economic reality for most recycled organics processors is that expenditure (capital interrelated with operational) into the composting system requires careful analysis to balance cost and capability, alongside the impacts on all other elements of the holistic process management, in order to achieve technically successful and balanced economic outcomes for the operation as a whole.

Higher technology composting systems are now being implemented for processing materials that have traditionally been difficult to process in outdoor turned windrow systems, such as food organics. In-vessel composting systems are becoming more common, although infrastructure costs are usually higher.

The other key driver for technological advancement is the achievement of quality assurance standards such as AS4454 and NZ4454 in respectively the Australian and New Zealand contexts. Quality assurance standards not only provide security for the end-users of compost products, but also provide a template for operators to achieve safe, hygienic, efficient, and environmentally compliant operations, which are focused on profitable market relationships.

This section on composting systems gives readers some basic information about the distinguishing characteristics of the main types of systems that are commercially available.

Compost Production Process

Composting systems are often described in terms of a complete process from the reception of raw material through to the handling of the end-product. However, when only the composting process itself is considered, most systems are nearly always variations of a common theme.
All systems aim to control and/or optimise compost production by manipulating temperature, oxygen and moisture during composting. Another important control over compost quality is achieved by the selection, pre-treatment and mixing of the raw materials prior to composting.

Some composting systems can more effectively deal with specific types of organic materials. For example, highly odorous material (e.g. food organics and some industrially-produced organics) are more easily processed in systems with forced aeration and odour control equipment. This technology allows for better control and minimises negative environmental impacts such as odour.

The most common form of composting is the turned windrow system. This system is adequate for many organic materials, but requires a high degree of process control in order to maintain optimum composting conditions. Temperature and aeration control is managed by establishing the initial mix and windrow dimensions and then by physically turning the mass by either a front-end loader, excavator or specialised windrow turner.

The capital outlays for windrow type systems are relatively small (unless a concrete pad is installed also depending upon turning system), but operating costs can be high, because they are usually labour intensive. Improved process control is achieved by utilising forced aeration systems. Forced aeration improves control of both temperature and oxygen during composting.

Systems using forced aeration do not necessarily produce a compost of higher quality than windrow systems, but shorter processing times are usually possible. Environmental control of odours and leachate can usually be built in with systems utilising forced aeration. Forced aeration systems are usually more expensive to install, but operating costs can be lower compared to those of turned windrow systems.

The major difference between various composting systems mainly concerns the first stage of composting — preliminary decomposition or pasteurisation. The aims of this stage of composting are usually to:

- Maximise the rate of decomposition of the readily available organic fraction
- Eliminate pathogens and weeds from the starting materials - pasteurisation and
- Control leachate and odours.

This period of intensive control is usually employed only for a short period (from 3 to 14 days in most cases).

Further second-stage decomposition, or maturation / curing, usually then takes place in conventional windrows. The maturation / curing phase requires significantly less management than the active composting phase. Minimal odour generation occurs during the curing phase.
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Turned Windrow

- Most common system for organics of low odour-generating potential
- Low capital costs unless concrete pads are installed
- High operating costs (both capital and operating cost vary according to windrow turning system)
- Very flexible system - a range of organic materials can be composted and adjustments can be made within a composting cycle
- Aeration by turning with front-end loader or specialised machine
- Slow rate of decomposition due to varying conditions in pile
- Stable compost in 3-6 months
- Windrows can be outdoors or formed under a roof (no sides)
- Significant care and expertise needed for effective odour and leachate control

Passively Aerated Windrow

- Cheapest system; no turning
- Depending upon inputs windrows may be covered with finished compost to reduce odours. (For example, this system may be used for dealing with animal mortalities. This context is sometimes referred to as ‘above ground burial’, where the pile once established is left undisturbed for long periods so the amendment, in this context Greenwaste typically acts as a bio-filter)
- May be more space efficient than turned windrows
- Reduced flexibility - careful preparation of starting materials essential
- Little control of temperature and aeration during composting
- Compost in 3-6 months
Aerated Static Pile

- Medium capital costs
- Medium operating costs
- Forced aeration
- Reduced flexibility - careful preparation of feedstock is essential
- Space efficient
- Piles are usually covered (e.g. with compost) to reduce odours
- Some control of temperature and aeration resulting in faster composting (6-12 weeks); further curing usually required

Aerated Covered Windrow

- Medium capital costs
- Medium operating costs
- Cover for windrows reusable
- Forced aeration; computer control of composting possible
- Reduced flexibility - careful preparation of feedstock essential
- Space efficient
- Improved control of temperature and aeration resulting in faster composting (3-6 weeks); further curing usually required
Rotating Drum

- High capital cost
- Medium operating costs
- Less preparation of starting materials required due to constant mixing and size reduction
- Rapid initial decomposition in drum (up to seven days)
- Further decomposition required in windrows or aerated static piles
- Provides mixing and aeration by means of drum rotation and forced aeration

Agitated Bed or Channel

- High capital cost
- Medium operating costs
- Flexible system – both forced aeration and mechanical mixing used
- Space efficient
- Beds are covered in a fully enclosed building or roof
- Good capacity for odour and leachate control
- Rapid composting: 2-4 weeks; further curing usually required
In-vessel (horizontal configuration)

- High capital cost
- Automated system
- Uniform temperature and oxygen profile throughout contents of vessel
- Composting vessels can be housed in a building or outdoors
- Excellent control of odours and leachate
- Can be located with minimal buffer distances
- Very fast composting (7-14 days)
- Further curing in windrows or in-vessel usually required

In-vessel (vertical configuration)

- High capital cost
- Automated system and low operating cost
- Uniform temperature and oxygen profile throughout contents of vessel
- Composting vessels can be housed in a building or outdoors
- Excellent control of odours and leachate
- Can be located with minimal buffer distances
- Very fast composting (7-14 days)
- Further curing in windrows or in-vessel usually required

Centralised composting operations represent a cost-effective provision of a much needed environmental and community service. Modern municipal composting services, whether privately or publicly owned, are increasingly being viewed as essential infrastructure, necessary to fulfil the expectations broadly outlined in the national (increasingly reflected in local council) waste minimisation / management strategies.

A well designed organic recycling programme coupled to appropriate infrastructure will largely eliminate the potential negative environmental consequences associated with organic waste. This material is instead transformed into a valuable soil conditioner, which can be returned and made available to the local market. Organic recycling is virtually unique amongst major commodity associated recycling processes, in that the entire production (re-) CYCLE is achieved locally. This represents the most efficient utilisation of energy resources and achieves maximum local benefit.
4. Drop-off / Receival, Assessment, Pre-processing

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4.4 Other Collection Options
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4.8 Signage and Communication
4.9 Visual Impacts Positive or Negative
4.10 Safety

Compost Production Process

(see Figure 2 previous section)

The production cycle for the raw waste organic materials or feedstock begins with reception, (commonly associated at a public drop-off area), where assessment and pre-processing can be undertaken. The degree of pre-processing required relates to the type, quality and the nature of the downstream processing equipment (i.e. the size and effectiveness of the shredding system).

For example, generally speaking, large high speed grinders will handle large chunks of wood, so this material does not need to be separated. In small operations using, for example, wood chippers or an orchard mulcher, oversize branches may damage the machinery and are better separated and recycled as firewood.

Pre-processing (sorting) will be based on a variety of criteria associated with local operating conditions: Typically this may include:

- Removal of any rubbish contaminating the feedstock.
- Diversion of material not requiring shredding, (i.e. grass clippings, leaves and weeds), which may dropped off in a separate location in preparation for amendment / batch mixing or incorporation direct into windrows. NB: Because of the risk of chemical spray contamination some New Zealand operations separate and dispose of grass clippings.
- Separation of woody material too large or inappropriate for the shredder, (i.e. stumps, flax, bamboo, or large branch sizes). Firewood processing may be undertaken using, for example, a chainsaw and hydraulic log splitter, etc. In this instance the processed firewood is recycled to benificial use by direct sale back to the public.
- Where typically high moisture content materials, such as manures, food processing waste and biosolids are processed these may require specific initial handling facilities/ processes.

“Engineering is the professional art of applying science to the optimum conversion of natural resources to the benefit of man” – Ralph J Smith
Drop-off Areas

Receipt of garden organics (commonly called greenwaste) may take place at a resource recovery centre, transfer station or at a landfill site. Whatever the scenario it is vital that the appearance of the drop-off area evokes a sense of hygiene, professionalism and safety. In these instances the public drop-off point is essentially the ‘face’ of the whole operation and this presentation will significantly impact how the public will behave, view the programme and value the quality of the final products.

Drop-off Design Considerations

There appear to be two main styles of greenwaste drop-off in New Zealand. These can be described as 1- Concrete pit or steel bin systems (located below the point of disposal) and 2- Single level / Flat drop-off areas. The respective design advantages are; a pit / bin-system provides a distinct zone of separation between deposited material and the point of disposal (this means that machinery and the public are separated). Alternatively a flat dropoff area involves less capital expenditure and allows the clients 360 degrees of access around the vehicle / trailer and means that they can pull material from behind when unloading.

Both types of drop-off area are required to be kept clear to maintain a safe space. This is normally achieved by servicing the area with a rubber tyred loader to periodically push the greenwaste into a storage pile ready for shredding. It appears there are comparable risks, benefits and preferences associated with both designs. In terms of safety, the greatest contingency is provided by the alertness, training and competency of the staff working in the drop-off area.

Figure 3 & 4: Above - Single level drop-off vs Below - Split level pit design.

Because not all green waste (percentage by weight) requires shredding it may be cost effective to distinguish and separate material that does not require shredding. Shredding only the greenwaste fraction which requires this form of processing eliminates unnecessary cost and wear and tear on machinery. This pre-processing function is best facilitated by having clear physical separations at the drop-off area for non-shredded material (see Figure 5 below).

Other Collection Options

Other than the transfer station / public drop-off scenario, collection options are via commercial ‘green bag’ and garden care service providers, So-called green bags are alternatives to the wheelie bins and are used strictly for organic waste. In addition there are now several New Zealand Municipalities who offer the three wheelie bin system (i.e. Timaru and the North Shore of Auckland). In this instance one of the three wheelie bins will be designated for organic waste and will be collected within the kerbside recycling operation and taken to the organic recyclers for processing.

Normally the cost of organic waste is lower relative to waste to landfill, which encourages a greater level of organic separation from the mainstream waste. The expectation is that, in taking advantage of this price differential the public are required to uphold responsibility to cooperate with operational procedures, staff instructions, which are aimed toward eliminating contamination, thereby achieving safe and efficient pre-processing. This set of responsibilities apportioned to the public, are often referred to as the principal ‘separation at source’.
Separation at Source

Separation at source is a foundational concept upon which the economics of most recycling programmes are based. This concept describes the shared balance of respective responsibilities between the collective municipal recycling programme and the individual who participates in this.

On one hand municipal recycling programmes need to be user friendly, cost effective and conveniently located. On the other hand it is essential that individuals utilising recycling programmes follow instructions about where to deposit differing materials and, most importantly, about where not to put contamination. The principles of ‘separation at source’ are communicated as instructions by signs, pamphlets, conversation, training and are reinforced with staff activity.

Contamination

Another aspect of pre-processing is the removal of oversized material which is likely to damage or inhibit the shredding process. For example, Brentwood shredders require the removal of oversize material greater than 100mm, which can be readily processed and sold as recycled firewood.

Removal of any contamination is another critical element of pre-processing. Fundamentally it is much easier to remove a plastic bag before, rather than after (as many small pieces) it has been shredded. Operational staff play a critical role in communicating the compliance standards of the operation and, as a last resort, they need to physically remove contamination deposited at the drop-off.

A key real world observation is that, whenever any contamination or litter (i.e. a plastic bag full of weeds or a block of concrete) is present in the drop-off area other people will add to it. If standards of hygiene are ever seen to be lax they will automatically tend to deteriorate further. Investing staff time in the pre-processing phase (in particular in constructive communication with the public) lays the foundation for efficient process control and ultimately the quality of the final product.

Staff / Public Interactions

Effective pre-processing requires initial training and ongoing monitoring of the staff and public to create appropriate participation. Perhaps the most underrated feature of pre-processing is the opportunity this phase affords for quality one-on-one interaction with the public. Rather than this being seen as a regrettable necessity, this interaction should be embraced as a captive opportunity to build cooperation and establish a foundation for marketing and sales.

In taking advantage of this opportunity it is critical to identify staff who have people skills and to then provide them with the necessary training for this communication and relationship building role. Where the organic recycling facility is not open to the public, but only receives feedstock from contractors and large suppliers (for example from transfer stations), the target audience for building cooperative relationship is smaller but no less important, requiring different strategic approaches.

Signage and Communication

A key tool in presenting information to the public is on-site signage. Signs provide direction and specific instructions about the site - its operations, safety requirements and how pre-processing works. Signage also provides a marketing tool for the compost and garden products. Typically signage may include:

- Entry signs advising hours of operation,
disposal bins, unacceptable wastes, and an after hours contact telephone number
• Directional signs for waste disposal, recycling and any approved special wastes
• Instructional signs indicating rules operating at the site, such as, children remaining in cars, no scavenging, and no smoking
• Sales and marketing information.

The recycling industry is still in the process of evolving and moving beyond the ‘YUCK’ factor associated with landfills and waste. A important factor driving this transition is the landscaping and appearance of the public drop-off areas of composting operations. There are many examples of well designed and managed New Zealand organic recycling sites whose attractive appearance evokes a sense of confidence and professionalism.

Cost effective options to reduce the visual and operational impacts on residential and industrial neighbours include:
• Screening and beautification planting along boundaries.
• Sealing roadways and paths to reduce dust.
• Fencing for security and to trap any windblown litter.
• Bait stations to reduce vermin and programmes to deter birds (seagulls).
• Display gardens related to product range.

A concerted effort must be made to make a positive visual impact and win the confidence and respect of the public, neighbours and local authorities, as these relationships are of vital importance to the long-term running of composting operations. Recycling facilities need to be designed specifically for function, presentation and so that, they can be kept in a neat and tidy condition at all times. This is a constant challenge, which requires the diligent cooperation of staff and the ongoing scrutiny of the site manager. Generally speaking, well managed and properly funded composting operations need never be the subject of complaints relating to odour.

In the real world it is impossible to control all risk factors all of the time. Unfortunately complaints tend to be ‘contagious’ and multiply upon each other, so if at all possible it is best to avoid receiving any. If criticism is made public, it can be very hard to reverse negative public perception. In short, high operational standards which are continually reviewed with the objective of achieving best practice and evoking a sense of excellence needs to be the established norm.

Safety

Many Occupational Safety and Health (OSH) issues, associated with organic recycling, centre upon the location and risk minimisation measures related to machinery and vehicle movement. These measures translate into hardware such as signs, screens, shielding and cut-off switches, etc. that are a requirement of heavy machinery (i.e. shredding equipment) in public places. There have been some very serious accidents at New Zealand organic recycling operations. It is essential that resource recovery centres operate a pro-active and effective safety management programme.

The development of an OSH management programme is a specialised concern and often benefits from an independent perspective and dedicated expertise. In addition, experienced advocates, proactively inviting government OSH officials to inspect work sites and to audit the safety programme provide direction for continued improvement. Such practices establish a consistent track record of safety concern being translated into action, as well as demonstrating to staff the priority accorded to OSH issues.

“Common sense is the best sense I know of”
- Lord Chesterfield.
The ingredients of composting are organic by-products or waste materials. In the urban / city / industrial context these include food organics, bio-solids, garden organics, food processing residues, etc. In the on-farm context, ingredients include animal manures, bedding, forestry and crop residues and some processing wastes, etc. (NB: The On-farm Composting Handbook R. Rynk et al. (1992 available from www.biicycle.net) provides a good description of an extensive variety of potential ingredients and discusses their respective characteristics and associated issues). Any given feedstock in its raw state is unlikely to possess all the necessary characteristics for successful decomposition.

Because of this, to a large degree, effective compost management relies upon understanding the nature of the various input feedstocks and then appropriately preparing, amending / bulking and combining these into a mix, which has the overall characteristics required. This mixing function is often referred to as, blending the compost recipe. The starting point is identifying and understanding the variable nature (e.g. C:N ratio, Moisture content (MC), pH, Bulk density, etc.) of the individual starting materials.

**Primary Ingredient**

Often a composting process starts with a primary ingredient, (which may present problems for handling and treatment / disposal, for example, manures) which is then combined with secondary ingredients, which are deliberately chosen for their suitability in completing the composting recipe. ‘Amendment’ is said to be when materials are added to adjust the resulting characteristic (i.e. C:N ratio, MC, etc.) of the mix. ‘Bulking Agents’ is the term given to the material which is added to provide improvements in the structure (i.e. sufficient pore spaces for air movement) of the resulting mix.

**Characteristics of Common Raw Materials**

The range of input materials for composting is almost endless. The following table lists a number of common composting raw material types along with notes relating to their characteristics and handling. These notes have been adapted from information discussed in the ‘On-farm Composting Handbook’, R. Rynk et. al.
<table>
<thead>
<tr>
<th>Ingredients</th>
<th>General Properties &amp; Handling</th>
<th>MC (81 %)</th>
<th>N - (2.4 % dwt)</th>
<th>C:N (19)</th>
<th>Bulk Density (860 kg/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle Manure</td>
<td>Very good composting input. Generally high moisture content sludge unless mixed with bedding or stored for drying. Typically available from feedlots, truck-wash, settling ponds, etc. typically N - rich. Generally requires significant amendment with dry high C material (i.e. x 2-3 per vol). Low odour risk rapid decomposition.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry Manure</td>
<td>Good to very good composting input. Typically Comes in two forms Broiler litter (i.e. from free range with enclosed barns to caged layers systems where manure is automatically extracted. Each context has differing properties. In the tormer context the material is pre-mixed with bedding and maybe partially composted. In latter it is generally pure manure. NB: the figures provided are the comparative range of the average for each respective context, with broiler the first figure quoted in each instance). Generally very high Nitrogen content &amp; high pH (alkalinity may need adjustment), moderate / variable moisture content. Often available by periodic henhouse cleanout maybe mixed with bedding materials. Generally requires amendment, Odour generating potential (ammonia). Rapid decomposition resulting in nutrient rich / fertiliser grade compost. NB: this material is often direct land applied as an ‘organic fertiliser’ without any composting.</td>
<td>MC (37 to 69 %)</td>
<td>N - (2.7 to 8 % dwt)</td>
<td>C:N (14 to 6)</td>
<td>Bulk Density (509 to 873 kg / m3)</td>
</tr>
<tr>
<td>Horse Manure</td>
<td>Excellent composting input. Typically comes from two sources either from piles which accumulate from ‘de-dunging’ horse paddocks (collected and stored in raw state, so as not to spoil grazing) or from stabled horses in which case in is likely to be mixed with bedding. (As previous, the figures provided are the comparative range of the average for each respective context, with general free-range horse manure being the first figure quoted in each instance). Low odour potential depending on source may require amendment or be used as amendment. Rapid decomposition especially if bedding is straw. Sometimes sold in road-side stalls direct bagged for garden application.</td>
<td>MC (72 to 63 %)</td>
<td>N - (1.6 to 1.2 % dwt)</td>
<td>C:N ratio (30 to 41)</td>
<td>Bulk Density (814 kg / m3)</td>
</tr>
<tr>
<td>Pig Manure</td>
<td>Moderate to good compost potential. High Moisture content and Nitrogen rich with strong potential for odours if not well managed. Requires dry, high carbon amendment to ensure challenges of process and odour control are met. In NZ pig manure is sometime a feedstock for anaerobic digestion.</td>
<td>MC (80)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Manures</td>
<td>Good composting potential. Most other manures (e.g. sheep, rabbits, goats, etc) are useful for composting. Most farming systems in NZ are free range rather than hosed so availability is variable. Sheep manure is sometimes available from shearing sheds but is also sold directly as bagged fertiliser or pelletised. Truck-washes are another source of sheep manure slurdes. If combined with bedding or having been stored for long periods will generally be drier and higher in C:N. Low odour potential, readily compostable.</td>
<td>MC (69 %)</td>
<td>N - (2.7 % dwt)</td>
<td>C:N ratio (16)</td>
<td></td>
</tr>
<tr>
<td>Ingredients</td>
<td>General Properties &amp; Handling</td>
<td>MC (%)</td>
<td>N - (% dwt)</td>
<td>C:N ratio</td>
<td>Bulk Density (kg/m³)</td>
</tr>
<tr>
<td>-------------</td>
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</tr>
<tr>
<td><strong>Straw</strong></td>
<td>Excellent composting amendment. Dry &amp; high carbon, provides good porosity / texture, rapidly degradable. Often used as bedding so maybe pre-conditioned with manure or partially composted. Availability and cost depends on proximity to e.g. horse stables, etc.</td>
<td>12</td>
<td>0.7</td>
<td>(80 )</td>
<td>134</td>
</tr>
<tr>
<td><strong>Sawdust / Shavings</strong></td>
<td>Good to moderate amendment. Dry &amp; high carbon, slower degradability Usefull amendment and commonly available at lower cost, but increasingly used for bio-energy.</td>
<td>39</td>
<td>0.24</td>
<td>(442 )</td>
<td>242</td>
</tr>
<tr>
<td><strong>Woodchips</strong></td>
<td>Very good bulking agent but not as effective as an amendment because of large particle size. Generally dry &amp; high in carbon with large particle size often utilised in the context of forced aeration. Depending upon screen size may be screened out as oversize, hence be used. Often produced by the arboriculture industry from chipped branches. Can be sold directly as a mulch or for bio-energy, so depending upon marketing may be high value input. Pallets and C&amp;D waste wood sourced chips (e.g. from a tub grinder) may contain CCA treated or lead based painted timber hence chemical contaminants.</td>
<td></td>
<td></td>
<td>(560 to 641 )</td>
<td>263</td>
</tr>
<tr>
<td><strong>Bark</strong></td>
<td>Good material for composting. Has established markets and uses independently of any recycled organics composting (i.e. CAN, chicken manure or fish waste composted bark). Qualities similar to wood chips i.e. high C:N good bulking relatively poor amendment. Raw bark is often processed into grades (e.g. 5 o 20 mm chip for mulch and 2 to 5 mm fines for potting mix, etc). Relatively slow degradability which assists alternative uses e.g. as potting mix retains structure.</td>
<td>12</td>
<td>0.14</td>
<td>(223 to 496 )</td>
<td></td>
</tr>
<tr>
<td><strong>Grass Clippings</strong></td>
<td>Good composting material if handled properly i.e. on their own clippings tend to collapse and become anaerobic, causing odour. Grass clipping are a mainstay of most yard waste composting operations. Moderately dry to wet depending upon season with low C:N so good in combination with high C amendments. Commonly sourced from transfer stn / public drop-off and commercial users, may have accompanying revenue stream with tipping fee. In NZ depending upon season may be contaminated with spray residues, which is a serious issue.</td>
<td>82</td>
<td>3.4</td>
<td>(17 )</td>
<td></td>
</tr>
<tr>
<td><strong>Newspaper / Cardboard / Waste Paper</strong></td>
<td>Generally good to moderate properties as an amendment, but in NZ readily recyclable as high value raw commodity unless contaminated. Dry &amp; high C content moderate to good degradability with appropriate treatment. Usetical for moisture absorption but once wet loses structure Sometimes used as bedding. Inks mostly non toxic but may contain heavy metal contamination, glues may contain Boron, so should be monitored. If shredded may cause storage problems prior to use.</td>
<td>3</td>
<td>0.06</td>
<td>(398 to 852 )</td>
<td>115</td>
</tr>
</tbody>
</table>

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**MC**: Mass of Carbon
**N**: Mass of Nitrogen
**Bark**: The organic matter from the outer layer of trees
**Woodchips**: Chopped wood pieces used as a fuel or for mulching
**Grass Clippings**: Small pieces of grass used as composting material
**Newspaper / Cardboard / Waste Paper**: Recyclable materials used as composting material
<table>
<thead>
<tr>
<th>Ingredients</th>
<th>General Properties &amp; Handling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biosolids</strong></td>
<td>Ranges from septic tank residues to processed sludges. Potentially harmful (pathogens) and problematic e.g. odour issues and heavy metal contamination. Use in NZ is covered by Biosolids Guidelines and hence involves regulation, production and end-uses controls. High in N and MC (unless dewatered) depending upon source and processing so final products can be considered as nutrient enriched. Requires mixing, bulking and amendment to reduce MC increase C:N ratio and porosity. Highly degradable once into correct medium may produce volatile ammonia. Maybe first stage processed in closely managed in-vessel forced aeration bio-filtered system. If issues are able to be managed biosolids should be viewed as an composting asset because of high nutrients and attached tipping revenues.</td>
</tr>
<tr>
<td><strong>Recycled Compost</strong></td>
<td>Finished product or non compliant and reprocessed oversize can be utilised as an amendment, which lowers MC without raising C:N as this is already moderate. Composted products will supply micro-organisms but may raise EC / soluble salt concentrations.</td>
</tr>
<tr>
<td><strong>Shrub / Tree Trimmings and Leaves</strong></td>
<td>Greenwaste or Yard-waste are the mainstay of New Zealand Municipal composting. Once shredded, this material is basically ideal for composting and is relatively non problematic. As the basis for a compost operation green waste provides a very good butter tor a range of other more variable and complex inputs which may have associated issues. Specifically leaves are a good to moderate composting input. Relatively dry and high in C, so low odour potential. Good degradability when shredded and incorporated. Seasonal availability. Moderate MC absorption when used as an amendment. Because of transfer stn collection may have issues of contamination, also especially street sweepings.</td>
</tr>
<tr>
<td><strong>Household Food Organics / Vegetable</strong></td>
<td>Food organics are increasingly being sourced from the kerbside or directly from large producers such as restaurants or public events. Composting this material is an alternative to landfill and should attract a tipping revenue stream to compensate for the difficulties. Because of sourcing condition may vary through to highly putrescible. Typically high MC and N content low in C: N so has considerable health and odour issues requiring significant, immediate and effective amendment. Because of issues food organics is often handled via in-vessel systems. May be highly contaminated with trash / anything i.e. cutlery which may damage machinery and affect processing cost i.e. add-ons to screening process i.e. blower for plastic separation. May have associated problems with bio-plastics which some argue confuse contamination issues.</td>
</tr>
<tr>
<td>Ingredients</td>
<td>General Properties &amp; Handling</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------------</td>
</tr>
</tbody>
</table>
| Food Processing / Vegetable Wastes Horticultural / Crop Residues. | Good to fair composting provides challenges are overcome. Input types ranges from for example, coffee grounds, apple pomace, cocoa shells, corn cranberry, kiwifruit, potato, seeds, olive, grape, rice hulls soybean, tomato - tops trimmings culls damaged / spoiled, processing wastes, etc. Also includes filter press cakes which may be moderately dry and higher in C content. Moderate to wet MC with a moderate to low C:N, but highly variable and dependant on type and condition. Potentially high N content and good degradability requiring mixing, amendment and bulking to overcome poor structure and achieve adequate texture and porosity for aerobic composting. May have odour potential, flies and handling problems until incorporated into composting. Depending upon source may be trash / packaging contaminated. Maybe recycled directly as animal feed i.e. pigs / cattle. | MC (72 to 84 %)  
N - (2 to 6.9 % dwt)  
C:N ratio (5 to 16 )  
Bulk Density (634 to 1035 kg / m3) |
| Freezing Works Waste / Animal Mortalities | Covers Paunch grass, Blood, Meat waste, so called DAF waste and Carcasses, so is a highly variable category. Generally high MC and low C:N ratio. Good degradability but high odour / vermin / fly potential so requires excellent management systems. Requires significant amendment to reduce MC and bio-filter odours. Composting context includes above ground burial as an alternative to offal pits and also a bio-security responses re prophylactic slaughter with disease outbreaks. Often approached with in-vessel systems but can be undertaken via open windrows providing process control i.e. odour management and pathogen destruction. | NB: Figures quoted are for paunch grass.  
MC (80 to 85 %)  
N - (1.8 % dwt)  
C:N ratio (20 to 30)  
Bulk Density (861 kg / m3) |
| Fish Processing | Covers racks, frames, heads, tails, guts, crab / shrimp and mollusc shells etc, so significant variation in character. Generally high MC, low C:N, high N content so this material requires significant dry amendment, specialised handling and bio-filtering to control odour and other issues. Potential for tipping fees, regulation and high nutrient values in final products. | MC (76 %)  
N - (10.6 % dwt)  
C:N ratio (3.6) |
| Sea/Aquatic Weed | Good composting material when amended. Includes pond weed / cleaning, water hyacinth, residues from seaweed processing, beach clearing. High to moderate MC, various C:N ratios from low to moderate. Good degradability but poor structure, low to moderate risk of odour. Considered a source of a range of nutrients, but may have associated issues with elevated soluble salts. | MC (53 %)  
N - (1.9 % dwt)  
C:N ratio (17) |
| Paper Mill Sludge | Fair composting material. Includes waste pulp and fibre sludge, will be associated with the location of this type of industry. Very wet to moderate if dewatered High C:N ratio & low N, hence requires dry amendment with additional source of N. Good degradability but poor structure so specific amendment and bulking required. Low to moderate odour risk unless mismanaged. As with any industrial waste require contamination monitoring but may offer revenue stream with tipping / disposal tee. | MC (66 to 82 %)  
N - (0.57 % dwt)  
C:N ratio (54 to 250)  
Bulk Density (673 to 823 kg / m3) |
<table>
<thead>
<tr>
<th>Ingredients</th>
<th>General Properties &amp; Handling</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Ash</td>
<td>Maybe very dry or wetted to control dust low C and N but contains other nutrients e.g. Potassium, also may be contaminated by heavy metals depending on source materials. As composting input as will absorb moisture and raise pH (possible excessively &amp; requires caution) and has also been advocated as an agent for odour control. Composting is an alternative to landfill, so often carries a tipping revenue. Handling, mixing and end-use issues require careful management.</td>
<td>This material would need to be specifically tested as part of consideration as a composting input.</td>
</tr>
<tr>
<td>Fertiliser / Lime</td>
<td>Fertilisers and concentrated nutrient (N) sources are used for composting high C amendments (i.e. to lower the C:N ratio with bark / sawdust). There may be complexities with C:N balancing as carbon decomposes slowly and also excess N can volatilise as ammonia. Lime is considered some as an additive to adjust pH and control odour. Generally shouldn’t be required and maybe detrimental as a source of alkalinity if pH is elevated to the point of causing ammonia volatilisation.</td>
<td>As stated specifically</td>
</tr>
</tbody>
</table>
| Spoiled Hay and Silage | Moderate composting input. Moderate dry to wet, but highly variable depending on age, storage and conditions. Moderate to high C:N. N content varies according to crop type e.g. legumes will be higher than general grass. Availability variable depending on wastage & silage especially may have odour / (leachate) issue once in urban context. Should be useful as amendment but depending on production may be challenging to handle, e.g. bales are compressed and need to be broken open and watered. Other issues are seeds moderate good structure degradability if fully wetted and incorporated. | MC (9 to 67 %)  
N - (0.7 to 3.6 % dwt)  
C:N ratio (15 to 43)  
Bulk Density (variable kg / m3) refer to greenwaste / leaves / grass clippings |

NB: The characteristic property ranges and comments provided have been modified from those discussed in the ‘On-farm Composting Handbook’, R. Rynk et. al.

The figures quoted are either averages or ranges. Please refer directly to literature for covering notes and clarifications. The authors note that these figures should only be considered as representative.
Appendix K : Ingredients

In respect of Ingredients, Appendix K of the NZS4454 notes the following for Windrow composting systems:

- For all system types - Details of all types of feedstock used for composting shall be recorded to ensure traceability from delivery through to release of end-product.

- Ingredients containing high levels of toxic and inorganic contaminants shall be excluded.

- Inorganic contaminants shall be removed prior to processing and depending upon quantities may be removed after composting by screening.

- If ingredients are to come from waste sources, it is important that these organic materials are collected separately from other waste items, e.g. rubbish and recycling streams.

- Maximum permissible levels of toxic chemicals are dealt with elsewhere in this Standard (see 2.1).

- Stockpiling of ingredients will need to be controlled to avoid potential issues with personal health, odour, leachate, and vermin.

- For non-aerated windrows (also Turned pile) - High levels of nutrients, e.g. C:N ratio of less than 15:1, result in rapid microbiological activity and possible oxygen deficiency. Odours, including NH3 emissions, can occur.

- The optimum C:N ratio is between 30:1 and 40:1. Miller and Macauley (1989) (K.2) point out that high N ingredients tend to be high in available C and also the final compost can have high NH4+ which means it can be unstable and sometimes toxic.

- The final C:N ratio shall be approximately 22:1. High available energy on a volume basis can be reduced by the addition of plant-based bulking agents, e.g. straw, wood shavings or fine chips, of a high C:N ratio.

- For aerated windrows (also Aerated static pile or ASP)- Higher nutrient contents (e.g. C:N 25:1 – 35:1) than with the turned pile are possible because aeration lessens the chance of O2 deficiency, but too rapid microbiological activity and thus the need for increased aeration can dry out the compost too quickly and limit processing, resulting in pathogen survival and an unstable compost which reheats following water addition. Under good processing conditions, odours are minimised because large areas within the composting mass are processed at optimal temperatures (40 – 50 °C). Also, NH3 losses are minimised.

- For In-vessel systems - High nutrient ingredients can be used providing the high heat output can be controlled by aeration. Depending upon the type of system temperature, gradients in the composting mass can be virtually non-existent (1 – 2 °C), temperature regime and recirculating airflow ensure minimum odours and optimal NH3 incorporation.
6. Shredding

Purpose of Shredding

The primary purpose of Shredding is to reduce the bulk density of feedstock materials (garden organics / greenwaste) so that free air space (FAS) is reduced to the optimum levels that promote optimum thermophilic composting conditions (rapid microbial activity, appropriate temperature build-up and retention of moisture content).

Ideally Shredding should be undertaken regularly with the objective of keeping the drop-off area clear, mitigating hygiene and odour issues and ensuring that pre-processed material is blended, into an aerobic composting process as soon as possible (Some resource consents stipulate this within 24 hours of drop-off).

In the scenario where large mobile shredders are contracted in at intervals to provide this service, (i.e. once a month), then un-shredded material has to be stored awaiting the next visit. In this situation moisture that dries out has to be replaced and pockets of anaerobic activity can create a nuisance. Ideally shredding should occur as frequently as possible, which ensures that feedstock material will be introduced into a healthy sustainable aerobic composting process and issues minimised. Shredded material is sometimes wetted at the point of discharge from the shredder, this provides an even distribution of moisture through the material.

System Considerations

Indicative US data provided by R. T. Haug, (1993), stated that green waste is 70% grass clippings, 25% leaves and consists of only 5% brush (i.e. the component requiring shredding). Whilst this will vary between locations (and is likely to be different in a more urban / rural setting such as New Zealand), these statistics help to put the role of shredding in perspective, as clearly it is not an essential processing function for the entire organic waste stream. Shredding is necessary for woody branches and large materials which can’t effectively be composted without size reduction.

As is obvious from the volume and nature of by-product generated in the screening process, woody material does not decompose sufficiently in most commercial composting rotation timeframes (i.e. disintegrate sufficiently to pass through, for example, a 20 mm screening process) and become presentable in form and nature and ready for sale as final product.

The current New Zealand Industry standard shredding options are “a major capital and operational pre-processing cost”, R. Wark, (1999). There appears to be a balancing act in the cost vs. benefit...
of investing high capital and energy into initial shredding (either by direct ownership or contract service provision), vs. the increasing necessity for equipment which achieves a blending function, vs. compost process management systems and vs. screening and post-processing equipment, all of which are, in combination, necessary to achieve the requirements of NZS4454.

Types of shredders

In the ‘On-farm Composting Handbook’, R. Rink et al. (1992) described four primary types of grinding or shredding equipment.

1) Shear shredders in two forms, cleated belts and contra-rotating cutter shafts
2) Hammer mill
3) Tub grinders
4) Chippers (e.g. as used by arborists).

As the subsequent photos of current examples demonstrate, these generic types have been expanded upon and are manufactured and utilised in a variety of forms, some of which have merged the Shredding / Blending functions into a single system.

Figure 8 & 9: ZARGO, Selwyn District Council.

Figure 10 & 11: SEKO.

Figure 12 & 13: CRAMBO, Timaru District Council.
Figure 14: Tub Grinder, MetaNZ / Terra Nova, Christchurch.

Figure 15: WILLIBALD Composting New Zealand, Waikanae (Vertical hammer-mill type).

Figure 16 & 17: BRENTWOOD, Wanganui and New Plymouth.

Figure 18 & 19: RIPPER, Dunedin.

Figure 20: An early New Zealand-made option.
Low / High System

One distinguishing feature amongst the respective systems is the speed at which they operate. Both high and low speed systems typically have their strengths and challenges. The advantages of low speed shredders are that they are quieter, cheaper to operate and are perceived to be safer, because everything happens more slowly and there is less danger of flying debris. (NB: However, some of New Zealand’s worst industrial accidents have occurred with low speed shredders indicating this perception is not matched by the operational reality). These advantages have allowed low speed systems to be generally located closer to areas of public activity.

In comparison, high-speed shredders are often mobile, enabling them to serve a number of locations (or be moved around a site). High speed shredders have a large capacity and can be loaded in bulk by a digger or loader. The disadvantages appear to be noise, dust, operational cost and the danger of flying debris.

The third and final category mentioned by Rynk is Chippers. In reality these are more appropriate for arboriculture than commercial organic recycling. These systems lack the ability to cope with the high processing volumes of most commercial operations (i.e. because of the slowness of in-feed, as generally they process on branch at a time). They produce a quality chip which can be sold or utilised as mulch directly with or without composting. An alternative shredding system for small operations appears to be the use of tractor-driven orchard mulchers.
Figures 25 & 26: A Tractor driven Orchard Mulcher (Shredding) and a Chipper used for separate purposes in the same operation, Innovative Waste Kaikoura.

Comments

Choosing a shredding system requires careful analysis to balance input material to required output, cost and capability, alongside the impacts on the downstream composting management phases. The goal should be to achieve a successful balanced and economic result suited to the scale and context of the operation as a whole. In the context of most operations the general facts greatly empower the concept of pre-processing as a tool for shredding cost minimisation by reducing the volume requiring shredding and reducing the contamination which may damage machinery.

Appendix K: Shredding

In respect of Shredding, Appendix K of the NZS4454 notes the following:

- For all system types - To enable good structure for aeration during the compost process and to assist decomposition of “woody” material it is necessary to shred or chip this material prior to composting. There are a range of various machines that should perform this task. The type and size of machine should be suited to site-specific parameters and processing options. Shredded material may range in diameter from 12 mm to 40 mm and up to 400 mm in length.

- For In-vessel systems - As above, also the particle size of the material to be composted should be suited to the type of in-vessel system. Systems with larger cross-sectional areas require a coarser grading of material for composting to assist with aeration.
7. Initial Mixing

Optimum Parameters
The commonly quoted optimum parameters for aerobic decomposition are:

- C:N ratio, 25-30 to 1;
- Moisture content, 50-60%;
- Oxygen concentrations, greater than 5%;
- Average wet bulk density, 200-300 kg/m³ (this increases to 800-900 over the decomposition process);
- pH, 6.5-8;
- Temperature, 45-65°C for optimum thermophilic microbial action, including a period of 4 days at greater than 55°C.

The focus of initial mixing is to facilitate the subsequent composting management objectives. One definition of these objectives is provided by R.T. Haug (1986), to achieve “rapid, biological decomposition and stabilisation of the organic substrates under conditions which allow for the development of thermophilic temperatures as a result of biologically produced heat with a final product sufficiently stable for storage and application to land without adverse environmental effects”.

Once the pre-processing and shredding phases of the operation are complete, the material is then re-mixed with non-shredding material previously separated out. Initial mixing is the first stage of, which sets up the ongoing compost management process. As such, it is an important opportunity to adjust and optimise the above parameters so as to achieve a healthy and efficient decomposition as the foundation for end-product quality.

Feedstock Conditioning
Feedstock conditioning is an encompassing term for a process (including mixing) which aims at removing the process rate limitations in three critical spheres.

1) Physical / structural (Moisture, FAS).
2) Chemical (Lack of nutrients or chemical imbalances).
3) Energy / Thermodynamic (sufficient energy available to drive...
microbial kinetics). During this mixing / conditioning phase, moisture will be managed by amendment, bulking or supplementation. The same basic tools effect the initial C:N ratio, pH, and FAS management.

In a general sense the properties of greenwaste, (once shredded) coming into New Zealand organic recycling is anecdotally reported as falling naturally within the ideal range required for composting, making these operations relatively straightforward. However once the other types of feedstocks are envisaged, such as additional paunch-grass or manures, etc. significantly more management knowledge, skill and experience is required to maintain acceptable process control, hence outcome.

Various aspects of ‘feed conditioning’ are supported by advanced compost management literature and additionally by online resources, including free recipe calculators, such as that available on: http://compost.css.cornell.edu/science.html. Importantly, it should be realised that composting is undertaken utilising fallible machinery systems, whilst processing highly variable materials, under changing economic and social constraints, across a whole spectrum of seasonal and environmental conditions. In short, there is no replacement for the human software embodied in knowledge and experience.

Appendix K: Initial Mixing

In respect of Initial mixing Appendix K of the NZS4454 notes the following:

• For Turned pile - Good mixing of ingredients minimises gradients in the composting mass and results in consistent processing. Adverse effects of inadequacies of the initial mix can be minimised by frequent turning during processing. This frequency is determined by the need to balance adequate aeration and high temperature maintenance. Mixing by front-end loader generally gives satisfactory results.

• For ASP - Inadequate mixing must be avoided. A homogenous mix is of paramount importance to ensure consistent processing throughout the composting mass (minimum gradients of water, aeration, nutrient distribution and temperature). Because of the configuration of piles there may be limited opportunity to redress initial poor mixing in a static pile. Screw auger blenders provide good mixing but many other blending systems can be used.

• For Windrows, as above, but periodic turning during processing can redress initial mixing problems.

• For In-vessel systems - A homogenous uniform mix is essential before the composting process commences as for ASP (see K3(a)). Some systems enable further mixing within the vessel during the composting process, however the quality of the end product is determined by the initial mix.
As previously discussed, the foundation for effective composting process management is established by the operator during the pre-processing and initial mixing phases. After this point the suitably prepared material enters one of the four composting systems types outlined in Appendix K of the NZS4454 (Turned pile, Aerated static pile, Windrows and In-vessel). Within all of these systems, process control is exercised through turning, moisture control, aeration and if necessary, further amendment or bulking. In reality these parameters are all interrelated. For example, there is little point turning up the blowers in an ASP system if the porosity is low and there is insufficient free air space for thermo-convective air movement. Compost system management needs to be seen as a holistic balancing act involving several interrelated control measures.

In New Zealand open windrows are the most widely used composting system, as they are flexible and adaptable to a variety of feedstocks, involve relatively low capital for implementation and can be turned and aerated by a variety of equipment. Even the most sophisticated operations which utilise in-vessel systems to manage the initial high rate, most volatile, (thermophilic) decomposition phase, generally follow this up with an open windrowing phase in which, lower rate (mesophilic) curing, maturation takes place. Figure 27 (below) illustrates the interrelationships between key compost management parameters.

Figure 27: A generic picture of what is happening in a composting windrow.
Decomposition Process

The decomposition process in the windrows can be broken down into two phases. 1. The high rate initial phase, which is characterised by thermophilic temperatures, odour potential, high oxygen (O2) uptake and rapid - biological volatile solids - (BVS) reduction rates. 2. The secondary low rate phase, which is characterised by reduced O2 uptake rates, lowering temperatures and reduced odour production potential, as the product reaches maturity and stabilisation.

During the active composting period, the temperature will fall if oxygen becomes scarce because microbial activity is limited and decreases. Conversely, if oxygen is available and microbial activity is intense, the temperature can rise above 70°C. At this point, many microorganisms begin to die or become dormant and BVS reduction rates decrease. In many respects temperature can be viewed and is a good summary indicator (and is measured and recorded as such) of other descriptive parameters and the overall health and success of the decomposition process as a whole.

Compost Maturity

Maturity criteria can be quantitatively defined in terms of;

1) Specific oxygen consumption rate (mgO2 / kg volatile solids per hour).
2) An absence of phototoxic compounds.
3) A reduction of BVS.
4) A return to near ambient temperatures.

Additionally, it is worth discussing the somewhat blurred distinction between initial stabilisation, which equates to the cessation of microbial activity and later maturity where desirable end use character and a negation of potential phototoxicity develops.

During the curing / maturation and storage phases, new microbial species transition into the dynamic mix in which Bacteria were initially predominant. Notably once temperatures lower, fungi are able to invade the material as a food source. Fungi continue to progress and expand the decomposition process. This is especially relevant as the high carbon, woody material, achieves only limited breakdown during the early rapid aerobic, thermophilic decomposition phase. One of the management challenges associated with storage, once temperatures decline, can be waterlogging as the decomposition dynamic is no longer generating sufficient heat to dry off rain water ingress. This can be a particularly seasonal issue coming out of a wet winter, which becomes critically apparent when seeking to screen high volumes of overly wet compost to meet high spring sales demand.

Environmental and Health and Safety Management

In the New Zealand context, largely because of the combined influence of our Occupational Health and Safety legislation and the RMA, compost process management must also focus on safety and environmental standards. Predominant among these is the manifestation of odour, which has a significant nuisance potential and is arguably the composting industry’s number one management issue.

Another airborne issue is bio-aerosols or secondary pathogens, most likely in the form of dust containing fungal spores (notably Aspergillus fumigatus), which may cause allergic respiratory illness in predisposed individuals. A further potential issue is in the form of primary or enteric pathogens, such as, tetanus, viral agents (hepatitis), intestinal parasites and bacteria (i.e. Faecal coliforms and Legionella) and fungal opportunists. These may invade through

Figure 28: A typical New Zealand open windowing site, showing leachate catchment and control system to bottom right of picture.
ingestion, respiration or direct to the bloodstream through cuts.

All of these issues are a potentially serious concern for worker and public health. Appropriate OSH management is required to address these potential issues (such as protective clothing and immunisation).

Another environmental issue related to site construction, process management and resource consents is that of the nutrient rich leachate, which may be generated from composting windrows. Leachate must be minimised in the production cycle and circumvented from negatively impacting the aquatic environment (for example, causing eutrophication of waterways or contamination of ground water).

Appendix K: Odour Control System

In respect of Odour Control System, Appendix K of NZ54454 notes the following:

• With in-vessel or enclosed systems - It is most likely that materials with high moisture and nitrogen levels will be composted. Typical wastes with these characteristics may include food wastes, bio-solids, “soft” vegetation, animal by-products, manures etc. The materials have the potential to cause odours whilst stockpiled, if not mixed appropriately and if aeration and temperature levels are not managed appropriately.

• The type of odour treatment shall be determined by the type and size of the system and site-specific parameters. Odour is an issue that may arise from anaerobic conditions during the compost phase that may impact on overall end-product quality. Similarly odour issues will need to be managed so as to not impact on neighbours.

Dimensions

Generally speaking, windrows are sized according to which cross-sectional volume is most likely to facilitate successful aerobic composting conditions. Cross-sectional volume is the function of the combined height, width and shape relationships of a windrow. For example, smaller windrows have a greater surface area to volume ratio and hence are likely to provide better air flow when composting material with a higher bulk density and lower porosity. An example of such material would be a mix made from manure sludge (typically high moisture content) amended with sawdust / wood shavings. Conversely, smaller windrows will lose heat more rapidly than larger windrows, because of the relatively higher surface area to volume ratio.

Shredded greenwaste is likely to possess a good balance in the mix between large and small particles and comparatively may be composted in larger windrows, which facilitate rapid temperature build-up, whilst maintaining adequate airflow / oxygenation and good spatial utilisation of the composting site.

The Dimension choices made within the composting have a significant bearing upon the total processing capability or potential throughput of any given site. Like most composting management decisions dimension interrelates with a range of other factors. For example the type of turning equipment utilised will influence windrow dimension. High speed straddle type turners will only function within maximum height and width dimensions. Alternatively, the size and weight of either rubber tyred loaders or excavators used for windrow turning will effectively limit the size of composting windrows.

Figure 29 & 30: A large dimension open windrow utilised for stabilised material at an Australian operation vs a fixed dimension of the New Zealand, HotRot in-vessel technology, which includes an in-process turning mechanism.

In-vessel or Enclosed configuration composting systems possess a pre-determined dimension designed and constructed into them. This design process seeks to factor the optimum dimension against the targetted feedstock, capital and
operational cost and through-put considerations.

As the composting process shifts from a high rate to a low rate decomposition phase and hence proceeds towards maturity, the nature of the material changes. This progression can enable changes in windrow dimension to be made, without necessarily creating management issues. Where recorded feedstock type is consistent, and once time temperature considerations have been achieved, it is not uncommon because of natural shrinkage for windrows to be in effect combined as they are turned and relocated. Maturating / curing and storage piles’ dimensions can be increased based upon the increasing stability of the composted material.

**Appendix K: Dimensions**

In respect of Dimensions, Appendix K of the NZS4454 notes the following

- For Turned pile - Heights of less than 3 m for low available energy (carbon) ingredients (e.g. green wastes) and 1.5 – 2 m for higher energy ingredients (e.g. animal manure mixes) are recommended. Oxygen deficiencies resulting in odour production are more apparent in larger masses, but lessened insulation and thus limited self-heating is characteristic of smaller masses, in which survival of pathogens is more likely.

- For ASP - Because of the aeration, piles that are slightly larger than turned piles are satisfactory, but composters shall aim for 1.5 – 3 m height, depending on whether high or low energy ingredients are used. Aeration minimises the extent of anaerobic zones so that odour production is reduced, but aeration can also cool and dry out smaller masses, thus limiting self-heating and resulting in pathogen survival.

- For Windrows - Can be horizontally-extended piles, formed by a front-end loader, or rectangular windrows formed by a turner. Extended piles are generally 1.5 – 3 m high, and rectangular windrows are generally 1.5 – 2 m high and wide, with the length of both being limited only by the composting area available.

- For In-vessel - There is a range of systems and technologies which determine the dimensions of in-vessel systems.

**Windrow Turning**

Turning acts as a mixing tool via which homogeneity is re-established throughout the windrow mass and ensures its entire volume is exposed to the high temperature, central core of the windrow and hence achieves the time temperature requirements established in the NZS4454 which ensures seed mortality, as well as, destruction of plant propagules and pathogens.

Windrow turning will occur regularly, but intervals will vary according to the composition of feedstocks, the maturity of respective windrows, the size type and availability of equipment, seasonality and a range of other management factors. The timing of windrow turning rests within the composting manager’s jurisdiction and may even be reduced to daily intervals if this is required to gain the upper hand on a problem organic waste input. Alternatively, turning frequency be limited for an interval until a specific risk of odour generation passes. This resilience and flexibility are two of the major strengths of a windrow composting system.

**Figures 31 & 32:** A “Scraab,” straddle type windrow turner, which establishes the resulting pile dimension vs. a small excavator turning compost within a bin of fixed dimensions.

The compost manager’s efforts at process optimisation (maximising decomposition rate) will be reflected through the compost process duration or so-called rotation length. In many instances it may be economically desirable to
manage for the shortest possible production cycle. However, this is balanced against the biological desirability for a curing / maturation phase to follow the high rate stabilisation phase to allow time for the physical character of the resultant compost to continue to develop.

### Appendix K: Turning

In respect of Turning Appendix K of NZS4454 notes the following:

- **For Turned pile**: The frequency of turning is determined by the parameters for moisture, temperature and oxygen (in K2(f), (g) and (h)). The type of machinery for turning varies and is site-specific.

- **For ASP**: The concept of the static pile is that it is not turned during the composting process. There are some static pile technologies whereby the material is turned during the composting process. The frequency is determined by the type of technology and composting methods that are adopted.

- **For Windrow**: Frequency of turning is determined by the following parameters for moisture, temperature and oxygen. With organic materials that pose a potential pathogen risk (see table 3.1),

### Duration

The windrowing process takes between 3 and 12 months. The length of this rotation is related to a range of factors. For example the level of commitment to process management, the size of the site, the ability to sell final product and the degree of maturity (i.e. completeness of the composting process) sought prior to sale. The duration of the composting process also relates to the type of product being developed. For example, a very basic process which achieves the minimum requirements for stabilisation and seed mortality may be sufficient, as in the production of mulches or low value material for land spreading.

Alternatively, a longer, more complete decomposition cycle (i.e. high followed by low rate phases, proceeding from stabilisation through to maturation), will result in an attractive material with a high humus content and associated benefits of rich dark brown colour, low respiration, inherently low nitrogen draw down potential, etc. The duration of the decomposition process has important ramifications for quality assurance, risk management and the operations’ sales and marketing strategy. For example, immature compost continues to exercise an ongoing oxygen demand as it continues to decompose. If prematurely put inside an airtight plastic bag, is likely to revert to anaerobic activity and produce an unpleasant odour.

### Appendix K: Duration

In respect of Duration, Appendix K of the NZS4454 notes the following:

- **For Turned Pile**: Temperature decline due to reduced microbiological activity following available nutrient (e.g. carbon) depletion indicates the completion of composting. Premature temperature decline can occur where high nutrient ingredients give rapid processing and high water loss to the point at which water limits microbiological activity. Water addition will renew activity. Generally, duration will be between 6 – 10 weeks. This shall ensure that sufficient mixing (between 2 – 3 times each week) introduces the whole composting mass to regions of the pile where pasteurising conditions are achieved. A curing period of a minimum of two months shall follow to ensure that compost is mature.

- **For ASP**: Processing times will be in the order of 6 – 10 weeks depending on nutrient levels and moisture content. Curing of the finished product shall be for 2 – 3 months.

- **For Windrows**: Composting for 4 – 6 weeks with 1 – 2 turns per week shall ensure that all the composting mass reaches the prescribed temperature/time conditions for sanitisation and compost stability. Curing for one month is recommended.

- **For In-vessel**: The duration time shall depend upon the type of process and whether the maturation area is enclosed. Longer duration within the vessel reduces potential odour during the maturation phase. Some in-vessel systems may have an initial 3-day pasteurisation phase with 5 weeks for maturation in enclosed buildings with appropriate odour extraction and treatment. Alternatively other systems may have a 6 – 28 day process with outdoor maturation. The outdoor maturation requirements shall be site-specific.
Mature Products

After the curing / maturation phases, the final products are normally screened ready for sale. In addition, final products may be bagged, sold by the trailer or truckload, or re-blended into value-added specialist mixes such as sports turf and soil conditioning mixes. The oversized by-product from the screening process will either be re-processed and re-incorporated in the production processes as a bulking agent or re-processed directly into a marketable form (e.g. coarse mulch).

Screening is required at the end of the windrowing process to remove oversize material and contamination such as plastic bags. Aside from the dictates of the NZS4454 (Table 3.1, the choice of mesh size is determined by the intended end use / market sought for products.

Markets such as sports turf and potting mix amendment require specific size fraction of (e.g. 0-5 mm, which enables it to be used as a blending component in specific mixes). General garden compost used as a soil conditioner may have particle size ranges varying anywhere from 0 up to 15-25 mm. The larger, sticky component, whilst lessening the visual appeal of the product, actually enhances its beneficial soil amendment abilities by increasing the permeability and improving the texture of the soil. These woody components continue to decompose in the soil at soil temperatures largely by virtue of the presence of Fungi and Actinomycetes occurring naturally in the soil environment.

Figures 33 & 34: A SEKO small mobile trommel and a TROMMEX excavator powered screen.
Screen Design

New Zealand experience appears to indicate that ‘Trommel’ type screens are the most cost-effective option for screening compost. This is because the self-cleaning action of the rotating trommel allows sticky material to fall out of the mesh when it is inverted during rotation. This is as opposed to shaker type screens, which tend to more easily clog as long, sticky materials lodge inside the screen mesh without passing through, nor clearing from the screen. Another design alternative is ‘Star’ type screens which appear to be effective and overcome the challenges associated with shaker screens.

Each screen design type will offer comparative advantages and challenges. It is important to realise that compost has distinctly different
product attributes and handling properties from top soil, bark and gravel products, so a system which works for product one may not work well for another in all conditions. Another challenge is for a single screening plant to be able to produce multiple product size ranges. Equipment purchase decisions need to take a wide range of factors into consideration.

Trommels also appear able to cope with the varying moisture content associated with seasonal conditions for composting. It is notable that periods of maximum sales demand often coincide with spring and autumn. The former season, following on from winter is where the compost stockpiles are at their highest moisture content. Sometimes it is advantageous to cover maturing compost to ensure it does not sponge up excessive rainfall and become un-screenable. The latter phases of window management should be geared toward preparing the maturing product for successful screening. In recent years breathable covers have become available for both odour management and this issue.

Typically many Kiwi operations have designed and built homemade screening plants. Commercially available trommels, such as, the New Zealand made ‘Powerscreen’ provide a more expensive but capable machinery asset. In the case of large multiple site composting companies, mobility and high through-put may be a key requirement, in order for one machine to service a number of locations. The expense of this type of plant may be further justified in the event of outside contract screening being available, for example, either from other composting operations or from earthmoving contractors screening top soil. Out-work of this nature would offset the cost of the machinery, providing it did not interfere with the core business of the company.

**Appendix K: Screening**

In respect of Screening, Appendix K of the NZS4454 notes the following:

- For all systems - There is a range of various machines to screen compost. The particle size to be screened is determined by the type of end-product to be produced as specified in table 3.1.

**By-product Processing**

An important aspect of the screening process is dealing with the by-product. By-product is oversized material, which is often contaminated with plastic bags and rocks etc. Depending on the shredding system, this may consist of up to 25% of the input to the screening process. This material can be viewed as a significant problem and / or alternative an under-utilised asset and opportunity.

Once contamination is removed, high speed tub grinding or hammer milling has the potential to turn this by-product into a potentially high value mulch product. Many organic recycling operations have large stockpiles of oversized by-product. Those with high speed shredding equipment may be able to re-grind the material and reincorporate it into the composting process.

**Storage**

Once the compost fines are produced, they will be negatively affected by rainfall, contamination by wind-borne and bird-deposited seed, etc. if not protected from new forms of contamination.

Storage is a key to preserving the quality of this product to its point of sale. High quality bulk storage generally necessitates the utilisation of indoor bins, or at least covered concrete bins. In addition, specific point of sale storage needs to keep different products separate and to preserve quality.

![Figures 43 & 44: Point of sale concrete storage bins on a tar-seal pad and a close-up of oversize by-product ready for further processing. NB: In this case it is sold as feedstock for thermal combustion for bio-energy.](image)
**Appendix K: Storage**

In respect of Storage, Appendix K of the NZS4454 notes the following:

**3.1.5 Protection**

Both packaged and bulk product should be protected so that, under normal conditions of handling, storage and transport, the contents do not become contaminated by extraneous matter (e.g. plant propagules, pathogens and pests (such as Phylloxera)), and the contents of packages are not released unintentionally. Packaging shall contain perforations to allow for pressure equalisation, and ease and safety of handling.

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**Blending**

In order to produce the wide variety of niche garden products that are required in today’s gardening marketplace, blending to some degree is essential. To produce soil mix, for example, compost, pumice, bark, topsoil and fertilisers and trace elements may be mixed together at specific ratios to produce a distinct new product. In this case the objective would be to enhance the existing conventional topsoil product (normally stripped during earthworks), thereby improving its appearance and increasing its value and marketability.

Blending is readily achieved by ground mixing on a large, uncontaminated open space. Ideally this area should be sealed or concreted. This allows a front-end loader to essentially blend the materials together until homogeneity is achieved. Again, contamination-free storage is a requirement for each specific product line. Alternatively, more sophisticated specialised blending machinery is available to produce specific new product lines.

Composts made from recycled organics can be used as the base for potting mixes. Composts made from recycled organics have the potential to naturally boost nutrient value, to impart disease resistance and improve the particle size distribution of the potting mix. Examples of blended products are the Living Earth Company’s ‘Potting Mix’ and ‘Lawn mix’.

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**Bagging**

Bagging is an opportunity to brand and present products to a diversified retail market. Normally, where product is sold in bags some form of automatic bagging machine is used to load bags to a specific weight or volume. Bags are either sealed by heat sealing or tied with a wire tie. Normally bags will be printed with company branding and graphic design and product information. Alternatively, this content may be attached to the bag via an adhesive label.

Automated bagging machinery is specialised equipment and relatively expensive. Therefore potential investment needs to be weighed against the operational scale and market opportunities. The bagged compost market offers increased potential returns and an extended sales reach,
Figures 47 & 48 & 49: These pictures illustrate the graphic detail, marketing opportunity and competitiveness of the retail bag market for compost products.

but also higher exposure to competition and other potential issues.

Off-site contract bagging is an option to undertaking the bagging function as part of the composting operation, but introduces additional cost through transportation and contract charges. Once bags are filled, bulk handling is best achieved on pallets which must be collectively shrink wrapped to hold the bags in place. The loaded pallet can then be handled with a forklift for loading onto trucks etc.

Inevitably once bagged, the compost products will be stored for an indeterminate time awaiting sale. In addition, when bags are on-sold and transported beyond the immediate jurisdiction of the producer, for retail sale via a third party, additional potential product liability issues may be encountered. These can be mitigated by achieving compliance with the NZS4454.

The bags for storing compost material should allow limited aeration to prevent anaerobic conditions from developing inside the bag. They should be at least opaque to reduce light penetrating and causing algae to grow, and should contain product advertising and point of sale information, which achieves the specific ‘packaging, marking and documentation requirements (Chapter 3) of the NZS4454.

Generally speaking, the practical challenges and extra cost of bagging are offset by the elevated net price per volume achieved by selling bagged material in smaller volume increments. Bagged product is an opportunity to brand the company and also serves to profile the professionalism and status of the recycling programme to a wider retail market. One key to running a successful bag line is to, if possible, sell as many as possible directly to the public from the production site. This will be possible where a public drop off is operating and numbers of potential customers are entering and departing the site. Direct sales (either in bulk or bags) avoid having to accept a reduced wholesale price necessitated when on-selling product in whatever form to a secondary retailer who will need to achieve a mark-up.

Appendix K: Packaging Marking and Documentation

In respect of packaging marking and documentation, Appendix K of the NZS4454 notes the following requirements:

3.1.1.1 Health Warnings on Bag:

CAUTION

Ordinary garden soil and products like compost and potting mix may contain a variety of living micro-organisms, some of which, on rare occasions can cause illness in humans.

Serious infection is rare. However, for older people or those with reduced immunity, infection can be life threatening. We recommend the following precautions:

• AVOID OPENING BAGS IN ENCLOSED AREAS
• AVOID INHALING THE MIX
• ALWAYS WEAR GLOVES AND WASH HANDS AFTER USE

See your doctor if you develop high fever, chill, breathlessness or cough.

In summary, the following applies in respect of the volume of packaged materials (3.1.3).

The actual volume at the time of packing
(measured according to Appendix G and packaged in multiples of a litre) must be ≥ the volume stated on the primary packaging.

NB: Because all parties need to be aware that settling will occur during transport, it would appear prudent for this fact to be stated on the packaging.

For bulk materials, volume determinations are subject to agreement between the supplier and the purchaser (e.g. loose or settled volume, or weight at a specified moisture content). This appears to necessitate communication the point of sale and clear signage and documentation (e.g. statements on invoices) which clarifies company policy.
Learning About Compost Marketing

Sales and Marketing is a specialised subject, students of which will benefit from reference to dedicated expertise. For example ‘The Practical Guide to Compost Sales and Marketing’ by Ron Alexander is a well respected reference in this subject (www.alexassoc.net). In addition ‘The Buyers Guide for Recycled Organics Products’, the ‘How to Use Recycled Organics Products’ and the ‘Guide to Selecting, Developing and Marketing Value Added Recycled Organics Products’ are part of the excellent information series published by the Recycled Organics Unit (ROU) (www.recycledorganics.com). The previously mentioned ‘On-farm Composting Handbook’ also contains valuable information on the properties and benefits of compost.

Compost Properties

Generally speaking, NZS4454 certified compost products made from recycled organics may confidently be said to have many positive benefits. Such quality assured organic compost will greatly improve the follow properties of the soil environment:

- Physical (improves aeration, water management and structure).
- Chemical (improves organic carbon and nutrient management).
- Biological (increasing beneficial micro-flora and fauna).

Importantly, quality assured composts made from recycled organics are produced by managing natural processes. Production is a controlled process, which is monitored to ensure optimum environmental conditions and is systematically tested for stability, maturity and to ensure a wide spectrum of quality parameters are achieved prior to sale. The transformation of organic waste materials into high quality compost products achieves numerous sustainable environmental benefits. When purchasing recycled organics compost products, customers are making an eco-positive choice, which benefits their local environment.

Figure 50: Positive sales and marketing images.
The Beneficial Attributes of Recycled Organics

Compost products made from recycled organics contain a natural balance of nutrients and minerals essential for healthy plant growth. NZ54454 certified products have been naturally pasteurised during thermophilic decomposition. During the production process the naturally generated heat destroys all weed seeds and soil-borne plant pathogens and disease. This makes the final product clean, healthy and safe. Research has established that these products contain natural organic disease suppressant properties, which are beneficial to the soil environment and growing plants.

Ron Alexander lists the following characteristic benefits of recycled organics compost, which have been established by decades of research.

- "Improves the soil structure porosity and bulk density – creating a better plant root environment.
- Increases the moisture infiltration and permeability of heavy soils – improving drainage and reducing erosion and run-off.
- Improves moisture holding capacity of light soils – reducing water loss and nutrient leaching.
- Improves and stabilises pH.
- Improves cation exchange (CEC) of soils – improving their ability to hold and make available nutrients of plant use.
- Supplies a variety of macro- and micro-nutrients.
- Supplies significant quantities of organic matter.
- Supplies beneficial micro-organisms to the soil – improving nutrient uptake and suppressing certain soil-borne diseases.
- Can bind and degrade specific pollutants”.

As an amendment in growing media (for example potting mixes), compost provides essential bulking material, which resists shrinking, through which roots can easily grow. When used in combination with other materials, compost provides the water and nutrient holding capacity, plus air space needed to promote good root growth. The pH of compost is usually near neutral, which is preferred for most agricultural crops.

“The man of virtue makes the difficulty to be overcome his first business, and success only a subsequent consideration” – Confucius (551 BC).

Soil Biology

Most plant nutrients in compost are in an organic form; they are released slowly over a long period of time as a result of increased microbial activity. In addition, this beneficial biological activity is stimulated by the application of compost into the soil environment. It is this positive attribute, which has lead to the, oft-quoted adage, where compost is said to add ‘LIFE’ to the soil. The soil is a living system and compost is literally the right food to make the soil system naturally healthy. Healthy soil produces healthy food. Healthy growing systems, rich in natural organic life, require less (or even better still no) chemicals, fertilisers or pesticides.

Encouraging beneficial microbiology, or life, in the soil enables essential nutrients to become available to the roots of plants over a sustained period. Therefore the nutrients are more resistant to leaching than, for example, is the case when applying chemical fertilisers. The availability of nutrients from compost is related to the rate of microbial activity. Because, during the coldest and wettest parts of the year, microbial activity decreases, this naturally reduces the likelihood of nutrients being leached from soil enriched with compost.

Greenwaste compost is made from garden material from the local environment, hence when it is sold back to local customers it effectively closes the loop and recycles the complete spectrum of nutrients and soil carbon back into the local soil environment. Composts are rich in humic acids, which aid in making certain
plant nutrients available. Compost promotes sustainable and long-term soil health and vitality with an annual nitrogen mineralisation rate for availability of between 8-12% of the total nitrogen in the compost. Studies on the residual properties of compost on agricultural soils have reported measurable benefits for 8 years or more after initial application. This contrasts with the rapid and short-lived availability of the high nitrogen, phosphorous and potassium (NPK) of chemical fertilisers.

Environmental Properties

These many positive environmental properties are a significant point of marketing distinction. Whilst composts alone may not provide the nutrient levels necessary for the accelerated plant growth expected by commercial operators, it generally has an adequate supply of plant nutrients to keep most plants healthy for several years. There appears to be a strong case for commercial operations to examine reducing their dependency on chemical fertilisers by thinking about the holistic health and sustainability of their soils. The elevated organic matter in compost-enriched soils reduces nutrient leaching, hence enhances the impact of the nutrients supplied by chemical fertilisers.

Whilst the beneficial biological properties of compost are complex, diverse and not fully understood, increasingly research is discovering and defining many specific benefits which have positive commercial applications. Composts are known to contain naturally occurring fungicides and beneficial organisms that help suppress disease-causing organisms. When used in potting mixes and seedling beds, compost helps reduce the need to apply soil fungicides. Production of trees and shrubs has been shown to have benefited through the promotion of the growth of mycorrhiza-associated fungi. These fungi are essential for the growth of certain species and may be particularly important in establishing vegetative cover on disturbed soil such as abandoned strip mines and landfill covers.

The collective product attributes (pH, Macro / micronutrients, Soluble salts, Bulk density MC, OM, Stability and Micro-biology) of recycled organics compare very favourably with other commodity types which compete in all market segments (i.e. home garden, horticultural, agricultural and landscaping, etc.). Importantly recycled organics should be viewed as a distinct product - neither fertiliser top soil, potting mix nor peat, but rather a unique product, versatile in character (based upon feedstock type) and in application having synergetic and, in many cases superior, properties to many traditional agricultural and horticultural products.

“... they are ill discoverers that think there is no land when they can see nothing but sea”. Francis Bacon (1561-1626)

Quality

The advent of the New Zealand Compost Standard –NZS4454 has provided a reliable internationally recognised level of quality assurance to the customers of recycled organics. The NZS4454 covers all necessary quality parameters, such as pH, soluble salts, growth indices and particle size, as well as covering the presence of such undesirable components as weed seed, heavy metals, phyto-toxic compounds and foreign objects.

Because compost quality criteria also depend on end use, the NZS4454 stipulates transparency and disclosure of information in terms of packaging marking and documentation. The standard encourages communication and the development of an ongoing, detailed working relationship focussed upon individual customer requirements. Because quality is also judged by the uniformity of the product from batch to batch, the NZS4454 defines sampling and testing requirements to ensure representation and fairness. Some end-users may consider the raw materials used as the basis for quality, favouring compost made from specific inputs by specific process management. Appendix K of the NZS4454 delineates traceability and the benchmarks of best practice across a spectrum of systems and methodologies.

Figure 52: Positive sales and marketing images
Appendix K: Compost Applications

Ron Alexander lists the following as generic compost applications:

**Soil Amendment:**
- Turf establishment
- Garden bed preparation
- Reclamation / remediation
- Nursery production
- Roadside vegetation
- Agricultural production

**Growing media component:**
- Container / potting mixes
- Landscape (e.g. rooftop, raised planters)
- Backfill mixes (tree and shrub planting)
- Golf courses (tee, green, divot mixes)
- Manufactured topsoil

**Surface supplied:**
- Garden bed mulch
- Erosion control media
- Turf topdressing

The intention of the NZS4454 is to provide a benchmark of quality assurance which will assist the sustainable growth of the recycled organics market in New Zealand. Once the requirements of the NZS4454 have been demonstrated, Standards become a marketing asset.

Ron Alexander lists the following market positioning and external considerations as a framework for researching and building an individually tailored sales and marketing strategy:
- Geography and location priorities
- Priority ‘Target Market segments’
- Applications matched to product characteristics
- Comparative competition
- Feedstock characteristics related to potential niches
- Price / revenue requirements

- Transportation, market access
- Infrastructure vs manufacturing options
- Technical expertise to address market needs.
Temperatures during composting

The temperature reached during composting depends on the size of the pile or system, its moisture content, aeration and the availability of food for the microbes — principally carbon and nitrogen.

Heat in composting systems is produced by microorganisms when they consume food (organic materials).

Heat builds up in compost when the insulating properties of the mass results in the rate of heat gain being greater than the rate of heat loss. Small volumes of organic materials (<1-2 m³) may not heat up because the heat generated by the microbial population is lost quickly to the atmosphere.

The outer layer of compost in a non-enclosed system insulates the interior of the pile, allowing temperatures to build up in the centre.

Temperature has a self-limiting effect on microbial activity and thus the rate of degradation of organic materials.

The highest rates of decomposition of organic materials usually occur at thermophilic temperatures between 50 and 55 ºC.

Thermophilic conditions begin at temperatures above 45 ºC (Figure 1).

The different phases of composting are represented in Figure 1. As shown in Figure 1, temperature can also indicate when a compost product is stable or mature.

Figure 1. Temperature development and stages in aerobic composting.
Keep in mind however that temperatures also rise and fall during composting as a result of other factors, such as limited moisture or air.

**Temperature and composting organisms**

Temperature affects the rate of decomposition of organic materials by directly influencing the make-up of the microbial population. Bacteria, fungi and actinomycetes all play a major role in the decomposition of organic materials during aerobic composting.

In addition, some types of invertebrates such as nematodes, mites, earthworms, snails and slugs consume organic residues, but they are only active at cooler temperatures.

As such, a dynamic food web is at work in a compost pile in which there is a succession of organisms that dominate depending primarily on temperature and the types of food available for consumption.

The initial period of composting, which is characterised by a rapid increase in microbial activity and the first signs of a rise in temperature, is mainly due to the activity of mesophilic bacteria consuming freely available compounds (Figure 1).

As the temperature rises towards 45°C, mesophilic organisms begin to die off (because it is too hot for them) and thermophilic (heat loving) organisms then begin to dominate.

If the temperature reaches to 65-70°C, the thermophilic organisms start to die off, and only some spore forming bacteria can survive. At this point, the rate of decomposition slows.

The highest rate of decomposition occurs mostly during the thermophilic stage of composting (>45°C), due mainly to the activity of thermophilic bacteria.

**The curing phase and composting organisms**

Once the temperatures begin to drop, aeration is usually done (by turning or forced delivery of air) to keep temperatures in the thermophilic range to maximise the level of decomposition and to ensure pasteurisation (killing of weed seeds and pathogens).

During the curing phase, after temperatures begin to fall, fungi and actinomycetes re-invade the compost and decompose the more resistant materials such as cellulose and lignin. These microbes are naturally present in soil.

Re-invasion of compost with beneficial microbes, such as bacteria, fungi and actinomycetes during curing usually occurs when the compost (whether in a windrow or in-vessel system) is placed in areas where contact or exposure to soil is possible.

These microbes can often be seen just below

**Figure 2.** Typical temperature development at the centre and the outer surface of a turned windrow during composting. Data represents mean weekly temperatures.

**Figure 3.** Typical temperature development at the centre and the outer surface of a forced aeration in-vessel composting system. Data represents mean weekly temperatures.
the surface of a compost heap as a white or grey layer.

The curing phase is very important in reducing the presence of phytotoxic compounds usually present in immature compost (see Information Sheet No. 5-9).

**Temperature profiles**

Temperatures attained in composting systems are rarely uniform throughout the entire mass.

Temperatures on the outside of a windrow can be 20 to 45°C cooler than the insulated centre.

Such temperature differences may be as small as 2-5°C in an insulated in-vessel composting system.

Temperature differences between the surface and centre of a composting system, such as an aerated static pile, can be reduced by applying an insulating layer to the surface, such as straw, peat or finished compost.

Typical temperature profiles in a turned pile and a forced aeration in-vessel composting system is shown in Figures 2 and 3.

**Temperature and pasteurisation**

Temperatures above 55°C are necessary to destroy weeds and pathogens (animal, human and plant).

Pathogens are microorganisms capable of producing disease or infection in plants or animals. Pathogens can be killed by heat produced during thermophilic composting.

This is a process known as pasteurisation.

Pasteurising conditions usually occur throughout the entire mass in an in-vessel system because the insulating walls of the vessel minimise heat loss.

Pasteurising temperatures cannot occur in materials on the surface of an un-insulted windrow because heat is lost to the atmosphere (Figure 4).

To ensure that the entire mass is subjected to pasteurising temperatures, the exterior must be turned and deposited into the centre of the pile where pasteurising temperatures occur.

Microbial pathogens (and weed seeds) can be killed in composting systems as most can only grow under low temperature conditions (<37°C).

A wide range of beneficial microorganisms, however, are not killed under these conditions.

**Appendix K: Temperature**

In respect of Temperature, Appendix K of NZS4454 notes the following:

- For All systems - A time / temperature profile shall be recorded to ensure that optimal processing has occurred.
- For Turned pile - High temperature achievement is a function of pile dimensions, moisture content and available nutrient levels. Pasteurising temperatures of 55°C for three consecutive days or equivalent shall be achieved for the whole composting mass. Feachem et al., suggest 45 – 50°C for about 12 days shall destroy the pathogens Ascaris,

**Figure 4.** Typical temperature zones in an open air turned windrow (in cross-section). Note that the exterior of the windrow cannot achieve pasteurising temperatures, due to heat loss to the atmosphere. To ensure that all of the windrow is pasteurised —to eliminate weed seeds and pathogens — the outside of the windrow must be turned and deposited into the centre where high temperatures occur.
Salmonella and enterovirus (see Farrell (K.3)). With organic materials that pose a potential pathogen risk, the temperature for turned piles shall be maintained at equal to or greater than 55 °C for at least 15 days with a minimum of 5 turnings (Biosolids Guidelines (K.4)). For garden waste and materials that pose a lesser pathogen risk, the temperature shall be maintained at equal to or greater than 55 °C for at least 15 days with a minimum of three turnings (K.5). Thorough mixing during turning ensures that colder, outer zones are turned into the pile, where higher temperatures are achieved. Covering with insulating mesh cloth or finished compost (approximately a 30 cm deep layer) maintains higher temperatures in outer zones. When measuring temperature, a profile of the pile shall be obtained, e.g. at 30 cm below surface then every 30 cm to the centre.

- For ASP - Because the compost is not turned, pasteurising temperatures of 55 °C are difficult to achieve for the outer zones. Insulation with mesh cloth or finished compost can overcome this problem and with this approach the static pile may replicate conditions of an enclosed system. Pereira et al (1987) (K.6) notes that pathogen survival, however, is always possible, but can be less than 100 cfu g-1 after 10 - 30 days. The entire mass of the pile shall reach 55 °C+ for at least 3 days.

- For Windrows - Similarly to the turned pile and ASP methods, temperature gradients exist within windrows. Cooler temperatures occur both in the outer zones and the inner, anaerobic zones (when present) in non-aerated windrows, and in aerated windrows, cooler temperatures occur in the inner aerated core and higher temperatures (up to 80 °C) in the middle zones(K.7). Turning can re-introduce pathogens, which survive in the cooler zones, into the pasteurised compost which must then once more achieve pasteurising temperatures. If the turning procedure is not efficient, pathogens will survive(K.3).

- For In-vessel - The bioreactor construction and aeration system shall ensure temperatures can be maintained. The temperature profile within compost vessels shall achieve the temperature ranges as shown in K2(g). For enclosed or covered piles and windrows it may be necessary to turn the material to achieve the temperature profiles. Temperature feedback control, generally monitoring outlet air, is used to adjust aeration and thus temperature modification.
12. Oxygenation

Importance of oxygen

The microorganisms responsible for aerobic composting, by definition, cannot grow in the absence of oxygen. Many microorganisms are capable of growth at low oxygen concentrations, while some are killed in the presence of oxygen (termed anaerobic microorganisms). When microorganisms feed on the carbon component of organic materials for their energy, oxygen (O2) is used up and carbon dioxide (CO2) is produced. See Figure 1 for a scanning electronic micrograph of a common microorganism present in composting systems.

The oxygen concentration in air is about 21%, but aerobic microorganisms cannot function effectively at concentrations below about 5% in compost.

Oxygen concentrations of about 10-14% in a compost mass are ideal and results in optimum composting conditions (provided other parameters are correct).

In windrow systems, aeration is assisted by physical turning with either a front-end loader or a specialised windrow turner. The main reasons for turning windrows are to move the outside

Figure 1. Scanning electron micrograph of thermophilic Bacillus sp. bacteria commonly found in composting systems (left). Note their characteristic ‘rod’ shape. A phase-contrast light microscope picture of Bacillus sp. bacteria in chain form (right). These bacteria are in a spore generating phase. Heat resistant spores are produced when temperatures exceed that tolerable by the cells (e.g. temperatures above 65°C).
portions of a windrow into the middle, and to loosen and fluff the material so that air can move more freely into the windrow.

The agitation of composting particles that occurs during turning stimulates higher rates of decomposition by exposing new surfaces to microbial attack.

Windrow turners are usually more effective at breaking up clumps and aerating the mass than front-end loaders.

Windrow turners are also more effective at mixing the materials as they pass over a windrow.

Note that oxygen supply to a composting system does not have to involve turning.

Mechanical blowing or sucking air into and/or through materials by an aeration fan can remove excess heat and also increase the concentration of oxygen in the material.

**Mechanism of aeration**

Oxygen gets into the pile or system by convection and diffusion. Natural convection is the movement of outside air into a compost pile or system as a result of the “chimney effect” — warm air rises through the pile or system and cool air enters the lower sections, as long as the mix is “loose enough” to permit air flow (Figure 2).

Diffusion then transports oxygen into the smaller pores of compost and into the water layer surrounding compost particles.

In windrows or piles, convection is assisted by physical turning.

Turning only adds a small amount of oxygen directly, but it loosens and fluffs the material (reducing its density) so that air can move more freely into the windrow by convection.

In ‘forced aeration systems, convection also occurs mechanically with blowers — delivering air by suction or blowing or a combination of the two.

Forced aeration is a feature of aerated static pile or in-vessel systems. In the case of static piles, forced aeration by blowing also has the advantage of delivering warm air to the cooler outer layers, which assists in decomposition.

Another advantage of forced aeration systems is that the exhaust air can be recirculated and treated to remove odorous compounds.

Convection can be increased by constructing piles or windrows over channels or inserting pipes that extend from outside through to the core of the heap (passively aerated windrow).

**Oxygen profiles**

Turning or the forced delivery of air into a composting mass is necessary to ensure that the entire mass is kept in an aerobic state.

As with temperature, the concentration of oxygen is not uniform throughout the composting mass.

The centre of a turned windrow often has the lowest concentration of oxygen, whilst

![Figure 2. Convective flow of air in a compost windrow.](image-url)
the exterior surface often has the highest concentration of oxygen.
This occurs because oxygen entering the outer surface of the pile is consumed by microorganisms before it has a chance to reach the centre (Figure 3).
The centre of the pile, therefore, becomes anaerobic, resulting in odour production. When these piles are turned, odours are often released into the air, potentially affecting the amenity of neighbours.
To minimise the release of odour during turning, turning should be performed when the concentration of oxygen decreases to about 12-14% (Standards Australia AS 4454, 2002). This is usually measured at the centre of the pile where oxygen limitations are most pronounced.
Changes in the concentration of oxygen after physical turning of a windrow can be seen in Figure 4.

**Odours produced during composting**

Odour formation is strongly associated with the development of anaerobic conditions in composting systems.
These odours are produced through the anaerobic decomposition of organic matter.
Composting odours are mostly produced as vapours, though particulate (i.e. aerosol) odours can be produced.
Table 1 lists some specific compounds reported to cause odour problems during composting. Note that it is often difficult to identify individual components of an odour by olfaction (i.e. through smelling with your nose).
The main odour produced by composting operations is ammonia.
Odours can easily be treated in composting systems that permit the collection of process air. Examples include in-vessel systems with forced aeration, or an aerated static pile with a suction-type aeration system.
Process air produced by these systems can be directed to a biofilter — a vessel containing mature compost — to remove the odourous compounds from the air.
Bacteria present in the biofilter decompose the odourous compounds and use them as a food source, thereby removing the smell from the air.

**Figure 3.** A typical oxygen profile of a turned windrow of size reduced garden organics and biosolids three days after turning during the thermophilic stage of composting.

**Figure 4.** Typical changes in the concentration of oxygen at the centre of a turned windrow consisting of size reduced garden organics and biosolids during the initial stages of composting. T, physical turning.
### Table 1. Some compounds implicated in composting odours, and their characteristics. Modified from Miller and Macauley, (1988).

<table>
<thead>
<tr>
<th>Compound</th>
<th>Formula</th>
<th>Characteristic odour</th>
<th>Threshold (nL/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanal</td>
<td>CH$_3$CHO</td>
<td>Pungent</td>
<td>2</td>
</tr>
<tr>
<td>Butanoic acid</td>
<td>CH$_3$CH$_2$CH$_2$COOH</td>
<td>Rancid</td>
<td>0.28</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NH$_3$</td>
<td>Pungent</td>
<td>37</td>
</tr>
<tr>
<td>Trimethyl amine</td>
<td>(CH$_3$)$_3$N</td>
<td>Pungent</td>
<td>4</td>
</tr>
<tr>
<td>3-methylindole (skatole)</td>
<td>C$_6$H$_5$C(CH$_3$)CHNH</td>
<td>Faecal</td>
<td>7.5x10$^{-5}$</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>H$_2$S</td>
<td>Rotten egg</td>
<td>1.1</td>
</tr>
<tr>
<td>Carbon oxysulfide</td>
<td>COS</td>
<td>Pungent</td>
<td>-</td>
</tr>
<tr>
<td>Dimethyl sulfide</td>
<td>CH$_3$SCH$_3$</td>
<td>Foul</td>
<td>20</td>
</tr>
<tr>
<td>Dimethyl disulfide</td>
<td>CH$_3$SSCH$_3$</td>
<td>Foul</td>
<td>-</td>
</tr>
<tr>
<td>Diethyl sulfide</td>
<td>CH$_3$CH$_2$SCH$_2$CH$_3$</td>
<td>Foul</td>
<td>0.25</td>
</tr>
<tr>
<td>Methanethiol</td>
<td>CH$_3$SH</td>
<td>Decaying cabbage</td>
<td>1.1</td>
</tr>
<tr>
<td>Ethanethiol</td>
<td>CH$_3$CH$_2$SH</td>
<td>Decaying cabbage</td>
<td>0.016</td>
</tr>
<tr>
<td>1-Propanethiol</td>
<td>CH$_3$CH$_2$CH$_2$SH</td>
<td>Unpleasant</td>
<td>0.075</td>
</tr>
<tr>
<td>1-Butanethiol</td>
<td>CH$_3$CH$_2$CH$_2$CH$_2$SH</td>
<td>Skunk like</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Notes**

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62
Introduction to quality management parameter for compost operations

13. Water / Moisture Content

Inside This Sheet

13.1 Importance of water
13.2 Excess moisture causes anaerobic conditions and odours
13.3 Appendix K: Moisture Content

Importance of water

Moisture, or water, is essential to all living organisms. The optimum moisture content for composting is generally between 50 and 60%. Below about 30%, microbial activity virtually stops. Moisture contents above 50% are critical for effective pathogen and weed control during the thermophilic stage of composting.

Organic particles are attacked by microorganisms present in a water film surrounding these particles (Figure 1). If water becomes limiting, the water films reduce in size and microorganisms die of water stress. No water, no decomposition!

Moisture is lost during composting by evaporation. This has the benefit of cooling the compost and can prevent overheating and associated reductions in microbial activity.

With windrows, water can be added during turning with a mechanical windrow turner connected to the water supply. Where this is not possible, or where front-end loaders are used for turning, water can be added manually by hose, sprinklers or soaker hoses.

Care must be taken to minimise pooling during watering by providing adequate drainage and water (run-off) collection systems. Pooling water is a problem because it can attract disease-spreading breeding mosquitoes and other insects.

Figure 1. Decomposition model for solid particles in a composting system. Decomposition is performed by microorganisms present within the liquid film and on the surface of particles. At high moisture contents, the air-filled zone between the particles become filled with water, restricting oxygen movement, leading to the development of anaerobic conditions (Rynk et al., 1992).
Where possible, collected water (containing valuable nutrients) should be re-used to maintain good levels of moisture in the compost, in the process of avoiding discharge into the water table.

Significant moisture loss can occur in aerated static piles and in in-vessel systems too, particularly when air is forced into the material with a blower.

The feedstock around the ventilation pipe can dry out and cease being decomposed if the moisture content falls below 30%.

To minimise excessive drying around ventilation pipes, a combination and blowing (positive) and sucking (negative) aeration modes have been used successfully.

The sucking aeration mode encourages moisture movement toward the ventilation pipe, thereby encouraging decomposition to occur.

**Excess moisture causes anaerobic conditions and odours**

As moisture content increases, the thickness of the layer of water surrounding each compost particle increases (Figure 1). Secondly, water fills the smallest pores (the space between particles) first, creating water filled zones between particles.

The decomposition of organic matter occurs at the interface between this water layer and the surface of the particle. Oxygen diffusion into the film of water around particles is sufficient to meet the needs of aerobic microorganisms when moisture content of compost is maintained between 35 and 60%.

**Appendix K: Moisture Content**

In respect of Moisture Content, Appendix K of NZS4454 notes the following:

- **For All systems** - The method for measuring moisture content is described in Appendix F.
- **For Turned piles** - dry mixes are best, e.g. 45 – 65%. Higher moisture contents reduce O2 diffusion rates. This increases the possibility of foul odour production, a slower processing rate and allows a higher rate of survival of pathogens because of lower temperature. Too low a moisture content can minimise evaporative cooling so that the pile overheats, unless it is so dry that microbiological activity is inhibited (e.g. 30 – 35 % at starting).
- **For ASP** - The initial moisture content can be near the water-holding capacity (WHC) of the ingredients (70 % - 75 % w/w).
- **For Windrows** - See turned pile (K2(f)) for non-aerated windrows and ASP (see K3(f)) for aerated windrows.
- **For In-vessel** - Water can be added to the maximum water holding capacity of ingredients. The amount of moisture is be determined by the respective processing systems. Typical moisture contents may range from 50 % up to 78 %. Excess moisture may drain off and need to be collected by leachate drains. Aeration can dry out the compost however, resulting in premature temperature decline, and thus pathogen survival and heating, following pre-wetting. Very fine particulate ingredients may require a bulking agent, e.g. straw or wood chips depending on fan capacity.

**NB:** For additional background knowledge, Appendix K provides recommendations for further reading and lists technical references -K6 and -K7 (Page 51).
14. Bulk Density
(Porosity, structure, texture and particle size)

Particle size characteristics and aeration

Porosity, structure and texture relate to the physical properties of the materials such as particle size, shape and consistency. They affect the composting process by their influence on aeration (Rynk et al., 1992).

The physical properties of a composting mix can be adjusted by selecting suitable raw materials and by grinding or mixing. Materials added to adjust these properties are referred to as bulking agents (Rynk et al., 1992).

Bulking agents reduce the density of a compost mix, enabling improved air flow.

Some compost mixes that do not contain sufficient bulking agents tend to be too dense, reducing air flow and often quickly become anaerobic. These mixes produce odour and decompose slowly.

It is therefore very important that compost mixes are prepared consistently. If the recipe is incorrect, more time is required for decomposition and it is very difficult to produce a consistent product.

Getting the compost mix correct and using the recipe consistently saves time and money.

Figure 1. Particle size and its effect of porosity and air flow resistance. Mixes comprising very small particles (left) undergo rapid decomposition and are susceptible to the development of anaerobic conditions. Mixes comprising a range of small and large particles are less susceptible to the development of anaerobic conditions (right).
Porosity

Porosity is a measure of the air space within the composting mass and determines the resistance to airflow.

Porosity is determined by particle size, the size gradation of the materials, and the continuity of the air spaces.

Structure

Structure refers to the rigidity of particles — that is, their ability to resist settling and compaction.

Good structure prevents the loss of porosity in the moist environment of a compost pile.

Texture

Texture refers to the available surface area for microbial attack.

Most decomposition during composting occurs on the surfaces of particles. As particle size reduces, the amount of surface area for decomposition increases.

For example, an apple chopped up into many pieces will decompose much more rapidly than a whole apple in a composting system because there are more surfaces for microbial attack.

When the majority of particles in a mix are small (<3 mm), anaerobic conditions can develop because of the resistance to air flow (Figure 1). This occurs because the mix is too dense, thereby reducing porosity.

When the majority of particle sizes in a composting mix are large (>50 mm), decomposition proceeds slowly because of the low surface area for microbial attack.

Thus, a compromise is needed between small particle sizes to encourage rapid decomposition and large particles to maintain porosity (Figure 1).

For most raw materials, an acceptable porosity and structure can be achieved if the moisture content is less than 65% (Rynk et al., 1992).

“Education is what survives when what has been learned has been forgotten” – B F Skinner
W hat is the carbon to nitrogen ratio?

Carbon (C) in organic matter is the energy source and the basic building block for microbial cells.

Nitrogen (N) is also very important and along with C, is the element most commonly limiting.

Microorganisms require about 25-30 parts of carbon by mass for each part of nitrogen used for the production of protein.

A carbon to nitrogen ratio of 30 parts carbon to 1 part nitrogen (by mass) is written as a ratio, 30:1. Therefore, a C:N ratio of 500:1 (e.g. sawdust) represents a high C:N ratio, and 5:1 (e.g. meat) represents a low C:N ratio.

Microorganisms also require adequate phosphorus, sulfur and micronutrients for growth and enzyme function, but their role in composting is less well known.

Preparing feedstock to an optimum C:N ratio results in the fastest rate of decomposition — assuming other factors are not limiting (e.g. oxygen, moisture, nutrients etc.).

In general, a high C:N ratio slows the rate of decomposition so that the composting process takes longer.

How organic materials break down

Compost feedstock is a complex mix of organic materials ranging from simple sugars and starches to more complex and resistant
molecules such as cellulose and lignin.

In general terms, composting microbes first consume compounds that are more ‘susceptible’ to degradation in preference to compounds that are more resistant (Table 1).

The breakdown of organic matter is therefore a step-wise reduction of complex substances to simpler compounds.

During the intensive phase of composting, the more easily degradable compounds are broken down first (Table 1).

Feedstocks that contain a high proportion of compounds that are difficult to break down, such as lignin, require longer periods of composting — decomposition of lignin occurs more rapidly during the curing phase, at mesophiliic temperatures.

However, the decomposition of organic matter is a dynamic process because different composting microorganisms have the capacity to utilise compounds of varying complexity and resistance to degradation.

For many organic materials, a period of maturation is also essential to eliminate compounds that are toxic to plant growth (phytotoxic).

C:N ratios of common feedstock materials

The chemical and physical characteristics of various feedstock materials can be seen in Table 2.

Concept of available carbon

Not all materials contain carbon that is readily degraded through microbial attack.

For example, much of the carbon present in woody garden organics is unavailable to microbial attack — such as that present in the form of lignin.

Addition of wood chips as a bulking agent to food organics or manure, for example, does little to supply carbon to the mix, though its main function is to increase porosity and air flow through the mix.

Organic materials, such as grass clippings, undergo rapid decomposition because they are high in nutrients (such as nitrogen) and high in available carbon, present mostly in the form of starch and hemicellulose.

Inclusion of only available carbon (instead of total organic carbon) in the C:N ratio for compost recipe calculations is rarely done due to the difficulty in accurately estimating available carbon.

The concept of available carbon is important in understanding why some organic materials break down a lot faster in composting systems than others.

"For successful technology reality must take precedence over public relations, for nature cannot be fooled" – Richard Feynman.

Table 1. Susceptibility of organic compounds found in compost feedstock to decomposition.

<table>
<thead>
<tr>
<th>Organic compound</th>
<th>Susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugars</td>
<td></td>
</tr>
<tr>
<td>Starches, glycogen, pectin</td>
<td></td>
</tr>
<tr>
<td>Fatty acids, lipids, phospholipids</td>
<td></td>
</tr>
<tr>
<td>Amino acids</td>
<td>Very susceptible</td>
</tr>
<tr>
<td>Protein</td>
<td></td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>Usually susceptible</td>
</tr>
<tr>
<td>Cellulose</td>
<td></td>
</tr>
<tr>
<td>Lignocellulose</td>
<td></td>
</tr>
<tr>
<td>Lignin</td>
<td>Resistant</td>
</tr>
</tbody>
</table>
Table 2. Physical and chemical characteristics of various feedstocks.

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Moisture</th>
<th>Structure</th>
<th>C:N</th>
<th>%N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Garden organics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed tree and shrub prunings</td>
<td>dry to moist</td>
<td>good</td>
<td>70-90</td>
<td>0.5-1</td>
</tr>
<tr>
<td>Eucalyptus bark</td>
<td>dry</td>
<td>good</td>
<td>250</td>
<td>0.2</td>
</tr>
<tr>
<td>Eucalyptus sawdust</td>
<td>dry</td>
<td>average</td>
<td>500</td>
<td>0.1</td>
</tr>
<tr>
<td><em>Pinus radiata</em> bark</td>
<td>dry</td>
<td>good</td>
<td>500</td>
<td>0.1</td>
</tr>
<tr>
<td><em>Pinus radiata</em> sawdust</td>
<td>dry</td>
<td>average</td>
<td>550</td>
<td>0.09</td>
</tr>
<tr>
<td>Grass clippings</td>
<td>moist to wet</td>
<td>poor</td>
<td>9-25</td>
<td>2-6</td>
</tr>
<tr>
<td><strong>Food organics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed food organics</td>
<td>moist to wet</td>
<td>average</td>
<td>14-16</td>
<td>1.9-2.9</td>
</tr>
<tr>
<td>Vegetable produce</td>
<td>wet</td>
<td>poor</td>
<td>19</td>
<td>2.7</td>
</tr>
<tr>
<td>Fruit</td>
<td>wet</td>
<td>poor</td>
<td>20-49</td>
<td>0.9-2.6</td>
</tr>
<tr>
<td>Fish</td>
<td>moist to wet</td>
<td>poor</td>
<td>2.6-5</td>
<td>6.5-14.2</td>
</tr>
<tr>
<td><strong>Biosolids</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biosolids</td>
<td>moist to wet</td>
<td>poor</td>
<td>5-16</td>
<td>2.6-9</td>
</tr>
<tr>
<td><strong>Agricultural organs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wool scour waste:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) raw deaner sludge</td>
<td>moist</td>
<td>poor</td>
<td>13.8</td>
<td>0.81</td>
</tr>
<tr>
<td>(2) raw flocculated sludge</td>
<td>moist</td>
<td>poor</td>
<td>19</td>
<td>1.61</td>
</tr>
<tr>
<td>Tannery waste (hair)</td>
<td>dry to moist</td>
<td>average</td>
<td>3.1-4.3</td>
<td>11.7-14.8</td>
</tr>
<tr>
<td>Mixed abattoir wastes</td>
<td>moist to wet</td>
<td>poor</td>
<td>2-4</td>
<td>7-10</td>
</tr>
<tr>
<td>Chicken manure (layers)</td>
<td>dry to moist</td>
<td>poor</td>
<td>3-10</td>
<td>4-10</td>
</tr>
<tr>
<td>Chicken manure (broiler)</td>
<td>dry to moist</td>
<td>poor</td>
<td>12-15</td>
<td>1.6-3.9</td>
</tr>
<tr>
<td>Seaweed (kelp)</td>
<td>dry</td>
<td>poor</td>
<td>200-750</td>
<td>0.06-0.8</td>
</tr>
<tr>
<td>Sawdust</td>
<td>dry</td>
<td>poor</td>
<td>100-150</td>
<td>0.3-0.5</td>
</tr>
<tr>
<td>Wheaten straw</td>
<td>dry</td>
<td>good</td>
<td>127-178</td>
<td>0.2-0.25</td>
</tr>
</tbody>
</table>

**Paper products**

| Newsprint                      | dry          | poor      | 398-852 | 0.06-0.14|
| Paper                          | dry          | poor      | 127-178 | 0.2-0.25|

*Sources: Rynk *et al.* (1992); Handreck and Black (1994); State Chemistry Laboratory unpublished data, Werribee, Victoria.*

**Other nutrients**

Apart from carbon and nitrogen, compost microorganisms require an adequate supply of other nutrients such as phosphorus, sulfur, potassium and trace elements (e.g. iron, manganese, boron etc.).

These nutrients are usually present in ample concentrations in compost feedstock, though phosphorus (P) can sometimes be limiting. A C:P ratio of between 75 and 150:1 is required.

Feedstock with low P levels can include gum leaves, woody plant residues and grass clippings. Good sources of P include superphosphate fertiliser, poultry manure, bone meal and rock phosphate.
Introduction to quality management parameter for compost operations

16. pH

Role of pH in composting

The composting process is relatively insensitive to pH, within the range commonly found in mixtures of organic materials, largely because of the broad spectrum of microorganisms involved (Rynk et al., 1992).

Although opinions vary, the optimum range for composting is somewhere in the range of 5.5 to 9.

It is important to note that composting is likely to be less effective at 5.5 or 9 than it is at a pH near neutral (pH 7).

pH does become important with raw materials that have a high percentage of nitrogen (e.g. manure and biosolids).

A high pH, above 8.5, encourages the conversion of nitrogen compounds into ammonia gas, resulting in nitrogen loss from the compost (Figure 1).

“Experience is that marvellous thing which enables you recognise a mistake when you make it again” - Franklin P Jones.

![Figure 1](image.png)

Figure 1. Typical changes in pH during the composting process (Gray and Biddlestone, 1971). Note that above pH 8.5, ammonia formation occurs. This results in nuisance odour production and a reduction in the nutritional value of the compost.
Loss of nitrogen in the form of ammonia to the atmosphere not only causes nuisance odours, but also reduces the nutrient value of the compost.

Adjusting the pH downward below 8.0 reduces ammonia loss. This can be achieved by getting the right balances of materials in the compost recipe, or by adding an acidifying agent, such as superphosphate or elemental sulphur.

An outer layer of compost, used with aerated static piles and passively aerated windrows, helps to reduce ammonia loss. The (moist) particles in the layer retain ammonia as it passes out of the pile.

The ammonia is converted to less mobile forms of nitrogen in the cooler and more stable environment of the outer layer (Rynk et al., 1992).

The biofiltration of nitrogen occurs best when the moisture content of the outer layer of mature compost is maintained at around 60%.

“It is amazing how quickly nature consumes human places after we turn our backs on them. Life is a hungry thing” – Scott Westerfield.
Introduction to quality management parameter for compost operations

17. Parameter Interrationships (Recipe, Time, Curing)

Inside This Sheet

17.1 The compost recipe
17.2 Processing time
17.4 Curing

The compost recipe

Ideal compost recipes allow for rapid microbial breakdown of the organic fraction, whilst minimising impacts on the environment through the generation of odour, leachate and attraction of pests and vermin.

Minimising the time that feedstocks are retained on site means that the processing capacity of the site can be increased.

Well managed commercial composting operations that have good compost recipes can process significantly more material — into quality products — than those that are poorly managed and have poor compost recipes.

The formulation of good compost recipes, therefore, is essential so that a composting operation can maximise revenue generated from the sale of products in the market place.

Key factors that influence the composting recipe are (as discussed in previous Information Sheets):

- C:N ratio
- moisture content;
- particle size and porosity
- pH; and
- other nutrients such as phosphorus.

“80% of success is turning up - Woody Allen”

<table>
<thead>
<tr>
<th>Condition</th>
<th>Reasonable range</th>
<th>Preferred range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon to nitrogen ratio (C:N)</td>
<td>20:1 – 40:1</td>
<td>25:1 – 35:1</td>
</tr>
<tr>
<td>Moisture content</td>
<td>40 – 65%</td>
<td>50 – 60%</td>
</tr>
<tr>
<td>Oxygen concentrations</td>
<td>Greater than 3%</td>
<td>Greater than 1%</td>
</tr>
<tr>
<td>Particle size (diameter in mm)</td>
<td>3 – 13</td>
<td>Varies</td>
</tr>
<tr>
<td>pH</td>
<td>5.5 – 9.0</td>
<td>6.5 – 8.0</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>45 – 65</td>
<td>55 – 60</td>
</tr>
</tbody>
</table>

* These recommendations are for rapid composting. Conditions outside these ranges can also yield successful results.
  b Depends on specific materials, pile size and/or weather conditions.

Table 1. Recommended conditions for rapid composting (modified from Rynk et al., 1992).
Processing time

The length of time it takes to convert raw materials into mature compost depends upon many factors, including:

- feedstocks used;
- temperature;
- moisture; and
- frequency of aeration.

To achieve the shortest possible composting period, sufficient moisture, an adequate C:N ratio and good aeration is required.

Recommended conditions for rapid composting are shown in Table 1.

Conditions which slow the process include a lack of moisture, a high C:N ratio, low temperatures, insufficient aeration, large particles and a high percentage of resistant materials (such as woody materials) (Rynk et al., 1992).

For instance, if the compost is to be applied to cropland well before the growing season, it can be cured and finished in the field.

The duration of the composting process is somewhat governed by the type of composting used, and the level of process control the operator can exercise over the process.

A guide to typical composting times for selected combinations of methods and materials is given in Table 2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Materials</th>
<th>Active composting time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Range (weeks)</td>
</tr>
<tr>
<td>Windrow – infrequent turning</td>
<td>Garden organics + manure + amendments</td>
<td>26 – 52</td>
</tr>
<tr>
<td>Windrow – frequent turning</td>
<td>Garden organics + manure</td>
<td>4 – 16</td>
</tr>
<tr>
<td>Passively aerated windrow</td>
<td>Manure + bedding or Food organics + garden organs</td>
<td>10 – 12</td>
</tr>
<tr>
<td>Aerated static pile</td>
<td>Biosolids + woodchips</td>
<td>3 – 5</td>
</tr>
<tr>
<td>Rectangular agitated bay</td>
<td>Biosolids + garden organics or manure + sawdust</td>
<td>2 – 4</td>
</tr>
<tr>
<td>Rotating drums</td>
<td>Biosolids / food organics + garden organics</td>
<td>0.5 – 2</td>
</tr>
<tr>
<td>In-vessel (vertical configuration)</td>
<td>Biosolids / food organics + garden organics</td>
<td>1 – 2</td>
</tr>
</tbody>
</table>

* For example, with a front-end loader;
* For example, with a specialised windrow turner;
* Often involves a second composting phase (for example, windrows or aerated static piles).

Table 2. Typical composting times for selected combinations of materials and methods (modified from Rynk et al., 1992).
Curing

Curing is a critical and often neglected stage of composting during which the compost matures (Plate 1).

Plate 1. Photograph of a curing pile of compost prepared from food and garden organics. The material shown had been composted in an in-vessel (vertical configuration) system for approximately three weeks. The material is heaped in a small curing pile for another six weeks before being used as a composted mulch.

Curing occurs at low, mesophilic temperatures (<45°C) for periods of up to 6 months, depending on the material composted. In this process, the rate of oxygen consumption, heat generation, and moisture evaporation are much lower than in the active composting phase (Rynk et al., 1992).

Curing is normally performed in piles, preferably under cover and on an impermeable surface. Protection of the compost from rain is necessary for the material to slowly dry out, thereby allowing for easier handling.

During the curing phase, mesophilic microorganisms re-invade the compost, often enhancing its plant disease suppressive properties.

Curing also furthers the aerobic decomposition of resistant compounds, large particles and clumps of material that remain active after composting (Rynk et al., 1992).

Importantly, phytotoxic organic acids formed during the composting process are broken down during curing as well.

Because curing continues the aerobic decomposition process, adequate aeration is necessary. If piles are to be naturally aerated (i.e. no active means of aeration), pile size needs to be relatively small (height ~1 m) and moisture must be within an acceptable range.

When available space is limiting, thus necessitating the use of large curing piles, or if the moisture content of the compost is high, anaerobic conditions can form, leading to a slowing of decomposition and the production of odour.

Larger piles of moist material can be cured in an aerated static pile with forced aeration. Forced aeration assists in moisture removal and maintenance of aerobic conditions.

Appendix K: Oxygenation

In respect of Oxygenation, Appendix K of NZS4454 notes the following:

• For Turned pile - As well as being influenced by frequency of mixing, oxygen depletion is due to high microbiological activity (because of high nutrient levels), compactness of mass (related to size of particles), the ratio of air-to-water-filled spaces (depending on moisture content), bulking agent size and length of diffusion pathway (related to dimensions of pile). Oxygen concentrations of at least 12 – 14 % (and never less than 5 %) shall be maintained throughout the pile.

• For ASP - By the installation of either aerated concrete floors in the compost yard or perforated pipes installed at the base of the pile, oxygenation can be achieved by either positive pressure (blowing in at base), negative pressure (sucking through pile) or alternating pressure (‘suck’ then ‘blow’). Reports on investigations of these systems can be found in Leton and Stentiford (K.7). The mechanism of aeration can be further modified by manual temperature monitoring and regulating by a fan-on, variable rate (e.g. 3 – 10 min on every 15 – 20 min) or by a temperature feedback system to maintain compost temperatures at the predetermined level (controlled by single or multiple temperature sensors). All systems can provide adequate oxygenation and the choice of system depends on such factors as user preference and the physical and chemical characteristics of the raw materials.

• For Windrow - See turned pile (see K2(h)) for non-aerated windrows and ASP (see K3(h)) for aerated windrows. Forming windrows over air channels (no forced air) in the floor of the compost yard also reduces the formation of anaerobic cores and so minimises odour production.
• For In-vessel - The volume of air required to control temperature is far in excess of that required to maintain oxygen concentrations at greater than 12 – 14%. Forced air shall ensure adequate and even oxygenation throughout the composting mass. Monitoring provisions shall be implemented to control aeration.

Notes


• Recycled Organics Unit (2002). Recycled Organics Industry Dictionary & Thesaurus: standard terminology for the recycled organics industry. Internet publication: http://www.rolibrary.com


