

BOKASHI COMPOSTING: PERFORMANCE MONITORING TO ASSESS THE POTENTIAL OF COMMERCIAL LEVEL APPLICATIONS

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Introduction

Organic waste (kitchen/food waste, green waste, other organic waste such as food processing waste) forms around 28% of the total waste stream in New Zealand (MfE, 2009). It is also recognised that diversion of organic waste from small, fragmented mixed-waste sources such as household kitchens, supermarkets and restaurants presents challenges due to the difficulty and cost of diversion (MfE, 2009). As such, the treatment, handling and disposal of organic waste are subject to increasing commercial scrutiny in New Zealand, with a search for alternatives to landfilling. The Bokashi composting system is a simple, decentralised organic waste treatment option that could play a significant role in reducing the volumes of food waste currently disposed of to landfill.

Bokashi Composting (utilising Effective Microorganisms or EM) has been used at a household scale for over nine years in a number of communities, with high levels of user satisfaction (Pontin *et al*, 2002). The Bokashi system produces a “juice” during fermentation that can be utilised in a diluted form as a fertilizer, while the residual solid matter is buried and full degradation occurs in the soil in around a month (Pontin *et al*, 2002).

Current research is focused on scaling-up the technology for application in a commercial or small-community application. For a commercial-scale system, the quantities of the juice and residual material are larger, and therefore consideration of a designated re-use route is required. Bokashi NZ has developed 140L commercial scale bins, and trials are commencing in Hanmer Springs (Hanmer Business Association), Waitakere City (Project Circle) and Hamilton (Back to Earth) utilising hotel, café and supermarket waste. Food waste is intended to be returned to the soil in each trial.

A key driver of this study has been the need to gather further information related to the Bokashi system and its performance. A number of chemical and biological parameters are of interest, with a focus on those that relate to potential resource consent applications for commercial systems. In addition to this, certification such as Biogro will require performance monitoring to ensure Bokashi meets the required standards.

Given the potential variety of end-uses and applications of the Bokashi system, it is useful to ascertain the changes in the Bokashi system over time. This includes the concentrations of key constituents in the juice and bucket (waste), and changes through the application of the liquid and solid material in composting applications. This study undertook preliminary investigations on the nutrient content of the liquid and solid material, and the potential presence of key food-borne pathogens.

The Bokashi Process

The Bokashi process is a form of composting, whereby decomposition of organic matter occurs through a fermentation process, with microorganisms utilising the food waste as substrates for growth and generation of by-products for other microbes to utilise. In essence,

this process is similar to that which occurs in traditional composting and landfills, when the required conditions around pH, moisture, and availability of nutrients are met.

The key difference with Bokashi composting is the use of EM, or Effective Microorganisms to enhance the process. The EM is a mixed culture of beneficial and naturally occurring organisms that are inoculated into the composting process on a carbon-based bran/sawdust media. The EM is designed to function in a synergistic manner, and to directly and indirectly suppress pathogenic microbes present in the environment.

In general terms, EM comprises of the following groups of organisms:

- Lactic acid bacteria (*Lactobacillus sp.*, *Streptococcus sp.*).
- Photosynthetic bacteria (purple non-sulphur bacteria) (*Rhodospseudomonas sp.*, *Rhodobacter sp.*).
- Yeasts (*Saccharomyces sp.*, *Candida sp.*).
- Actinomycetes.

A brief description of the EM organisms follows.

Lactic acid bacteria produce lactic acid as a major or sole fermentation product and are categorised as aerotolerant anaerobes, meaning they grow anaerobically in the presence or absence of oxygen. Many species of lactic acid bacteria can grow well in pH values as low as 4, and thrive in acidic-rich carbohydrate media (Madigan *et al*, 2000).

Photosynthetic bacteria such as *Rhodobacter sp.* are categorised as purple non-sulphur bacteria, are naturally-occurring and nutritionally diverse. Most purple non-sulphur bacteria can grow aerobically by respiration, some anaerobically in the dark using fermentative or anaerobic respiratory mechanisms and being photosynthetic, they can utilise light as an energy source. The photosynthetic ability likely accounts for their competitive success in nature. (Madigan *et al*, 2000).

Yeasts are categorised as fungi that grow both aerobically and anaerobically. Under anaerobic conditions, yeasts utilise a fermentation mechanism to convert sugar to products such as ethanol (Madigan *et al*, 2000) in a process well-understood by home brewers of beer.

Actinomycetes are filamentous bacteria that resemble fungi. One member of this group, *Streptomyces sp.*, is a predominantly soil based microbe that is nutritionally diverse, and produces enzymes utilised to break down higher polysaccharides. They are strict aerobes and appear as white “mould-like” structures, and their antibiotic properties are well known (Madigan *et al*, 2000)). As part of the EM mixture, antibiotics will act against certain types of gram-negative pathogenic bacteria including known human pathogens such as *Escherichia coli*.

It can be seen that these microorganisms have a number of individual properties that enable them as a group to thrive in a fermentation process, and also naturally in the environment. Features such as the ability to degrade substrates anaerobically and antibiotic properties allow them to act as ‘probiotics’ in a number of uses. EM has predominantly been used in a number of applications to increase the microbial diversity of soils and plants with great success (see Yamada and Xu, 2000).

In the Bokashi system, the function of EM is to facilitate the enhanced degradation of organic waste in both an in-vessel system and subsequently in the natural environment.

Methodology

Trial Information

Sampling was undertaken to monitor two fermentations that were undertaken independently utilising different feed material. The two fermentations (Ferm 1 and Ferm 2) utilised a series of five Bokashi buckets (15 litres) with a composite technique utilised for obtaining liquid and solid samples.

Buckets for Ferm 1 were filled evenly over two weeks (8 filling events) using mixed food waste collected from a local café. Waste broadly consisted of whole food products (meat pies, scones, filled sandwiches, cheese toasties, corn fritters) egg shells, coffee grinds and some fruit and vegetable waste (potato peelings, silverbeet, broccoli, cabbage, oranges).



Figure 1 – Photograph of vegetable material that was utilised in trial Ferm 2

Buckets for Ferm 2 was filled evenly over one week (4 filling events) with approximately one third of the bucket made up of restaurant waste (pizza, lettuce, cold meat offcuts, sandwich offcuts, eggshells, mushroom stalks, potato, rocket stalks, chicken bones & chicken meat, potato peels) and the remaining two thirds of the bucket comprising of reject fruit and vegetable material from a greengrocer (including cabbage leaves, peppers, oranges, apples, pears, onions, celery, persimmon, leek, parsnip and pumpkin).

Each food waste addition to the buckets was accompanied with Compost-zing, a product that comprises of a locally-made EM inoculated bran/sawdust mix. The Bokashi buckets for each trial were stored inside in dark conditions at temperatures between 12 to 20 degrees Celsius and remained air-tight, with the exception of sampling for juice. Trial Ferm 2 was reported to be held at a higher temperature due to the nature of storage in an air-conditioned domestic dwelling. The duration of the in-bucket fermentation in this trial was five weeks, including filling.

Juice was collected from both buckets as a composite sample and analysed for composition and microbial parameters according to the sampling programme shown in Table 1. Solids samples were obtained utilising core sampling and pooled for composition analysis.

Table 1 - Summary of sampling programme

Time Period (weeks)	Ferm 1 Dates	Ferm 2 Dates	COD Analysis	Nutrient Analysis	Microbial Sampling	Solids Analysis
0	09/06/09	04/06/09				
1	16/06/09	11/06/09	X	X	X	
2	23/06/09	18/06/09	X			
3	30/06/09	25/06/09	X	X		
4	07/07/09	2/07/09	X			
5	16/07/09	7/07/09	X	X	X	X

The sampling programme was designed around testing costs and available sample volume.

Analysis techniques

Chemical and microbiological testing was undertaken by an IANZ accredited laboratory in accordance with Standard Methods (APHA/AWWA/WEF, 2005) and standard microbiological methods.

COD, or Chemical Oxygen Demand, is used as a lumped parameter to determine organic compounds present in a sample. Both total COD and soluble COD were determined on the juice sample at weekly intervals to monitor the generation of fermentation products. Nutrient analysis comprised of total potassium, total nitrogen, nitrate and nitrite-nitrogen, total Kjeldahl nitrogen, dissolved reactive phosphorus and total phosphorus. pH was also measured.

Microbiological sampling was undertaken with a particular focus on common foodborne pathogens including *Clostridium perfringens* (associated with meat), *Listeria monocytogenes* (potentially present in all food types), *Salmonella sp.* (associated with meat, poultry and milk) and *Staphylococcus aureus* (associated with cream-based foods and sandwich fillings). *Escherichia coli*. (common pathogen). Faecal coliforms and *Enterobacteriaceae* were also determined as common Indicator Organisms. An aerobic plate count at 35°C was also undertaken.

Solids analysis was undertaken on the fermented contents of the Bokashi buckets. These tests were for the components of fertilisers; namely total nitrogen, potassium and phosphorus.

Burial of Bokashi Compost and Soil Samples

Samples covering a full profile of nutrients and trace nutrients were also undertaken on the composition of soils and compost media pre and post burial of the Bokashi compost.

Trial Ferm 1 was buried in a compost heap with vertically interchanging layers of fermented food waste (ex Bokashi buckets), and a layer of bark-based media. A single pile was developed for the five buckets. The pile was topped with media and covered with a heavy

PVC cover, held in place by tyres. The covering served to maintain moisture and heat levels within the heap, and prevent any additional moisture from rainfall entering the pile. The pile was maintained for a period of 6 to 8 weeks to allow maturity within winter conditions, with a shorter time of 4 weeks being the normal time during warmer periods.

Trial Ferm 2 was placed in a recently-cleared section of garden that had not been cultivated for a few years. Trenches were dug diagonally across square plots (length around 1.4m) to a depth of around 25cm deep and 25cm wide. All fermented food waste from each bucket was buried in its own trench to a depth of around 15cm of material. The trenches were filled with soil and allowed to mature for 6 to 8 weeks.

Results and Discussion

The two trials demonstrated the effectiveness of the Bokashi composting process, with a reduction in the volume of waste during the fermentation, production of 'juice' and rapid degradation of waste when buried.

Aesthetic Observations and Breakdown of Waste

During the fermentation of trial Ferm 1, no objectionable odours were noted with a light golden brown juice (frothy) generated. Following fermentation, trial Ferm 1 was described as largely intact with predominantly fruit and vegetable waste in a recognisable form. Other food materials such as pastry were not identifiable. Some white threads associated with fungal or bacterial biomass (possibly Actinomycetes) were noted on the top layer of food in the bucket, as shown in Figure 2.



Figure 2 - Photograph of trial Ferm 1 post-fermentation, showing white threads associated with fungal or bacterial (Actinomycetes) growth

In trial Ferm 2, a dark brown juice was produced, with no objectionable odours noted throughout the fermentation. Fruit and vegetable waste was recognisable following the fermentation and pre-burial.

Aesthetic observations such as juice colour demonstrate the differences in fermentation, predominantly due to the different feed material utilised.

During the fermentation, a significant reduction of volume was observed in both Ferm 1 (approximately 10%) and Ferm 2 (approximately 33%). Juice volumes generated in trial Ferm 2 were significantly higher than Ferm 1 (5500 mL versus 1910 mL), as shown in Figure

3. This was attributed to the higher percentage of fruit and vegetable waste (high moisture content) in Ferm 2 and greater extent of fermentation, possibly due to higher temperatures during storage.

The observed loss of volume of food waste in the bucket was found to broadly balance the volume of juice generated. By assuming a density of food waste of 288 kg/m³ (Kreith and Tchobanoglous, 2002) and observed juice production, the volume reduction of waste was determined to be around 9% and 25% for Ferm 1 and Ferm 2 respectively.

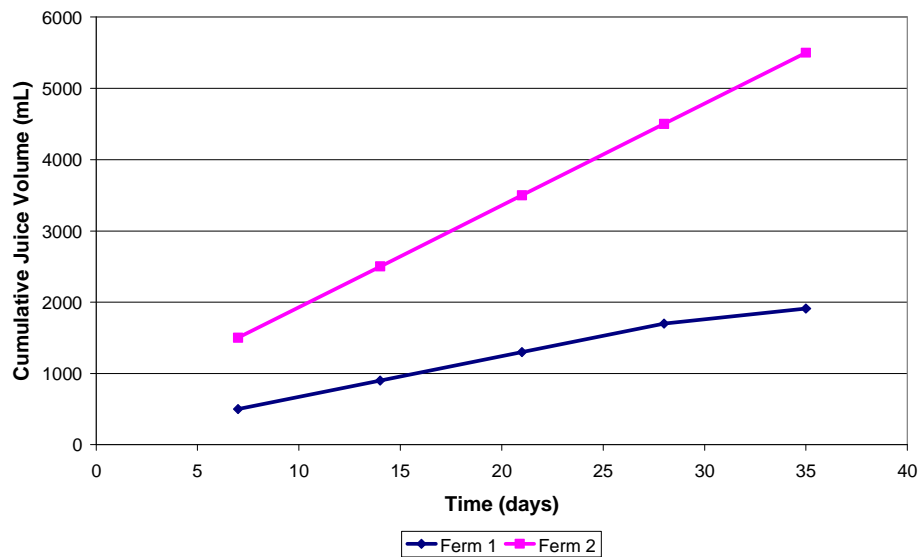


Figure 3 - Graph of cumulative juice volumes generated during fermentation over time (Ferm 1 Blue, Ferm 2 Pink)

Liquid Analysis

Table 2 and Table 3 summarise the results for COD and composition analysis of the juice samples over the fermentation period in Ferm 1 and Ferm 2 respectively.

Table 2 - Summary of COD and composition results for trial Ferm 1

Parameter	Units	Time (d)				
		7	14	21	28	35
pH	units	4	4.2	4.1	4.3	4.4
TK	g/m ³	3800		3100		2600
TN	g/m ³	4500		3400		2500
NO ₃ -N + NO ₂ -N	g/m ³	15		14		0.18*
TKN	g/m ³	4500		3300		2500
DRP	g/m ³	4.3		2.1		600*
PO ₄ -P	g/m ³	13		6.5		1800*
TP	g/m ³	2800		2000		1400
CODs	gO ₂ /m ³	140000	130000	120000	96000	57000
COD	gO ₂ /m ³	160000	140000	130000	120000	90000

* Results shown in grey appear erroneous, and were not considered in analysis. The cause of this is unknown at this stage.

It can be seen that the juice is a concentrated organic mixture, with a very high soluble COD content and very low pH due to the formation of organic acids during fermentation. The pH

of the juice is consistent with levels expected during a lactic acid fermentation process (pH of approximately 4) where the actions of lactic acid bacteria are predominant, and other fermentative species find it difficult to survive. No data was available on the profile of organic acids due to difficulties in testing such a concentrated mixture.

The content of nutrients including potassium (TK) nitrogen (TN), phosphorus (TP) is also high, making the liquid highly suitable for use as a fertiliser. The low results for nitrate/nitrite nitrogen and phosphate-phosphorus is consistent with a predominantly anaerobic fermentation. The majority of nitrogen is present as ammonia. The pH of the liquid requires neutralisation before application to plants, with this typically being achieved by significant dilution with water.

All parameters in Ferm 1 declined over the duration of the trial, as did juice volumes indicating that the fermentation was slowing down over time as rapidly degradable components of the food waste were solubilised.

Table 3 - Summary of COD and composition results for trial Ferm 2

Parameter	Units	Time (d)				
		7	14	21	28	35
pH	units	4.3	4.1	4	4.1	4
TK	g/m^3	2700		3300		3300
TN	g/m^3	2000		2300		2700
NO ₃ -N + NO ₂ -N	g/m^3	43		63		47
TKN	g/m^3	1900		2300		2700
DRP	g/m^3	1.1		0.42		0.77
PO ₄ -P	g/m^3	3.3		1.3		2.3
TP	g/m^3	360		650		830
CODs	gO_2/m^3	83000	83000	83000	94000	77000
COD	gO_2/m^3	83000	85000	91000	95000	99000

COD levels were comparatively lower in trial Ferm 2 indicating a more dilute juice, with similar levels of acidity observed indicating the formation of organic acids as in trial Ferm 1. Overall levels of nutrients were markedly different with nitrogen levels (TN and TKN) around half of those in trial Ferm 1. This indicates the differences in fermentation products between the trials expected due to markedly different food waste utilised as feed material for the fermentation. Oxidised nitrogen and phosphorus species (nitrate/nitrite and phosphate) were also very low in this trial.

In contrast to trial Ferm 1, most components were stable or increased during trial Ferm 2 indicating that the fermentation could have continued beyond the period of composting within the buckets. This is also highlighted in analysis of the cumulative organic carbon (mass) generated during the trial (as COD), shown in Figure 4. While there is a noticeable tailing off the Ferm 1 towards week 5, Ferm 2 appears to continue to produce fermentation products as reflected by higher volumes of a more dilute juice.

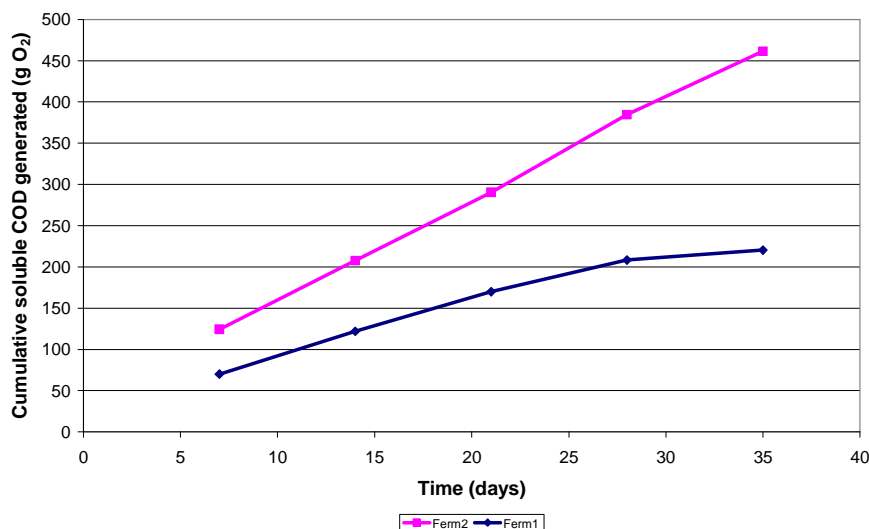


Figure 4 - Graph of total cumulative soluble COD generated over time (Ferm 1 Blue, Ferm 2 Pink)

Microbial Analysis

The results of microbial testing are shown in Table 4.

Table 4 - Microbial results for juice sourced from fermentation

Parameter	Units	Detection Limits	Ferm 1, Day 7	Ferm 1, Day 35	Ferm 2, Day 7	Ferm 2, Day 35
APC35	cfu/g	1.00E+01	1.40E+08	9.40E+08	4.80E+08	7.90E+06
Faecal Coli	MPN/g	3	9	<3	<3	<3
E.coli	MPN/g	3	9	<3	<3	<3
Enterobact	cfu/g	5	<50	<5	<100	<5
Staph aur	cfu/g	10	<10	<10	<10	<10
Clostr per	cfu/g	10	<10	<10	<10	<10
List mono	no/25g	0	nd	nd	nd	nd
Salmonella	no/25g	0	nd	nd	nd	nd

APC35 = Aerobic Plate Count at 35°C, Faecal Coli = Faecal Coliforms, E.coli = *Escherichia coli*, Enterobact = *Enterobacteriaceae*, Staph aur = *Staphylococcus aureus*, Clostr per = *Clostridium perfringens*, List mono = *Listeria monocytogenes*, Salmonella = *Salmonella sp.*

From the results above, it can be seen that all microbial species analysed were below detection limits in the final juice samples from both fermentations on Day 35. The only microorganisms detected at very low levels were *Escherichia coli* on Day 7 in Ferm 1, with these likely sourced from a component of the fresh food waste, or potentially from cross-contamination during sampling.

These results are significant as it demonstrates that the juice is able to be utilised for direct fertilisation of food crops without concerns of spreading common food pathogens.

Aerobic Plate Counts were very high during both trials, with a rapid increase in aerobic heterotrophic growth during Ferm 1, and a significant decline in Ferm 2. Some aerobic growth is expected during the fermentation due to the presence of air in the buckets, although the majority of fermentation activity is expected to be undertaken by anaerobic fermentative organisms such as those in the EM inoculation. Therefore, the aerobic plate count test is not considered to be truly indicative of the growth related to the EM fermentation.

Nutrient Content of Solids and Decomposition

Tests were undertaken to determine the composition of fermented food waste prior to disposal. Results for both trials (converted to dry basis assuming moisture content of 70%) are shown in Table 4, with a comparison to literature values.

Parameter	Units	Ferm 1	Ferm 2	Bokashi Fermentation ¹	Food Waste ²
Total C	%			30.05	46.78
Total N	%	2.38	0.87	1.21	3.16
Total P	%	0.22	0.11	0.63	0.52
Total K	%	0.44	0.51	0.4	0.9
C:N Ratio				25	15

1 – Sekeran, 2005; 2 - Zhang *et al*, 2007.

The composition of the fermented food waste at the end of the trial is comparable to results achieved in other trials, and as expected is dependent on the feed material. Some reduction in nutrient content can be expected during the fermentation due to the loss of species such as ammonia as part of the juice generated. The material is suitable for use in composting, however the carbon to nitrogen (C:N) ratio is likely to be lower than the optimum of 25 to 40 for composting processes (Crites and Tchobanoglous, 1998).

Figure 5 shows material post-fermentation prior to formation into a compost heap in trial Ferm 1.



Figure 5 - Fermented food waste (Ferm 1) pre-burial in compost heap

Figure 6 shows the material after four weeks in the bark compost pile (Ferm 1). It is noted that the material was unrecognisable and significant biological activity was noted with large numbers of worms and other macroflora. The disappearance of buried material from Ferm 2 in soil was slower than Ferm 1, with food still visually present after 4 weeks. After 8 weeks, waste was largely broken down, although a few traces of food material were visible. This extended period of decomposition was over the coldest part of the year and the soil was not rich in biological activity prior to disposal. No odour or runoff was detected in either burial site. Further results from the analysis of soil and compost material were not available for the preparation of this paper.



Figure 6 – Buried food waste in a compost heap (Ferm 1) after four weeks

Conclusions

The following are key conclusions derived from the Bokashi composting trials for food waste:

- Common food pathogens were below detection limits during sampling of both trials, with low levels of faecal coliforms only present in one sample. All juice following fermentation had tested microbial species present.
- Both fermentations had no discernable odour during the 5 week composting process.
- Juice production, degree of waste stabilisation and juice composition were dependent on the make-up of food material composted. Fermentation in Ferm 1 appeared close to completion in the 5 week trial, while Ferm 2 continued to have high organic acid production rates.
- The juice is highly concentrated with organic acids and a pH of around 4. It has a high nitrogen, phosphorus and potassium nutrient content. It is likely that lactic acid bacteria play a key role in the fermentation process due to their environmental preferences being met.
- Solid material breaks down rapidly in soil or a compost pile, with food waste unrecognisable after about four weeks. The nutrient content of the food waste has low levels of nutrients that are similar to other carbonaceous compost additives.

This project has also demonstrated the effectiveness of the Bokashi composting system as a suitable low-tech method for processing organic food waste at source.

Further testing is planned to determine the make-up of organic material in the juice, particularly focussed on volatile fatty acids present such as lactic and acetic acid. Testing will also be undertaken on commercial-scale trials with consideration given to other pathogenic organisms that are tested as part of regular composting.

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