ON-SITE COMPOSTING AT UNIVERSITY OF CANTERBURY

UC SUMMER SUSTAINABILITY RESEARCH SCHOLARSHIP 2012-2013

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Executive Summary

This report evaluates the on-site food waste recycling trial conducted at the University of Canterbury (UC) and investigates issues around expanding the trial.

In 2012, UC and the halls of residence on campus generated approximately 179 tonnes of food waste. One third of the food waste was recycled through UC’s waste recycling program and composted off-site at the Organic Processing Plant in Bromley, 12 km away from UC. Waste generated by the halls of residence is managed independently and most of the food waste is sent to landfill. The amount of food waste sent to landfill in 2012 was approximately 130 tonnes. To divert the food waste and recycle nutrients back to UC’s community gardens, the Sustainability Office initiated an on-site food waste recycling program with the Rochester and Rutherford Hall in 2010. The pilot work was interrupted by the Christchurch earthquake in 2011 and restarted in 2012. The trial used an innovative technique, EM bokashi-fermentation decomposition, which involves two stages: fermentation in an enclosed vessel and aerobic decomposition on a pile.

A literature survey was performed and a simple experiment was conducted to analyse and observe the process. It was found that the decomposition rate of the 2012 pilot trial was relatively slow. The undecomposed substances formed thick masses of moist, soft pulps which released an unpleasant smell. Inconsistent fermentation was determined to be the main cause, but reducing the food size pre-fermentation should greatly improve the outcome. The system could be scaled up by using a machine to reduce the initial food size and a tractor to make a large static pile to create a low oxygen condition for fermentation. The fermented material could be buried, tilled into soil or made into compost depending on the growing methods.

Human pathogen transmission is the main concern when using the EM bokashi-fermentation decomposition technique to recycle food waste generated from diverse individuals. Food waste can contain various disease causing viruses, bacteria, fungi and parasitic worms. However, no peer-reviewed paper investigating whether the fermentation process is effective at the destruction of pathogens was found. In the short term, it is suggested that UC collaborates with the halls of residence to incorporate their food waste into UC’s off-site recycling program while continuing to experiment, test and improve on-site recycling techniques. Off-site recycling practices would facilitate future on-site food waste recycling by familiarising students and kitchen staff with the collection system, and quantifying and qualifying the food waste.
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Finally, thanks to my partner, Olly Powell, for proof reading the report.
1 RESEARCH OBJECTIVES

This summer sustainability research project aims to evaluate the on-site food waste recycling trial conducted at the University of Canterbury in 2012. The objectives are to:

1. Identify problems of the pilot work
2. Provide recommendations for improvement
3. Investigate technical issues around scaling up the pilot trial.

2 BACKGROUND

Since UC Sustainability Office initiated a comprehensive waste recycling program in 2009, some on-campus food waste is recycled and made into compost at the Organics Processing Plant in Bromley, rather than being disposed of in landfill. However, a large amount of food waste generated by halls of residence continues to be sent to landfill. The exact amount of food waste generated on campus is currently unknown, but it was estimated to be approximately 179 tonnes in 2012, and 73% of which (130 tonnes) came from the halls of residence.

The Draft University of Canterbury Sustainability Strategy 2012-2022 (UC Sustainability, 2013, pp.11-12) proposed an on-site organic waste decomposition system that diverts all food waste, recycles nutrients to create an edible landscape and provides fresh produce on campus. The on-site food recycling system plays a key role closing the loop on UC’s food system. As Figure 1 shows, the on-site food waste recycling links with on campus edible gardens which produce fresh, healthy vegetables and fruit that can be consumed again by the students and staff. In contrast to the current “out of sight, out of mind” waste management strategy (Dearden & Hunter, 2012, p.2), the new approach allows students and staff take responsibility for the waste they generate and engage in waste management and food production, thus enhancing sustainability culture on campus. It also provides opportunities for sustainability research, education, community involvement and student employment.

UC Sustainability Office works in liaison with the Rochester and Rutherford Hall initiating a trial using an innovative technique, EM bokashi-fermentation decomposition, to break down food waste. The main goals are to reduce the environmental impact from minimisation of waste to landfill and to explore potential processes to recycle food waste on campus. This summer research project intends to evaluate the pilot work, identify problems and provide recommendations for improvement. The issues around expanding the trial are also investigated.
Figure 1: An on-site food waste recycling program would close the loop of UC's food system.
3 MICROBIAL DECOMPOSITION OF FOOD WASTE

3.1 Food Waste

Food waste is an easily decomposed organic substance with high water, fat and sodium chloride content. It is highly versatile, and can be raw or cooked. Food waste can easily produce offensive odour and putrid juices, and attract pests such as rodents, ants, cockroaches and flies. It also provides a perfect breeding bed for maggots. Therefore, composting food waste, especially in an open system, has not gained wide acceptance (Donahue, Chalmers & Storey, 1998). Food waste is also hazardous because it may contain pathogens.

However, sending food waste to landfill increases environmental risks and prevents nutrients being recycled for agronomic use. It is also likely to release methane, a potent greenhouse gas, into the atmosphere. Oxygen entrained is rapidly depleted after burial, so landfill refuse is broken down predominantly through an anaerobic process. Barlaz and Palmisano (1996, p.10) proposed that methane was rapidly produced during the third phase of anaerobic refuse decomposition in landfill: the methanogenic phase (after the initial hydrolysis and acidogenic phase).

3.2 Aerobic Composting

3.2.1 Definition

The term “composting” can be confusing because it is sometimes used loosely referring to any process that breaks down organic matter. In this report, composting means a biological decomposition process which is primarily aerobic (oxygen demanding). During the composting process, organic matter is decomposed through activities of successive groups of microorganisms with various functions (Danon, Franke-Whittle, Insam, Chen & Hadar, 2008, p.133). Heat, water vapour and carbon dioxide are released in the process. The composting ecosystem is composed of complex and dynamic microbial populations and communities which change consistently as a function of temperature, oxygen, available nutrients and moisture levels. A composting process is controlled by managing the effects of microbial activities so that a favourable environment can be maintained.
Mason (2007, p.4) provided a well-defined expression of composting:

“Composting is the biological decomposition and stabilization of solid organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, low in moisture, free of pathogens and plant seeds, and can be beneficially applied to land.”

In summary, composting decomposes organic solid through an aerobic microbial process which include a thermophilic stage, producing an end product (compost) that can be beneficially applied to land.

### 3.2.2 Phases

Figure 3 illustrates the phases of a typical aerated composting heap. The composting process can be divided into four phases based on the temperature change: a mesophilic phase (20 to 45°C), a thermophilic phase (45 to 70°C), a cooling phase and a maturation phase (Barlaz and Palmisano, 1996, p.17).
Mesophilic Phase
At the beginning of the composting process, mesophilic bacteria (moderate temperature loving bacteria) can multiply rapidly using simple chemical compounds. Heat is produced during microbial respiration, and the biomass of the compost heap serves as an insulator. The temperature would increase if the rate of heat generation is greater than the rate of heat loss which depends on the surface area to volume ratio. The larger the compost matrix, the more likely the heat would be maintained.

Thermophilic Phase
Temperature exceeds 45°C in thermophilic phase, and thermophiles (heat loving microbes) become dominant. The decomposition rate peaks between 45°C and 60°C, but many pathogens can be killed if temperature is above 55°C for a period of time and above 82°C most of the microbial activities cease (Miller, 1996, p.135). It is usually a highly controlled phase in a well-managed composting system, so the decomposition rate and eradication of pathogens can be optimised.

Cooling Phase
During the cooling phase, the temperature drops from 50°C to the ambient temperature. Readily available nutrients have already been used up by the thermophiles, so the microbial activities slow down. Heat liberated is no longer able to maintain a high temperature. At the
early stage, populations of actinomycete increase. Actinobacteria secrete enzymes outside the cells (extracellular enzymes) breaking down more complex chemical compounds (Miller, 1996, p.117). When the temperature drops below 35°C, fungi capable of breaking down matter that is even more resistant to decomposition become dominant.

**Maturation Phase**

Temperature is stabilised in the maturation phase. The degree of the maturity required would depend on the end use. Mature compost is critical to safe and successful agronomic use. Immature compost may introduce phytotoxic substances, such as ammonia and volatile fatty acids (Barlaz and Palmisano, 1996, p.17) which can inhibit the growth of plants.

Psychrophilic decomposition is also done by actinomycetes and fungi, but it occurs between 6°C and 19°C (Harrison, 2008, p.713). The rate of psychrophilic decompostion is relatively slow, so it is usually not considered as a composting process.

### 3.2.3 Common Large Scale Process Configuration

**Passive**

Passive, turned windrow, aerated static pile and in-vessel composting are common large scale composting methods. Passive composting stacks composting material in piles. It involves little management and agitation, but the process is slow due to a low aeration rate (Rynk, 1992, p.24). Passive composting is a common method to compost leaves. The Grounds Maintenance at UC uses this method to make leaf mold.

**Turned Windrow**

Turned windrow composting features long rows of heaped up composting material turned periodically (Figure 4). Windrows can be fully exposed to outdoors or have weather protection structures built. The advantages of the windrow system are lower setup costs and reduction in processing steps (as the turning operation also breaks up and mixes the material) (Miller, 1996, p.143). However, the process control is limited since spatial variations of temperature and oxygen are inevitable.
Aerated Static Pile
Aerated static pile (ASP) composting uses a blower to control and supply air to the material as shown in Figure 5 (Rynk, 1992, p.31). The pile is not turned or agitated once it is formed. This method is usually used for composting biosolids from wastewater treatment plants; otherwise a mixing process could be added at the initial stage. Since the size of the pile can be larger (as the amount of oxygen and temperature can be well managed), and no space between piles is needed, the static piles require smaller land areas than windrows. ASP also conserves nitrogen and limits the release of odours because of no turning, while more than one-third of the nitrogen may be lost in a turned windrow composting system, and odour is likely to be released (Rynk, 1992, p.39).
In-vessel
In-vessel composting confines the composting material within a building, bin, drum, container or vessel. Many commercial products have been developed, while some are custom designed and made. This method usually has higher setup costs, and operation and maintenance expenses may also be higher. However, if the system is well designed it could reduce labour, land area, odour problems, weather problems, composting time and ensure consistent compost quality. Figure 6 is an in-vessel composting technology developed by HotRot, a New Zealand company.

![In-vessel composting technology developed by HotRot](image)

**Figure 6: An in-vessel composting technique developed by HotRot (after Mason, 2007, p.9).**

**Christchurch City Council**
Food waste and green waste collected from green kerbside bins in Christchurch are composted at the Organic Processing Plant in Bromley. Figure 7 illustrates the procedural diagram of the composting plant. After the organic matter is broken up and sorted in the process building, it is composted in an in-door tunnel system for seven to ten days. The tunnel is an enclosed configuration which has a very high level of process control (Miller, 1996, p.114). The waste is pasteurised and in a stable condition, which means it would not attract vermin, birds and has no unpleasant smell (Christchurch City Council, 2013). Subsequently, the composting process is continued in an outdoor turned windrow system for another month.
1. The organic matters are broken up and sorted in the process building.

2. The preprocessed material is composted in an in-door tunnel system for seven to ten days.

3. The composting process is continued in an outdoor turned windrows system for another month.

Figure 7: The schematic of the Christchurch City Council’s Organics Processing Plant in Bromley (after Christchurch City Council, Organic Processing Plant Schematic A and B).
3.3 Anaerobic Decomposition

Anaerobic digestion is a serial process in which microorganisms break down organic matter in the absence of oxygen. Figure 8 shows the general pathway of anaerobic decomposition (Brook and Madigan, 1988, p.655). Large chemical compounds are first hydrolysed by cellulolytic and other hydrolytic bacteria into soluble simple monomers. In the acid forming phase, fermentative bacteria convert the monomers into carboxylic acids, which results in a decrease in pH in the system. Then acetogenic bacteria transform the resulting acids into acetic acid, carbon dioxide and hydrogen. In the final stage, methane and carbon dioxide are produced by methanogens. However, if fermentative microorganisms are dominant over acetogens and methanogens, carboxylic acids and hydrogen will accumulate causing the pH of the system to continue to fall (Barlaz, 1996), which can inhibit the methane producing phase.

![Diagram of Anaerobic Decomposition](image)

**Figure 8: General pathway of anaerobic decomposition.**
4  EM BOKASHI-FERMENTATION DECOMPOSITION

4.1 Effective Microorganisms (EM)

Effective microorganism (EM) is a brand name for various liquid or granular products containing nutrients in which a mixture of selected beneficial microorganisms can be cultivated. Japanese professor Teruo Higa from the University of Ryukyus in Okinawa selected this combination of approximately 80 species of co-existing beneficial microbes in the early 1980s and suggested a wide range of application: fertiliser, deodorant, and decomposition stimulator of substrate mineralization (Ndona, Friedel, Spornberger, Rinnofner and Jezik, 2011). Some of the microorganisms require oxygen for growth while some don’t. The exact microbial composition is not specified in detail, but it is known to contain mainly lactic acid bacteria, yeasts, some phototrophic bacteria (bacteria that obtain energy from light), antinomycetes and microorganisms which can survive conditions below pH 3.5 (Mayer, Scheid, Widmer, Fließbach, and Oberholzer, 2010, p.231).

Table 1 briefly describes the characteristics of the EM microbes and lists some known species which have minimum 10⁵ viable organisms per mL of EM concentrate (Daly and Stewart, 2009). Most of the EM microbes are heterotrophic, requiring organic compounds for nutrition, so EM is most effective when mixed with organic matter that can provide carbon, nitrogen and energy for the microorganisms.

EM is claimed to increase plant growth because EM may enhance microbial activities in soil, hence accelerate the break-down of organic compounds increasing inorganic nutrients available for plants (Daly and Stewart, 2009). It is also reported that EM can suppress pathogenic microorganisms since the organic acids produced from lactic bacteria are strong sterilizing compounds (Sekeran, Balaji and Bhagavathi, 2005). However, the scientific data on the effects of EM applications onto soil and plants are scarce, and the results are varied. Some studies show that EM increases soil quality and nutrient delivery, crop yield and quality while others found no positive effects (as cited in Mayer et al., 2010)
Table 1: The composition, characteristics and some known species of the EM.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Characteristics</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactic Acid Bacteria</td>
<td>• Are acid tolerant.</td>
<td>• <em>Streptococcus lactis</em>: commonly used to sour and coagulate dairy products</td>
</tr>
<tr>
<td></td>
<td>• Do not require oxygen to respire but the presence of oxygen often stimulates the growth.</td>
<td>• <em>Lactobacillus</em> spp.</td>
</tr>
<tr>
<td></td>
<td>• Produce lactic acid as one of the primary fermentation products of carbohydrates.</td>
<td></td>
</tr>
<tr>
<td>Yeasts</td>
<td>• Are acid tolerant.</td>
<td>• <em>Aspergillus oryzae</em>: a filamentous fungus used in Japan and China to ferment soy beans.</td>
</tr>
<tr>
<td></td>
<td>• Belong to fungal Kingdom.</td>
<td>• <em>Mucor hiemalis</em>: a filamentous fungus.</td>
</tr>
<tr>
<td></td>
<td>• Grow both aerobically and anaerobically.</td>
<td>• <em>Saccharomyces cerevisiae</em>: commonly used in wine making, baking and brewing.</td>
</tr>
<tr>
<td></td>
<td>• Some can ferment carbohydrates, and many can respire both carbohydrates and non-fermentable organic compounds.</td>
<td>• <em>Candida utilis</em>: used industrially in the production of proteins for food.</td>
</tr>
<tr>
<td>Photosynthetic Bacteria</td>
<td>• Can produce energy through photosynthesis.</td>
<td>• <em>Rhodopseudomonas sp.</em> (the numbers are unspecified): purple nonsulfur microbes that commonly found in soil.</td>
</tr>
<tr>
<td></td>
<td>• Grow both aerobically and anaerobically.</td>
<td></td>
</tr>
<tr>
<td>Antinomycetes</td>
<td>• Grow only aerobically.</td>
<td>• <em>Streptomyces albus.</em></td>
</tr>
<tr>
<td></td>
<td>• Are filamentous bacteria, and have a white mould-like appearance.</td>
<td>• <em>Propionibacterium freudenreichii</em>: commonly used to produce some cheese.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• <em>Streptomyces griseus</em> (the numbers are unspecified).</td>
</tr>
</tbody>
</table>
4.2 EM Bokashi

Bokashi is a term originated from Japanese meaning “obscuring the direct effectiveness” (Nishio, 1998, p.9). Many Japanese organic farmers apply bokashi, which typically contains subsoil from mountains, rapeseed meal, chicken manure, fishmeal, bone meal and rice bran (Nishio, 1998, p.11), as fertiliser. If directly applied to soil, rapeseed meal and fishmeal can attract pests such as flies and vermin, so Japanese farmers developed a technique to briefly decompose the mix making it less attractive to the pests. The partially decomposed organic matter is called bokashi, which is usually inoculated with low-heat tolerant aerobic microbes.

EM bokashi is bokashi inoculated with EM. The inoculation occurs under low oxygen conditions (microaerobic), making it distinct from other bokashi (Yamada and Xu, 2001). The granular EM product usually uses rice bran, wheat bran or saw dust as a main substrate. Various commercial products are available globally, but some people also make their own. In New Zealand, ZingBokashi NZ, a Canterbury business, has manufactured EM bokashi since 2003.

4.3 Common Use in New Zealand

4.3.1 Household Scale

Even though EM was introduced to New Zealand back in the mid ‘90s and initially used as an organic fertiliser on farms (Daly and Stewart, 1999, p4), EM bokashi has gained its popularity in the New Zealand household in the new century. EM bokashi is used as a starter to initiate the decomposition of food waste and the system is often referred to as bokashi composting. However, strictly speaking bokashi composting is not a composting system because part of it occurs in a low oxygen environment and the process lacks a thermophilic phase. The system is better described as a two-stage mesophilic process that breaks down solid food waste.

4.3.2 Phase One: In-vessel Microaerobic Fermentation

In the first stage, the food waste is contained in an enclosed vessel (usually a 10 to 15 L bucket) undergoing lactic fermentation for a minimum 14 days in a low oxygen condition. Figure 9 provides a schematic of the system. The steps are:

1. Food waste is drained, broken into smaller pieces.
2. The food waste is mixed with EM bokashi. The EM bokashi:food ratio is 1:133 to 1:66 by volume (one to two tablespoons of EM bokashi are mixed with 2 L of food waste).
3. The mixture is added and compacted into a 15 L bucket with a tightly closed lid till full. Excess liquid is regularly drained off. The liquid can be diluted and used as fertiliser.
4. The full bucket is sealed and left to ferment in a warm place out of direct sunlight for 10 to 14 days.
In phase one, the food waste is pre-digested (fermented) but may retain the original shape. White mycelial-like growths, which are likely to be some aerobic antinomycetes, usually form on the surface where the substrate contacts the air. The degree of the decomposition is less advanced than aerobic composting, so the fermented material has to proceed to the second stage to allow further degradation.

Based on Yamada and Xu (2001), the enclosed vessel which provides a low oxygen environment encourages the growth and multiplication of the lactic acid bacteria and yeast contained in the EM. Even though lactic acid bacteria are independent of oxygen, but the presence of oxygen often stimulates the growth (Lahtinen, Ouwehand, Salminen and Wright, 2011, p.9). As the
The concentration of the lactic acids produced by the bacteria and yeast increases, the pH of the system decreases. The low pH environment can suppress the propagation of many other microorganisms such as some pathogenic bacteria and methane producing bacteria as mentioned in section 3.3. Bacteria that oxidise ammonia to nitrate (nitrosifying and nitrifying bacteria which are aerobic) cannot exist in this environment because they require oxygen. If the fermentation is consistent, no putrefied or rancid odour should be produced. The fermented food may also be less attractive to pests, and the enclosed vessel physically prevents pests access to the content.

### 4.3.3 Phase Two: Aerobic Burial

In the second phase, the fermented food is mixed with some soil and buried underground to continue the decomposition process in an enclosed environment but in the presence of oxygen. ZingBokashi recommends mixing some soil with the fermented food waste, burying the material in a layer no more than 250 mm thick, and covering a 50-75 mm layer of soil; seeds can be planted immediately and seedlings after one week. It is suggested that the material should break down and becomes unrecognisable as food after one month.

The second stage of the system is necessary because it allows further decomposition. Since the bacteria that oxidise ammonia to nitrate, which is the available form of nitrogen to the plants, are suppressed in phase one, the aerobic environment also plays an important role to promote nitrification (Yamada and Xu, 2001, p.266).

The burial treatment also has the following advantages:

- Incorporating nutrients into the soil
- Maintaining moisture content
- Minimising risk of attracting pests
- Providing a physical barrier to the release of potential odour.
4.4 Large-scale Practices

4.4.1 Mudbrick Vineyard and Restaurant on Waiheke Island

Since 2004, Mudbrick Vineyard and Restaurant on Waiheke Island near Auckland has used EM bokashi to recycle its food waste. The method is illustrated in Figure 10. The total decomposition period before applied to soil is approximately five to eight months.

The steps are:

1. Food waste was collected and mixed with EM bokashi daily.
2. The mixture was added to a 240 L wheelie bin till full. Excess liquid was regularly drained off.
3. The full bin was sealed and left to ferment for six to eight weeks.
4. The fermented food was layered with spent potting mix to form a pile approximately 2 m$^3$. The material continues to break down without being turned.
5. After three to six months, the end product is applied to the restaurant's vegetable garden beds.

The gardener reported that the process is odourless and does not attract vermin (Sargent, 2009).

Figure 10: The schematic of the EM bokashi decomposition system at the Mudbrick Vineyard and Restaurant on Waiheke Island.
4.4.2 University of Missouri–Columbia’s Experiment

In 2000 and 2001, University of Missouri-Columbia conducted a pilot trial to recycle food waste generated on campus using EM bokashi with a satisfactory result. The method and the experiment conducted were clearly described in Means, Starbuck, Kremer and Jett’s paper (2005). Figure 11 illustrates the procedure they used. The total decomposition period before planting was only 41 days.

The steps are:

1. Food waste was collected from a student dining hall
2. Food waste was shredded to 30-100 mm pieces to form a pulp-like slurry
3. Shredded food was centrifuged to remove excess liquid in the dining hall
4. Processed food was mixed with EM bokashi with a ratio of 1:5.3 by volume. The University of Missouri-Columbia prepared its own EM bokashi with EM concentrate. The production method is described in the paper “Microbial Inoculum Preparation” section (Means et al., 2005, p.117).
5. Mixed material was left in an enclosed fermentor (a modified 190L plastic barrel) for 20 days. Excess liquid was regularly drained off.
6. The end product from the fermentation process was incorporated into soil (Mexico silt loam) by tilling to a 150 mm depth using a rotary tiller. The application rate is 1.25 (dry weight) kg/m².
7. After 21 days, melon seedlings were planted into the plot.

After one week of fermentation, it was noted that the material was not recognisable as food, did not produce offensive odour and white mycelial-like growth appeared on the surface. The results from the growth trials showed that the addition of the soil amendment promoted the growth of the melons.
Phase 1: In-vessel Microaerobic Fermentation

- Fresh food waste generated from a student dining hall
- Shred it into 30-100 mm pieces
- Centrifuge shredded food to remove excess water before fermentation
- Mix with EM bokashi
- Compact into an enclosed 190 litre bin and leave it for 20 days

Phase 2: Tilling into soil

- The fermented material is incorporated into soil by tilling to a 150 mm depth using a rotary tiller. Leave it for 21 days
- Plant watermelon seedlings
- Determine the yield.

Figure 11: The schematic of the EM bokashi decomposition experiment conducted by the University of Missouri-Columbia in 2000 and 2001.
5 EVALUATING UC's 2012 PILOT TRIAL

5.1 Background

University of Canterbury (UC) has conducted a trial to decompose some food waste on-site. To prevent the main problems of degradation of food waste, odour and pests (Donahue et al., 1998), UC has adapted a two stage EM bokashi-fermentation decomposition system. The schematic of the pilot trial is shown in Figure 12. An EM bokashi fermentor, a modified 140 L wheelie bin, was used in phase one, but the fermented food was not buried in phase two as in the domestic scale system. Instead, the fermented substances were made into piles because it was believed that the currently available land on campus is not enough for a continuous burial.

![Schematic diagram of the University of Canterbury's on-site food waste recycling trial.](image-url)

The food waste used in the trial was collected from the Rochester and Rutherford Hall. The Rochester and Rutherford Hall is one of UC's halls of residence, located at the corner of Ilam Road and Homestead Lane (Figure 13). The hall has its own kitchen and provides three meals per day to approximately 180 student residents during term time. On average, 70 L or 40 kg of food waste is generated a day. The food waste was previously disposed of along with other landfill waste, as most of the other kitchens of in house catering and café on campus do.

A non-site EM bokashi-fermentation decomposition trial was launched to divert the food waste generated from the Rochester and Rutherford Hall in 2010. The practice was interrupted by the
Christchurch earthquake in 2011, but it started again in May 2012. The 2010 trial was relatively crude. The fermentation process did not work properly because the then fermentors did not have a satisfactory drainage system, and food waste was over saturated in the fermentors. The second stage decomposition site did not have a drainage system, so offensive odour was produced. However, the design of the fermentors has since been improved and a purpose-built decomposition site has been constructed. In May, September and early October 2012, the Rochester and Rutherford Hall recycled approximately 2860 L (1.5 tonnes) of food waste on-site. The current plan is to use the well-decomposed end product on the Dovedale community garden, one of UC’s community gardens established in late 2010.

The following section will be focused on the 2012 trial.

Figure 13: The locations of the kitchen of the Rochester and Rutherford Hall and the decomposition site on the Grounds Maintenance’s land.
5.2 Procedure

5.2.1 Collection
The pre-consumer food waste from the kitchen and the post-consumer food waste from the dining hall were collected every day. Students discarded their food into a 50 L bucket set up under the dishes collecting table in the dining hall. The kitchen staff mixed the inoculum, EM bokashi, with the food waste and deposited it into a 140 L EM bokashi fermentor.

The recommended EM bokashi:food ratio is 1:20 by volume, which is higher than the ratio for the domestic system (1:66). According to ZingBokashi, inoculating a large amount of food with EM bokashi evenly by hand is difficult, so increasing the amount of EM bokashi added can ensure a more consistent fermentation result. However, in practice the kitchen staff only used a ratio of 1:200, which was 10 times lower than the recommended ratio.

5.2.2 Fermentation
The EM bokashi fermentor is a modified 140 L wheelie bin as shown in Figure 14. A plastic mesh sits inside about 150 mm above the bottom of the bin (Figure 15), which has a tap attached to it (Figure 16). The tap allows the liquid produced during fermentation to be drained off. A 2 L milk bottle has the side cut off was used to collect the liquid daily. It was reported that the liquid produced from a bin was less than two litres a day. The liquid was poured into the grease trap outside the kitchen. The property manager believed that this practice helped reduce the odour released from the trap.

Seven EM bokashi fermentors sat outside against the kitchen wall. The kitchen staff put the food waste into the bin closest to the backdoor. Once the bin was full, it was moved to the other end, and an empty bin was ready to be refilled. A tag on the lid was used to record the date the bin was filled. Full bins were left to ferment for approximately seven days. An environment low in oxygen was created by a sealed lid and a bungee cord, which kept the lid closed tightly (Figure 17).
5.2.3 Transportation

Initially, student employees wheeled the fermentor to the second stage decomposition site after the food waste was fermented for approximately seven days. The site, which is under Grounds Maintenance’s management, was approximately 400 m from the kitchen. The route (see Figure 13) to the site consists of approximately 90 m of bitumen through a car park, 200 m of footpath on Homestead Lane and 90 m unpaved road within the Grounds Maintenance’s land. Because the bin was heavy (up to 90 kg) and the road surface was not smooth, it was difficult for the student employees to wheel the bin by foot. The unpaved path became particularly difficult to walk on with a heavy bin when it was wet. Therefore, student employees started to transport the bins to the decomposition site using a car with a trailer.
5.2.4 Piling

The decomposition site

The purpose-built decomposition site is approximately 10 m² and located at the north-west corner of the Ground Maintenance's land (Figure 13), adjacent to the area where the Grounds Maintenance stores the leaf mold they composted. A structure illustrated in Figure 18 was constructed to contain the fermented material and collect leachate. The structure was made of timber frames with three separated bays. Bay 1 and Bay 2 can hold approximately 3 m³ fermented mass each and can be covered by a black plastic sheet attached to the back of the frame. It was intended to prevent excessive rainfall entering the pile and evaporation. However, the cover was not in use when inspected in December 2012. The smallest bay (not shown in Figure 18) which has a permanent cover over it was used to store a shovel, gardening fork and wheelbarrow. At the bottom of Bay 1 and 2 are two pieces of corrugated iron spaced apart by 100×50 mm untreated framing timbers. The top piece has many drilled holes allowing the leachate to drain down to the second piece. The leachate was then collected by the gutter at the end (Figure 19), and it currently flows onto the ground. Installation of a bucket to catch the liquid was planned though.

Figure 18: The structure built to hold the decomposition piles.

Figure 19: The side view of the decomposition site.
Layering the pile

Student employees were responsible for layering the fermented food with carbonaceous material to make the pile. The fermented food waste was layered with leaf mold (Bay 1) originally, but later pea straw was used (Bay 2). The pea straw was brought in and stored under a plastic cover. Student employees reported that pea straw was easier to apply than leaf mold.

It was not clear exactly how much pea straw and leaf mold were added, but it was suggested to layer one part of fermented food waste with two parts of carbonaceous material. The leaf mold which had a high moisture content was well composted (at least three years old), so the C:N ratio of the leaf mold was probably too high to be a suitable carbonaceous material. However, mixing one part of food waste with two parts of pea straw was reasonable. Table 2 shows the characteristics of food waste and straw given by the On-Farm Composting Handbook (Rynk, 1992, pp.110-111). The bulk density of food waste was estimated based on the experiment conducted for the project (Appendix). Based on those assumptions, one part of food waste mixed with two parts of straw gives a C:N ratio approximately 30:1, which falls within the preferred range given by the On-Farm Composting Handbook (25:1 to 30:1).

<table>
<thead>
<tr>
<th></th>
<th>Average C:N ratio (weight to weight)</th>
<th>Moisture Content (% wet weight)</th>
<th>Bulk Density (kg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Waste</td>
<td>15</td>
<td>69</td>
<td>0.500</td>
</tr>
<tr>
<td>Straw (general)</td>
<td>80</td>
<td>12</td>
<td>0.135</td>
</tr>
</tbody>
</table>

5.3 End Products

Both Bay 1 and Bay 2 still had relatively large portions of food waste that still had not decomposed after three to six months of piling. Figure 20 shows that the undecomposed food waste forms a thick mass of moist and soft pulp which release unpleasant odour when opened up. Lack of oxygen which was probably caused by oversized substrate material may explain the slow decomposition of the food waste. Most of the pea straw in Bay 2 was dry and had not decomposed (Figure 18, Bay 2). Pea straw which was added as an amendment (carbonaceous material) and a bulking agent (large stiff material to increase air flow inside the pile) might not have mixed well with the substrate material or the proportion was too high.
5.4 Comparison between UC, Mudbrick Vineyard and Restaurant and the University of Missouri-Columbia

Table 3 compares the EM bokashi-fermentation decomposition configurations used at the University of Canterbury (UC), Mudbrick Vineyard and Restaurant on Waiheke Island (MR) and the University of Missouri-Columbia (UM). The Mudbrick Restaurant and the University Missouri-Columbia’s configurations worked well as described in 4.4.1 and 4.4.2, even though the processes were not intended to be optimised. Both UC and MR did not reduce the size of the food waste before fermentation, but MR had a longer fermentation period (5~7 weeks longer than UC) and used a higher EM bokashi:food ratio (more than six times greater than UC’s).

By contrast, UM shredded the food waste into 30~100 mm pieces pre-fermentation and used a much higher EM bokashi:food waste ratio. Based on Means et al.’s account (2005), the material was unrecognisable as food after one week of fermentation. The smaller food size probably allowed more contact area for microbes to work on, so the fermentation process was accelerated as well as the in-soil decomposition rate. The UM’s configuration had the shortest total decomposition period. The high EM bokashi:food ratio may also guarantee a consistent fermentation process.
Table 3: Comparison between the configurations used at the University of Canterbury (UC), Mudbrick Vineyard and Restaurant on Waiheke Island (MR) and University of Missouri-Columbia (UM).

<table>
<thead>
<tr>
<th></th>
<th>UC</th>
<th>MR</th>
<th>UM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in Substrate Size pre-</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Fermentation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fermentation Period (weeks)</td>
<td>1</td>
<td>6~8</td>
<td>3</td>
</tr>
<tr>
<td>EM Bokashi:Food ratio</td>
<td>1:200</td>
<td>1:30</td>
<td>1:5</td>
</tr>
<tr>
<td>Total Decomposition Period before planting</td>
<td>More than 6 months</td>
<td>4~8 months</td>
<td>6 weeks</td>
</tr>
<tr>
<td>Post-fermentation Treatment</td>
<td>Above ground, uncovered static pile</td>
<td>Above ground, covered static pile</td>
<td>tilled into soil, 150 mm depth</td>
</tr>
</tbody>
</table>

5.5 Inconsistent Fermentation

Inconsistent fermentation may account for UC’s slow decomposition rate, and it may be due to a large substrate size combined with a short fermentation period. An experiment, which simulated the UC's configuration but used the recommended EM bokashi:food volume ratio (1:20), was conducted between December 2012 and January 2013. For the detail of the experiment, refer to Appendix. The experiment showed that birds dug out big pieces of fermented bread and fed on them in the first few days of piling, and in the second week maggots were bred on some big pieces of undecomposed food mass. The result indicates that the fermentation did not proceed consistently even with the recommended dose of EM bokashi. Based on the comparison in section 5.4 and the experiment, it is suggested that the inconsistent fermentation was due to oversized substrate material combined with a short fermentation period. Optimal EM bokashi:food ratio still requires investigation.

5.6 Practical Problems and Suggested Improvements

The practical problems of UC’s pilot work and suggested improvements are summarised in Table 4. No effort was made to reduce the size of the food waste pre-fermentation in the current configuration. As discussed in 5.5, a large substrate size may be the main cause of inconsistent fermentation and the overall slow decomposition rate. It is possible to require students and staff to cut the food waste smaller before discarding it, but it would need effort and resources to educate and communicate with more than 150 students each year, and the
outcome could not be guaranteed. A processing machine would ensure a consistent substrate size, but setup and on-going cost has to be considered. Other possible improvement to the fermentation process is to increase the fermentation period. However, the optimal fermentation time has to be investigated, and a longer fermentation period means a larger fermentation vessel and area.

Inconsistent fermentation may also be related to the low EM bokashi:food ratio used at UC; this can easily be solved by better communication. However, using more inoculum also increases the cost.

The current design of the fermentor is robust and easy to use for fermentation according to the users, but it is not practical to wheel the fermentor by foot for long distances. It requires high physical strength and may shorten the lifespan of the fermentor. The obvious solution is to move the decomposition site close to the fermentation site. Otherwise a motorised or human powered utility vehicle may be used to move the fermentors.

The second stage decomposition process (the piling process), encountered the most difficulties mainly due to the unsatisfactory design of the site. The primary problems are: emptying the fermented food to the pile, covering the pile and draining the excess liquid. Emptying the heavy fermentor was difficult, especially when the heap was piled up. It may be facilitated by installing an adjustable ramp, so tipping the bin manually is more manageable. The current plastic sheet, which covered the two bays, was heavy and difficult to use. It is suggested to have a cover for each bay for the ease of use. The leachate collected by the gutter flew to the ground producing offensive smell. The leachate management can be improved by adding a dry absorbent, such as newspaper or sawdust at the bottom of the pile.

Because the above ground piling was an open system, it inherently increases the risk of attracting vermin and releasing odour. The risk could be reduced by using a burial method.
Table 4: Problems of the current configuration and suggested improvements.

<table>
<thead>
<tr>
<th>Problems</th>
<th>Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collecting</td>
<td></td>
</tr>
</tbody>
</table>
| The size of food waste was not reduced pre-fermentation. | • Educating student residents.  
• Installing a shredding machine.               |
| Fermentation                                  |                                                                              |
| EM bokashi:food ratio was too low.             | Increasing staff’s understanding of the system.                              |
| Odour was produced if leachate was not drained regularly. | Adding draining leachate as part of work duty.                               |
| Transportation                                |                                                                              |
| The fermentor was too heavy to move long distances by foot. | • Transporting fermentors by vehicles.  
• Locating the second stage decomposition site closer to the kitchen. |
| Piling                                        |                                                                              |
| The fermentor was heavy and difficult to be emptied. | Setting up an adjustable ramp.                                               |
| The plastic cover was difficult to use.       | Setting up easy to use covers for each bay.                                 |
| The leachate flew to the ground producing odour. | Laying dry absorbent, such as newspaper or sawdust at the bottom.            |
| The risk of attracting vermin increased.      | Using the burial method.                                                    |
| The risk of releasing odour increased.         | Using the burial method.                                                    |
5.7 Comparison between the Burial and Piling Methods

Table 5 lists the advantages of the burial and piling method, revealing that the burial method may be a more appropriate method for the UC. As discussed in section 5.5 and 5.6, the UC’s pilot trial had an inconsistent fermentation result and the facility for piling needs to be improved. Those problems would not be issues if using a burial method. The nuisances caused by potential inconsistent fermentation, such as attracting pests and releasing odour, would be avoided if the fermented food had been buried under the ground. The site setup would also be simpler because making a shallow trench is the only necessity. No extra carbonaceous material needs to be imported, and nutrients are directly incorporated into soil so no extra labour and resources would be involved in distributing the end product.

<table>
<thead>
<tr>
<th>Burial Method</th>
<th>Piling Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The site setup is simple (trenched).</td>
<td>• Required land area is smaller.</td>
</tr>
<tr>
<td>• Nutrients are directly incorporated into soil.</td>
<td>• Piling may be a better option if the soil type is not suitable for burial.</td>
</tr>
<tr>
<td>• No additional carbonaceous material required.</td>
<td></td>
</tr>
<tr>
<td>• No excessive loss of the moisture content through evaporation.</td>
<td></td>
</tr>
<tr>
<td>• Minimised risk of attracting vermin.</td>
<td></td>
</tr>
<tr>
<td>• Provides a physical barrier to the release of potential odour.</td>
<td></td>
</tr>
</tbody>
</table>

5.8 Land Area Required for the Burial Method

UC used the piling method because of concerns about short of available space; however, no calculation has been done to estimate the land area required if a burial method is used. Based on the Rochester and Rutherford Hall’s statistics in May, September and October 2012, the hall generated approximately 72 L of food waste per day. Assuming the volume of the food does not change post fermentation, and the food waste is produced 270 days a year, the Rochester and Rutherford Hall generates approximately 20,000 L (20 m³) of food waste per year. If the fermented food is buried into the ground 300 mm deep and covered with a 50 mm layer of soil, 80 m² of land is required for burial. The total land area at the Dovedale community garden is approximately 570 m², so approximately 14 % of the Dovedale community garden’s land is needed to bury the hall’s one year food waste.
Following is the summary of the calculation:

- Daily food waste generated: 72 L
- Yearly food waste generated: 20,000 L
- Area required (weekly): 2 m²
- Area required (yearly): 80 m²
- Total land area of the Dovedale community garden: 570 m²
- Percentage of the Dovedale community garden’s land area needed in a year: 14%

Based on the estimation, only 14% of the Dovedale community garden’s total land area is required to bury one year’s food waste generated from the Rochester and Rutherford Hall. It would take seven years to cover the whole area of the garden if applicable. The result shows that there is enough space at the Dovedale community garden for the burial method. However, using the Dovedale community garden as a burial site may affect the garden’s current management plan, so modification may be needed. Liaison between the community garden and the Rochester and Rutherford Hall is also necessary.

Further investigation on the adequate time interval for the planting after burial and the subsequent burial on the same site is recommended.

5.9 Recommended Configuration

5.9.1 Substrate Size Reductions

It is suggested to reduce the size of the food waste pre-fermentation to warrant a more consistent end product if UC decides to continue an EM bokashi-fermentation decomposition system. As mentioned in section 5.6, it can be achieved by two ways: food broken manually by students and staff or installing a food waste processing machine. Requiring students and staff break the food manually does not need extra equipment, but a consistent size could not be ensured. A simple and small machine that could be handled by individuals and positioned in the dining hall would be a better option. Instead of depositing the uneaten food directly into the collecting bucket, students feed the food into the machine. EM bokashi may also be added at the same time. Using the shredding machine involves all the student residents, requiring all the consumers to take responsibility for the waste they produce.

A processing machine could be purchased, otherwise designing a shredding machine or modifying machines available on the market could be part of an engineering students’ design project.
A Bio-Regen unit developed by an Australian company BIO-REGEN PHOTONICS and used at the James Cook University to recycle food waste is an example of the type of the machine that can be used. The Bio-Regen unit was installed in the Uni Hall's kitchen as shown in Figure 21 (Connel, 2012). The kitchen staff and students add the food waste and EM into the machine which grinds and mixes the ingredients.

![Image](image.png)

**Figure 21:** A Bio-Regen Unit grinds and mixes the food waste with EM at the James Cook University (after Connel).

### 5.9.2 Fermentation, Transportation and Burial

It is suggested to increase the fermentation period, transport the fermentors to the Dovedale community garden by vehicle and bury the fermented material in the garden. Eight fermentors will be needed: four located at the Rochester and Rutherford Hall and the rest located at the community garden. The Hall would collect the food waste and start the fermentation process. It is estimated that half a bin would be used a day. Every Thursday (the garden's regular working time), the bins would be transported to the garden and continue the fermentation for another week. This would guarantee each bin is at least fermented for one week before burial. The bins which would have been fermented for one week at the garden are emptied into a 300 mm deep trench, mixed with some soil and covered by a 50 mm layer of soil. It is estimated that 2 m² of land would be needed every week.

Monitoring the decomposition progress of the fermented buried material of the configuration is recommended.
6  SCALING UP ISSUES

6.1  Background

It was estimated that the University of Canterbury generated approximately 179 tonnes (360 m$^3$) of food waste in 2012. Forty nine tonnes was recycled through the University’s off-site recycling program, while the amount four fully catered halls and two self-catered apartments created was estimated to be around 130 tonnes. The estimation was based on the 2012 statistics provided by the Rochester and Rutherford Hall indicating that each student resident produced approximately 0.24 kg of food waste per day. Assuming student residence time is 40 weeks a year and 1949 students reside on campus, 130 tonnes of food waste is generated per year.

Using a bulk density of 0.5 tonnes/m$^3$, UC creates approximately 360 m$^3$ of food waste per year. Burying 360 m$^3$ of food waste 300 mm underground and covering it with 50 mm soil would require 1432 m$^2$ of land, which would cover approximately 1.5 % of the Ilam fields. The calculation in this chapter is based on this estimation.

6.2  Decentralised System

Two different EM bokashi fermentation decomposition systems could be considered to recycle all food waste generated on campus: a decentralised system and centralised system. A decentralised system would require less machinery, have more students and staff engagement and work well with many small scattered edible communal gardens with rotational garden beds. For offices and Ilam apartments, smaller EM bokashi buckets can be used as fermentors while catering kitchens can use modified wheelie bins. The fermented food can be buried in the gardens near the offices or dining halls.

6.3  Centralised System

6.3.1  Phase One Fermentation

A centralised system would need more specialised equipment, but less staff and student involvement. A faster decomposition rate and a more consistent result are expected. The need for enclosed in-vessel fermentors may be eliminated by making a sufficiently large pile of the inoculated food to create a low oxygen environment within the pile. It is suggested to reduce the food size with a machine and to make large static piles with a tractor. Assuming 1.7 m$^3$ of food waste is generated per working day, a 17 m$^3$ pile can be made in two weeks. If each pile is left to ferment for three weeks, space for three piles would be necessary. Approximately 26 m$^2$ is needed, for piles two metres in height.

The optimal fermentation period and EM bokashi:food ratio need to be further investigated. The well fermented material should not attract pests and release unpleasant odour.
6.3.2 Phase two decomposition

Depending on the growing methods, three techniques can be used for phase two decomposition: tilling into soil, burying underground and making into piles on the ground. A centralised system should guarantee a consistent fermentation, so fermented material can be directly tilled into soil and seedlings planted three weeks later (Means et al., 2005). The fermented material can also be mixed with garden trimmings to make into a compost pile. The traditional burial method could also be employed.
7 SOME ALTERNATIVE FOOD WASTE RECYCLING OPTIONS

7.1 Comparison between the EM Bokashi Burial Method and Composting

Human pathogen transmission is the main concern with using EM bokashi burial method to decompose institutional food waste when comparing with composting. The food waste collected from the university is from a wide range of consumers who may carry infectious disease. Dairy products, meat and fish can also contain various disease causing virus, bacteria, fungi and parasitic worms. Food poisoning Salmonella and Campylobacter jejuni, Shigella that causes diarrhea, E. coli and Hepatitis A virus are a few examples (E & A Environmental Consultants, Inc., 2001). Pathogens can be spread by contact with hands, leachate, dispersion of dust and contamination of plants and animals. People, especially those who handle the food waste, can be infected by inhalation, ingestion and dermal transmission.

A well designed composting facility with high level of control, such as Christchurch City Council’s Organics Processing Plant in Bromley, can minimise the public health risk of decomposition of food waste. It is well established that maintaining a temperature above 55°C for at least three days can destroy most of the potential pathogens (Déportes, Benoit-Guyod and Zmirou, 1995). As mentioned in section 3.2.3, the Organics Processing Plant composts the organic waste in an in-door tunnel system for seven to ten days. The process has a high level of control and a high temperature is maintained, so the feedstock is pasteurised.

Even though the fermentative process in the EM bokashi burial method may suppress pathogenic microorganisms due to the low pH and low oxygen environment, no peer-reviewed paper was found to investigate this hypothesis yet. Human pathogen transmission may not be a big issue for a domestic level, but it becomes risky when the technique is applied on an institutional scale. It is suggested that the pathogen population should be monitored and investigation should be made into processes that would minimise the risk of pathogens if the EM bokashi method continues to be used on campus. Prolonging the time for burial before planting or avoiding recycling post-consumer food, dairy products, meat and fish may also reduce the risk.

Using a well-controlled composting system to recycle food waste on campus can ensure the quality of the end product and minimise the risk of public health. Composting can also decompose a wider range of organic matter. Composting works best when the feedstock’s C:N ratio is 25:1 while EM bokashi method requires the feedstock with a low C:N ratio which suits food waste. A composting system can be designed to decompose the food waste as well as other organic matter generated on campus, such as green waste, biodegradable cups which currently cannot be recycled by the council (McIver, 2011) and possibly wood ash from UC’s boilers.
However, a well-controlled system means a higher set up cost. In 2007, R5 Solutions Ltd quoted an in-vessel centralised composting plant for UC to compost source separated organic: food, soiled paper and card, degradable packaging and green waste. The capital cost of the system was approximately 500,000 New Zealand dollars. Even though in-vessel composting is the best composting configuration in regard to pathogen destruction and reduction in release of odour, aerosols emissions, cross-contamination and leachate (E & A Environmental Consultants, Inc., 2001), the initial capital cost is currently too high to make it feasible.

Table 6 compares the EM bokashi burial method and composting. In addition to the previous discussion in this section, the EM bokashi burial method is suitable for a decentralised system, but composting is not, because a higher amount of substrate is needed for the compost to reach thermophilic phase. Composting has a higher decomposition rate than the EM bokashi burial method because composting is an aerobic process.

<table>
<thead>
<tr>
<th></th>
<th>EM bokashi burial method</th>
<th>Composting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock</td>
<td>Low C:N ratio. Suitable for food waste.</td>
<td>C:N ratio 20-25:1. Food waste needs to be mixed with other organic matter that is higher in carbon.</td>
</tr>
<tr>
<td>Scale</td>
<td>Can be small.</td>
<td>Needs to be large enough to reach the thermophilic phase.</td>
</tr>
<tr>
<td>Inoculation</td>
<td>Yes.</td>
<td>No.</td>
</tr>
<tr>
<td>Destruction of Pathogens</td>
<td>Needs to be investigated.</td>
<td>Above 55°C for at least three days.</td>
</tr>
<tr>
<td>Odour and Pests Control</td>
<td>Good.</td>
<td>In-vessel is the best; aerated static pile is the second.</td>
</tr>
<tr>
<td>Processing Cycle</td>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td>Degree of Control</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

7.2 Off-site Food Waste Recycling

Using off-site facility is another option to recycle food waste on campus. As mentioned in section 2, food waste generated by the halls of residence and privately run restaurants on campus is managed independently and most of it is sent to landfill. Composting food waste at the Organics Processing Plant in Bromley, which is approximately 12 km from UC, has several
technical advantages as discussed in section 7.1. The community gardens could purchase the compost which complies with the New Zealand Standard for Composts, Soil Conditions and Mulches (NZS 4454:2005) back from the processing plant. It costs UC $7464 to recycle 49 tonnes of food waste in 2012, and the cost of the compost is approximately $50-75 per cubic metre. Based on the current cost, sending the food waste to the Organics Processing Plant is probably the most economical option. An off-site operation would also require little capital investment, supervision and processing labour.

On-site food waste recycling, however, has some benefits. It

- reduces stresses and demands on the transport network
- reduces transport fuel use
- avoids impacts of large centralised facilities
- closes the loop of the University's food system
- makes UC resilient to disruption of a centralised system
- provides an opportunity to engage students and staff in sustainable activities hence enhance sustainability culture on campus
- allows UC to recycle organics that is not accepted by the off-site facilities.

In the short term, it is suggested to collaborate with the halls of residence and privately run restaurants on campus to incorporate their food waste with UC's current off-site recycling program, while experimenting, testing and improving on-site recycling techniques. Off-site recycling can facilitate future on-site food waste recycling by familiarising students and kitchen staff with the collection system and quantifying and qualifying the food waste.
8 CONCLUSIONS

The on-site food waste recycling trial conducted at the University of Canterbury in 2012 was evaluated. The pilot trial had a relatively slow decomposition rate, and inconsistent fermentation was found to be the main cause. The primary problems were:

- A large substrate size combined with a short fermentation period
- Unsatisfactory design of the piling site
- Possibly insufficient inoculum (EM bokashi).

It is proposed that reducing the food size pre-fermentation and burying the fermented food waste would greatly improve the outcome.

The current pilot work could be scaled up by using a machine to reduce the initial food size and a tractor to make a large static pile to create a low oxygen condition for fermentation. The fermented material could be buried, tilled into soil or made into compost depending on the growing methods.

Human pathogen transmission is the main concern when using the EM bokashi-fermentation decomposition technique to recycle food waste on campus. No peer-reviewed paper investigating whether the fermentation process is effective at the destruction of pathogens was found. In the short term, it is suggested that UC collaborates with the halls of residence to incorporate their food waste into UC's off-site recycling program while continuing to experiment, test and improve on-site recycling techniques. Off-site recycling practices would facilitate future on-site food waste recycling by familiarising students and kitchen staff with the collection system, and quantifying and qualifying the food waste.
References


Appendix: The Experiment

Aims

An experiment was conducted between December 2012 and January 2013 to:

- determine if EM bokashi-fermentation decomposition process produces odour
- observe if bokashi-fermentation decomposition process attracts pests

when the recommended ratio of EM bokashi was added.

Because the on-campus food waste recycling trial was not performed over the summer research period, the experiment also helped the researcher comprehend the operational process of the system better.

Materials and Methods

Substrates
Approximately 200L of food waste were collected on campus from the university’s daily waste collection, a hall of residence and a café. The composition of the food waste was raw and cooked vegetable, peels, breads, pies, sausages, meat, coffee grounds, eggs and egg shells. The bulk density of the food waste varied between 0.35~0.65 kg per litre. The size of the food was maintained as received.

Fermentation
The experiment constituted two sequential parts: fermentation and aerobic decomposition. EM bokashi was used as an inoculum to ferment 100 L of the collected food waste in a 140 L bokashi big bin. The food scraps were fully coated with EM bokashi. For every 10 L of food, 500ml of EM bokashi were used (this was the manufacturer’s recommended ratio). The bin was then left to ferment for eight days which was similar to the Rochester and Rutherford Hall’s practice. The lid and tap were open once per day to examine the leachate, food surface and smell. The ambient temperature during the fermentation process was between 9°C at night and 26°C in the day.

The Burial Technique
After eight days of fermentation, the treated food waste was divided into two parts of approximately 45 L each and allowed to decompose further for 31 days (from 15 December 2012 to 14 January 2013). One part of the treated food was buried under the ground and the rest was piled above the ground. The burial sample was buried in a 900×450×200 mm trench mixed with 5 L of soil. A 20 mm layer of soil covered the top, so that no food material was exposed. The texture of the soil was light clay and it has lawn grown on it for the last 30 years.
The surface of the sample was inspected daily in the first week. After the first week, the soil surface was uncovered and the treated food was observed once a week.

The ambient temperature during the composting process was between 10°C at night to 30°C in the day.

**The Piling Technique**
The treated food was layered with four-year-old leaf mold on the ground. The food:leaf mold ratio was 2:1, and the final total volume of the pile was 72.5 L. The finished pile was loosely covered with a black plastic sheet to reduce moisture loss, while continuing to allow some airflow. Water was added when the pile became too dry.

The plastic sheet was uncovered and the appearance of the sample was inspected daily in the first week and then once a week.

The sample was also left to decompose for 31 days and the experimental environment was the same as the buried sample.

**Results and Analysis**

**Fermentation Process**
After eight days of fermentation, the volume of the food waste reduced from 100 L to 86 L, a 13.7% reduction. However, only approximately 40 ml of leachate was produced. The reduction in volume was probably due to the compaction of the substrate’s own weight.

The smell and appearance of the food waste did not change greatly over the fermentation process. However, since the second day, white-mold-like microbes covered the surface of the food. The microbes were probably some antinobacteria that favoured the aerobic environment.

No flies, maggots and other pests were observed during the process.

**The Burial Technique**
In the first day, the appearance of the sample did not change, but a chicken bone was dug out by an animal (likely to be a bird) in the second day. Therefore, the trench was covered with 50 mm of soil instead of 20 mm. There were no signs of digging since then. The surface of the sample remained unchanged during the process.

The soil was uncovered in the second, third and fourth week and the fermented food waste buried was compacted and paste-like. It produced very unpleasant odour but could not be detected if covered. The lack of oxygen under the ground probably caused anaerobic digestion to occur, so odour was produced.
The Piling Technique

Table 7 shows the change of the substrate during the above ground aerobic decomposition process. In the first week, white hyphae were formed on the surface of the pile. The fermented food substrate also attracted pests and some insects. Birds dug out and ate the bread. Fruit flies and ants were also present. It had a strong sour smell but is tolerable. However, the pile produced unpleasant odour after two weeks when maggots also bred on one of the big chunky pieces of food, probably a piece of chicken or a potato. The odour and maggots disappeared on the third weeks and a dark black coloured end product was produced after one month.

Table 7: Observations during the above ground aerobic decomposition process.

<table>
<thead>
<tr>
<th>Day</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>14</th>
<th>23</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>White hyphae on the surface</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Being dug out by animals</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruit flies</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ants</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maggots</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Insects</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odour</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

The final volume of the end product reduced from 72.5 L to 40 L, a 45% reduction. Approximately 12 L of the end product had a particle size greater than 10 mm. Most of the end material was unrecognisable as food but some remained food-like. It was noted that the bigger the food piece, such as the whole potatoes, apples and a chunk of pumpkin or meat were likely not decomposed properly. The fermented food in the centre of the pile also tended to not fully decompose, and this was probably due to lack of oxygen.

Conclusions

The results show that the fermentation process which occurred in the fermentor did not produce unpleasant odour nor attract vermin or flies. The fermented material buried underground and covered with a 50 mm layer of soil did not produce odour or release detectable odour. However, the above ground pile attracted birds, ants and flies to feed on the substrate in the first week and maggots were grown on one piece of undecomposed food after two weeks. It indicated that the fermentation process was inconsistent.