Treating food preparation 'waste' by Bokashi fermentation vs. composting for crop land application: A feasibility and scoping review

Report written for Gisborne District Council

February 2012. Report number 5-2012

Dr Charles N Merfield

The BHU Future Farming Centre

Permanent Agriculture and Horticulture Science and Extension

www.bhu.org.nz/future-farming-centre

Live, like you'll die tomorrow;
Farm, like you'll live for ever.

Disclaimer

This report has been prepared by The BHU Future Farming Centre, which is part of The Biological Husbandry Unit Organics Trust. While every effort has been made to ensure that the information herein is accurate, The Biological Husbandry Unit Organics Trust takes no responsibility for any errors, omissions in, or for the correctness of, the information contained in this paper. The Biological Husbandry Unit Organics Trust does not accept liability for error or fact or opinion, which may be present, nor for the consequences of any decisions based on this information.

Copyright and licensing

Citation Guide

Merfield, C. N. (2013). Treating food preparation 'waste' by Bokashi fermentation vs. composting for crop land application: A feasibility and scoping review. Lincoln, New Zealand: The BHU Future Farming Centre: 23

Table of contents

List of figures

1. Introduction

1.1. Purpose of this report

This report has been commissioned by Anne Lister of the Gisborne District Council to provide an overview of the feasibility of the use of Bokashi fermented food 'wastes' such as domestic kitchen scraps, as an alternative to composting and the application of the resulting products to crop land. The report gives an overview and comparison of composting and fermentation for management of biological 'wastes' in general and using Bokashi in particular and the issues that surround them, especially issues that need to be addressed or researched further.

- It has been written for a non-technical audience.
- It is based on the literature and the authors expertise in general agronomy, organic agriculture, composting and soil, i.e. it is not based on new research.
- The first part gives a general overview of the issues surrounding the use of composting and fermentation for food 'waste' management.
- The second part considers and analyses the issues surrounding the use and uptake of fermented, food 'waste' management and the use of Bokashi in particular.
- It concludes with recommendations on how to progress / what further work is required.

Due to the non-technical nature of the report, the use of references has been kept to a minimum. In addition the number of scientific papers in the peer-reviewed literature on Bokashi as a whole is limited (e.g., a subject search of Bokashi in CAB yielded 61 results) and the number of papers in total on the use of Bokashi fermented (not composted) food preparation 'wastes' is very small.

1.2. Context

There is a desire, both globally and in New Zealand, to divert biological materials (green 'waste'), such as food preparation 'waste', grass clippings and tree prunings, from landfill, due to multiple objectives such as limited landfill capacity and increasing cost and numerous side effects such as landfill generated green house gasses (GHG) such as methane and 'short circuiting' of nutrient cycles such as phosphorus and potassium.

1.3. Current management approaches

The standard (non-landfill) approach for dealing with 'waste' biological materials is composting. Composting is a controlled form of the natural decomposition process that occurs in all biological systems. It takes many forms, from simple cold compost piles used by home gardeners; through turned hot composted windrows, to carefully controlled, fully enclosed, hot composting vessels. The approach used depends on many factors, but the key ones include:

- How 'hazardous' the starting material is in terms of issues such as pathogenic microbes or weed seeds and concerns about side effects e.g., odours and flies;
- The speed at which the starting material needs to be processed.

For example, garden 'waste' is a low hazard, while food 'waste' and animal (inc. human) faces are high to very high hazards. Home gardeners are often unconcerned about the speed of the process, while for commercial composting operations, the amount of extra land required for slow cold-composting compared with quick hot-composting is a significant extra capital cost.

Composting is a mature technology, it is well understood and when correctly implemented, very effective within the constraints of composting as a process. A key issue with composting is the more hazardous the material to be composted, the more controlled and contained the composting process needs to be to avoid side effects such as microbial contamination and odours. This means that the cost and complexity of composting more hazardous materials can be considerable.

1.4. Anaerobic digestion

The main standard alternative to composting biological / organic 'wastes' is anaerobic digesting (bio-digesting), where microbes break down the organic matter anaerobically, to produce methane gas and digestate which has a high nutrient (fertiliser) 'value'. This is also now a well established technology, and requires purpose built equipment, which for large scale production is expensive. As the aim of this report is to compare composing with fermentation, bio-digestion will not be considered any further. It would however be valuable to include it in future work / comparisons.

1.5. Fermentation as an alternative to composting

Fermentation, is an alternative approach to managing biological materials, not just 'wastes'. For example there are many fermented human food products, e.g., sauerkraut and kimchi; and silage is fermented grass used as cattle feed. However, fermentation is very different to composting, which aims to speed-up / enhance decomposition, especially hot composting, while fermentation aims to completely halt the decomposition process, which is why it is able to preserve food. This is achieved through two main routes:

- The exclusion / elimination of oxygen, which is essential for decomposition (which at a chemical level is the same as combustion / burning), i.e. it is an aerobic process;
- The production of a range of organic acids that lower pH below that at which most microorganisms can survive / function.

Fermentation can also produce a wide range of bioactive compounds, such as antibiotics, that also help the process but are not normally the main drivers of fermentation / preservation.

Fermentation may therefore initially appears ill suited to biological 'waste' management, but its advantages are its ability to kill or inactivate pathogenic microbes and its lower cost due to it being 'lower-tech' that hot composting, especially closed vessel, systems. There are also a number of other important system level differences between the two systems, in terms of the by-products of the production process (e.g., polluting gasses) and the effects of composts vs. 'ferments' (fermented materials) following soil application. While the primary interests of those needing to collect, process and dispose of biological 'wastes' are often based around cost and safety, the system level effects are of greater interest to the end users, e.g., soil 'fertility' for growers / farmers, and society as a whole, e.g., production of unpleasant odours and GHGs. These multiple, and possibly conflicting factors, mean that a system level perspective is the most appropriate means of analysing pros and cons of composting food 'wastes' vs. Bokashi fermentation. If the use of fermenting is to be progressed, such a system level perspective will be a solid foundation for a formal and detailed Lifecycle Analysis / Assessment (LCA) of the two approaches, which is considered essential.

2. System level comparison of the fermentation and composting processes

This section gives a more detailed analysis of the composting and fermentation processes from a systems perspective.

NB. Water is considered from two aspects:

- One as a 'pseudo' element, where the water is not involved in, or produced by, any chemical reactions, i.e. it remains unaltered throughout the process. Plants, especially green plant material, is mostly water, e.g., fresh lettuce is about 95% water, and much or most of this water is never chemically altered. Water that is not involved in any chemical reactions is generally treated as being in a 'class by itself' i.e. separate to its constituent elements hydrogen and oxygen, as it is present in such large quantities that to include the H and O in water as equivalent to the H and O in other materials e.g., hydrocarbons, only confuses any analysis.

- Water, or rather its constituent elements, hydrogen and oxygen, are fundamental to the chemistry of photosynthesis and its reverse reaction respiration (decomposition). Water is broken apart in photosynthesis (the H is joined with C to make hydrocarbons and the oxygen liberated) while water is created in respiration, by hydrocarbons being broken apart and the H being joined back to O and the C also joined with O to make CO_2. While biochemistry is a huge mass of reactions, photosynthesis and respiration are among the few reactions where water is created or destroyed. Where large amounts of material are being decomposed / respired, larges amounts of water can be created. This water sometimes needs to be considered separately from water that is not involved in chemical reactions, and other times the amount of water produced is insignificant to the total amount of water present in the material.

Also, comparisons of materials, such as plants, compost and ferment, which can contain large quantities of water, should in most cases be analysed on a dry weight basis, otherwise the water content makes comparisons meaningless. Exceptions include situations where the water content is important, e.g., calculating transport costs.

Care and clarity are therefore always required when discussing water content, elemental analysis that includes H and O and where large amounts of decomposition (or photosynthesis) occur.

2.1. Composting

As outlined in the introduction, composting the process of breaking down complex biological/ organic chemicals / compounds into simpler forms, ultimately resulting in the material being converted from organic to inorganic chemicals / 'mineral salts' e.g., ammonium or potassium nitrate. This is an entirely natural process, however, hot composting, which is principally achieved through manipulation of the oxygen level within the compost, e.g., by turning, can dramatically speed up the process reducing the duration from many months to a few weeks. Hot composting also results in quite different guilds of microbes compared with the natural decomposition process / cold composting. While there are interim differences in composts made via hot vs. cold processes in terms of the types of biochemicals produced by the decomposing organisms, over the longer term / at a system level the end results are the same as all the biological compounds are reduced to humus and inorganic minerals.

2.1.1. The process of composting

Microbes use the energy and nutrients stored in more complex organic chemicals to respire (in the technical sense) and thereby convert hydrocarbons to carbon dioxide and water by oxidation (hence the need for oxygen in composting). This means that significant quantities of the (elemental) carbon, oxygen, and hydrogen in the solid starting material are converted to gaseous forms, which are then lost to the atmosphere. In addition, some of the nitrogen in the starting material is also lost to the atmosphere, either as ammonia or di-nitrogen. The amounts of C, O, H and N that are lost are highly variable, and depends on many factors, key of which are the C:N ratio of the starting material, and the temperature × duration combination, i.e., a cold compost after a few months may be hardly changed from the starting material, while a hot compost could of lost half its carbon and nitrogen after a few weeks. The amount of N lost typically varies from 25 to 75% though in extreme cases 90% of the original N can be lost during composting.

Also, a significant proportion of the energy stored in the biochemicals of the starting material is released as heat - which is why hot compost gets hot. This also means that water in the starting material, and that created by respiration, is also lost from the heap due to evaporation. The net result of all of this is the very obvious reduction in weight (both wet and dry weight) and volume of the starting material compared with the finished compost, i.e., this reduction is entirely due to the 'loss' of C, O, H, N and water to the atmosphere.

A key issue with composting, especially hot composting, is ensuring the ratio of carbon to nitrogen is in the 'sweet spot' of about 25-30:1 (C:N). If there is too much nitrogen in the material, e.g., there is too much green leafy material (which also contains a lot of water) composting often fails and the result is anaerobic putrefaction. This is because the microbes need carbon to 'balance' the decomposition of nitrogen compounds and if there is insufficient then microbes use alternative biochemical pathways to deal with the nitrogenous compounds, often the result of which is undesirable compounds e.g., methane. If there is too much carbon in the material, e.g., woody or strawy material, then the microbes are unable to utilise the carbon so the material takes a very long time to decompose as the limited N is constantly recycled within the heap.

It is the high temperatures produced during hot composting that kill harmful microbes, such as human, animal and plant pathogens and kills or deactivates other undesirable materials such as weed seeds and agricultural pesticides. Heat is generally a very reliable and effective means of killing living things providing the correct temperature × duration combination is achieved. However, some pathogens and pesticides can survive the hot composting process, e.g., sclerotinia and Clopyralid, so it is not an infallible process.

2.1.2. The outcome of composting

The end result of the composting process i.e., compost, is a material that is relatively stable, as most of the easily decomposable material has decomposed, leaving only the 'tougher' materials such as cellulose and especially lignin (wood).

Assuming any leachate is returned to the heap, all the lithospheric nutrients, (phosphorus, potassium, magnesium, etc.,) that were in the starting material will be retained in the compost. Large amounts of the atmospheric nutrients (carbon, oxygen, hydrogen, and nitrogen) and water are lost, considerably reducing the bulk (weight and volume) and the water content of the starting material.

The material is generally low hazard, so few handling precautions are required. It can be stored easily and for considerable periods of time, both on impermeable surfaces and also directly on soil, though safeguards regarding leachate are required, and it is best protected from rain, unless the amount of rainfall is unlike to create any leachate.

Compost makes a good soil 'conditioner' i.e., it improves soil structure by increasing organic matter, and it can supply agronomically useful quantities of nitrogen and the lithospheric nutrients, though amounts vary widely and depend on the starting material and for N also the age of the compost (older compost will have less N all other aspects being equal).

In a correctly managed composting process there should be no non-CO_2 GHGs produced, i.e. methane, and nitrous oxide. Large amounts of CO_2 are produced but as the CO_2 will have been recently removed from the atmosphere by the plants that make up the compost, the carbon balance will be neutral (excluding fossil fuels / energy used to run the composting operation).

2.2. Fermentation

Fermentation is also a 'natural' process though not far less ubiquitous than decomposition. Examples are the fermentation that occurs in the stomachs (rumen) of ruminants such as cows. However, most human controlled fermentation is different to most natural fermentation processes as these have evolved to break down very 'tough' organic compounds such as cellulose, as an aid to digestion - which is chemically the same as composting / decomposition. Most human controlled fermentation aims to prevent any further decomposition post the fermentation stage. So, as noted in the introduction, fermentation is very different to decomposition.

2.2.1. The process of fermentation

Fermentation is fundamentally an anaerobic process, which means, compared with composting, that very different guilds of microbes which are able to function, or can only function, without oxygen are active and therefore responsible for the fermentation process. The microbes consume a small(ish) proportion of the complex organic compounds and energy in the starting material to produce a range of compounds such as organic acids, e.g., lactic acid, butyric acid and acetic acid (vinegar) and biologically 'active' compounds e.g., antibiotics e.g., streptomycin. These materials, coupled with the absence of oxygen, then stop the 'normal' decomposition process / activities of decomposing microorganisms, and they also eventually stop the activity of the fermenting microbes themselves, i.e., the process is self limiting. From this point onwards the material can not decompose any further without the re-introduction of oxygen i.e. air. The closest natural version of this process is the formation of peat, where the decomposition of plant remains is halted by immersion in water with a very low oxygen content plus the presence of various organic acids, e.g., humic acid.

As this process can only proceed in the absence of oxygen, it means that the fermenting material has to be isolated from the atmosphere. This means that none of the C, O, H and N or any other elements present in the starting material can escape, and only a small amount of energy is liberated (the containers do not increase in temperature by any appreciable amount unlike hot compost which should reach 65°C). However, while the total amount of C, O H, N and all the other elements in the starting material can not change, their form can and often does change, e.g., organic nitrogen forms, e.g., protein, is transformed into mineral forms of N such as ammonium. However, the total amount of material that is transformed is often quite small, i.e., the starting material, such as fruit skins, would still be clearly discernable, unlike finished compost where only woody starting material could possibly be identified.

The microorganisms that 'power' the fermentation process mostly use 'simple' compounds as their food source, such as sugars, starches and proteins. They generally do not use more complex compounds such as cellulose or lignin. This means that only materials with a relatively high C:N ratio, e.g., 10:1 such as food preparation 'waste' that also contain high levels of water, are suitable for fermentation. Therefore material that is ideal for composting, i.e., with a 25-30:1 C:N ratio, may well struggle to ferment, and high carbon materials will not ferment at all and visa versa, material suited to fermentation is not suited to composting.

A small amount water is produced by the fermentation microbes (at least compared with composting) and also some water is liberated from the structures (e.g., cells) of the fermenting material, which mixes with some of the soluble organic and inorganic compounds (e.g., potassium salts) to form a leachate. Leachate normally needs to be drained from the fermentation vessel, as fermentation will not proceed beneath the leachate layer. The leachate can contain significant levels of dissolved organic and inorganic compounds , which are both valuable and potentially hazardous, e.g., polluting waterways. The most common material to compare this with is the leachate from silage which is recognised as being sufficiently hazardous, that in countries where silage use is widespread, e.g., the European Union, there are detailed laws requiring its proper management which are strictly enforced.

While the microbes that drive the decomposition process in composting are ubiquitous in the environment and therefore there is no need for starter cultures, the microbes that drive fermentation are often much less common. Fermentation therefore normally requires the addition of starter cultures of microbes to ensure that the correct species are present in sufficient quantity to ensure fermentation occurs as desired.

2.2.2. The outcome of fermentation

The end product of fermentation, 'ferment' must have exactly the same elemental analysis as the starting material as the process is sealed, i.e. nothing can get in or out, and the chemical elements cannot be transformed one to the other. Any research that indicates a change in elemental analysis are either wrong or the difference is within the margin of error of the test. Also only a small proportion of the starting material will have been involved in the chemical reactions of fermentation, so most of the material will be unaltered. This is in clear contrast with composting where large amounts of C, O, H and N and water are lost. Therefore the ferment will have exactly the same weight as the starting material (when leachate is included), and only a limited reduction in volume, i.e., bulk is mostly unchanged.

As long as the ferment is kept sealed (i.e., oxygen excluded) it will remain unchanged for considerable periods of time - to some extent 'indefinitely', just the same as pickled food sealed in a jar or peat in a bog. However, once oxygen is admitted, decomposition, and more likely putrefaction (due to the higher C:N ratio) will commence quite rapidly. Ferment therefore has more particular storage requirements than compost.

While there is extensive information on the hazards associated with compost due to its long and widespread use, there is little information on the possible hazards, especially longer time system level hazards, associated with ferment.

The issue of non-CO_2 GHG production as part of the fermentation process and land spreading needs to be carefully considered, both theoretically and empirically. The limited literature indicates that methane is not produced in significant amounts while no information on nitrous oxide has been found. There may be variation in GHG production, if they are produced, between different production systems, e.g., starting material, inoculants, temperature etc.

3. Comparing composting vs. fermentation for food ‘waste’ processing

The above analysis provides a foundation by which to compare the pros and cons of composting and fermenting food ‘wastes’.

Issue	Fermentation	Composting
Starting material C:N ratio	Works best with higher C:N ratio materials, e.g., food ‘wastes’	Needs 25-30:1 C:N ratio so food ‘waste’ needs high carbon material added
Water content	Needs / copes with higher water contents e.g., > 30%	Too high a water content can prevent effective decomposition
Change in elemental analysis	No change	Large amounts of C, O, H and N, and water lost to atmosphere
Change in chemistry	Limited changes in chemistry, most material un-altered	Substantial changes to chemistry of material from more complex to simple organic molecules and inorganic chemicals
Inoculation	Needs inoculants for consistency	No inoculants needed
Equipment required	Needs airtight vessels, sizes can vary considerable, from 10 litre pails to truck sized containers, e.g., 10 tonnes. Upper limit probably determined by need for heat to escape via conduction. Vessels are generally low tech, e.g., HDPE (plastic) drums with the main requirement being ease of filling and emptying, an airtight seal and a leachate drain with a tap.	Food ‘waste’ is a potentially hazardous material and with its high nitrogen and water content mean that fully enclosed composting is likely to be essential. Closed vessel composters are mostly substantial, relatively complex and expensive.
Potential for inactivation pathogens and other unwanted materials	Good evidence of the inactivation of animal pathogens (Truesdale & Green, 2010), limited to no information on plant pathogens, weed seeds and pesticides	Substantial evidence of an ability to inactivate all pathogens, weed seeds, pesticides, with exceptions well documented / known.
Potential for nuicence, e.g., flies, unpleasant odours, during production	Fermentation requires closed containers so nuicence potential eliminated	Open composting would be very likely to create multiple nuisances so closed composting likely to be essential

Issue	Fermentation	Composting
Potential for environmental pollution during production	Fermentation requires closed containers so gaseous pollution risk is effectively zero during production. However, leachate is considered to have high pollution potential if not correctly managed	Correctly managed closed vessel composting should have low risk of gaseous pollutants (mainly ammonia). However, open processes or poorly controlled could release large amounts of ammonia and if putrefaction occurs other gasses such as methane and hydrogen sulphide could be produced.
Potential for environmental pollution during application	The potential for GHG release during the disposal of ferment needs to be verified and other possible causes of pollution (e.g., nutrients and gasses) researched.	Correctly made compost should have no potential for non-CO_2 GHG production. Ammonia may well continue to be released. Leachate must be properly managed.
Processing time	Fermentation is external temperature dependent, with a range of one to six weeks for processing	With the requirement for closed vessel, hot and highly controlled composting processing times will be very consistent, and depending on system, range from one to four weeks.
Storage	Ferment must be stored in airtight conditions until the point and time of use. The best storage option is likely to be the vessel in which it was produced	Compost can be stored in piles on the soil over the short term (e.g., week or two) prior to application or best on an impermeable base and protected from rain for longer term storage.

4. Comparing the final use of compost vs. ferment on land / soil

One of the key benefits of compost production is the ‘transformation’ of what has been widely considered a ‘waste’ to be disposed of, into a valuable product for providing nutrients (‘fertiliser’) for agriculture / horticulture and also as a means of improving soil quality / health, mainly through improvements to soil structure, due to increased organic matter levels. While compost is most commonly associated with organic agriculture, the benefits of compost apply to any farming system, especially those with soils with low organic matter.

There are however a considerable number of myths and misunderstandings surrounding compost and fertilisers, even within scientific circles, so it is vital to get truly expert and independent advice in this area.

While the benefits of compost, when appropriately used, for soil quality and farm productivity have been exhaustively demonstrated, theoretically, empirically, and practically for many millennia (e.g., see (King, 1911)) the **comparative** effects of using ferment compared with compost are nearly unknown. To clarify, there are a small number of studies looking at the use of ferment and ferment leachate as fertiliser, but most of these do not compare compost made from the same starting material as the ferment. Further, and more importantly, the whole topic of fertilisers and soil conditioners is one of a high level of misunderstanding, including and even particularly, among those in farming and the fertiliser industry, especially those selling biological fertilisers.

4.1. Understanding fertilisers and soil ‘fertility’ and dispelling some myths

As the value of ferment vs. compost for farmers and growers (end users) will be an important, if not critical, component of the success or failure of fermentation of food ‘wastes’ as an alternative to composting, it is essential to clarify some of the myths and misunderstanding surrounding fertilisers and soil management.

First, there is a lack of standardisation of terminology. The term soil fertility is used in many ways, some of them contradictory, that the term should be clarified. The two main uses refer to:

- The level of available crop nutrients within a soil, i.e. as measured by standard soil tests. This kind of fertility can be increased by the addition of fertilisers, e.g., urea, compost, phosphate. This is best called soil nutrient status or levels rather than fertility.
- The inherent ability of a soil to store and release plant available nutrients and the size of those stores. This can normally only be altered to a relatively small degree by changing the amount of organic matter in the soil. This is best referred to as a soil’s nutrient holding capacity.

The term fertiliser also has multiple meanings. The two key ones are:

- The common meaning of fertiliser are mineral salts (inorganic compounds) that a farmer purchases ‘in bags’ and applies to his fields to increase crop yields.
- The wider term, is any material, inorganic or organic / biological that is applied to land / soil with the intention of supplying plant nutrients. It is this meaning that is used in this report.

The term nutrient refers to the 16 chemical elements that are essential for plant growth (carbon, oxygen, hydrogen, nitrogen, potassium, calcium, phosphorus, magnesium, iron, chlorine, manganese, boron, zinc, copper, molybdenum, silicon).

Within the growing ‘biological fertiliser’ industry, the term ‘soil conditioner’ is often used. It use is mostly meaningless. The only material that can really be considered to be a soil conditioner is large amounts, e.g., more than 10 tonnnes.ha^{-1} of biological/organic material such as plant residues, animal manures, compost and ferment. Biological/organic materials that are applied at rates of less than one tonne.ha-1 are unlikely to have any long term effect on soil quality or ‘condition’.

4.1.1. Fertiliser myths

The primary fertiliser myth is that there is a direct relationship between a materials fertiliser ‘value’ and the response of a crop. For example, some fertiliser manufacturers make claims along the lines ‘if you use this fertiliser it will increase your crop yield by 15%’. This is utterly incorrect. The response of a crop to the addition of a fertiliser is primarily dependent on the level of nutrients already in the soil (or growing medium). All plants have a response curve for each nutrient, Figure 1.

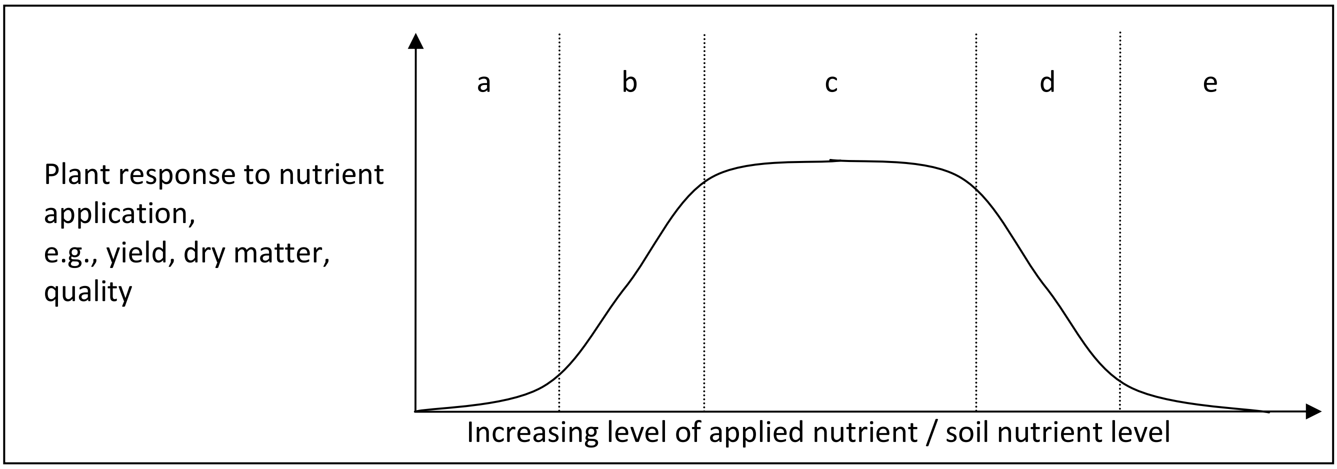

Figure 1. Generalised plant response curve to nutrient levels.

Where there are low levels of a particular nutrient the crop grows poorly (section a). As nutrient levels increase an inflection point is reached where the addition of an extra unit of nutrient creates a large growth response (section b). Then a second inflection point is reached where the curve levels off as the addition of more nutrients results in no further increase in growth (section c), due to the crop becoming satiated with that nutrient. Most nutrient response graphs only show this section of the curve, i.e., to the middle of section c. making a sigmoid shaped curve. However, if the level of nutrient continues to be increased, in most cases, and especially where the nutrients are applied in inorganic forms (minerals) a third inflection point is reached where the addition of more nutrient causes a decrease in plant growth, i.e., the levels of nutrient start to become harmful (section d). If nutrient levels continue to increase further a final inflection point is reached, after which the nutrient levels are toxic and will kill the plant (section e).

The shape of the curve for each nutrient varies, often considerably, especially between the major and micro nutrients. The shape also varies among different plant species, and for some crops, it can even vary considerably among cultivars. The curves are also effected by soil type, soil structure and climate, and there are complex interactions among the nutrients and soil pH, e.g., a change in the pH or levels of one nutrient can change the shape, often considerably, of other nutrient curves. The complexity of this system means that it is impossible to theoretically work out / calculate any given crop or cultivars response curve for a given soil / climate combination and/or their response to a fertiliser; these can only be established empirically.

The inarguable outcome of this is that the response of a crop to the addition of a fertiliser / nutrient could result in:

- A large increase in growth;
- No response at all;
- A large decrease in growth.

I.e., adding exactly the same fertiliser in different situation will result in completely different results. This means that the interpretation of empirical fertiliser trials requires considerable expertise, and the face value of the results, e.g., that adding the fertiliser created a considerable increase in growth, are specific to the conditions of that particular experiment and can not, and must not, be extrapolated to other conditions, e.g., other crops or cultivars, other soils, climates etc.

Perhaps the next most important myth surrounding fertilisers is that the form (e.g., mineral vs biological/organic) of the nutrient, is (1) unimportant (2) very important.

At a fundamental level, if there is insufficient levels of available nutrient in a soil, then plants / crops will show deficiency symptoms. If the 'missing' nutrient is applied, in any form that is, or can be easily converted by soil processes, into plant available forms, the deficiency will be resolved and healthy growth with resume. To put it simply 'an element is an element and rectifying its absence will solve the problem'. A number of people in the 'mainstream' fertiliser industry take this line, i.e., position (1). At the other end of the spectrum, especially those within the biological fertiliser industry, take position (2) whereby the form in which the nutrient is applied, has a major, if not a dominant impact on crop growth, i.e., that a particular formulation of a fertiliser (often containing many nutrients in multiple forms) will create a 'sum is considerably greater than the parts' effect, i.e., giving a much greater increase in crop growth compared with supplying the exact same quantities of nutrients (chemical elements) in another, particularly mineral (inorganic) form, and/or have significant advantages for soil health / quality. Both positions (1) and (2) are incorrect, or at best a significant simplification of a complicated situation. Reality lies somewhere in-between these two positions, i.e., all nutrients removed from land must be replaced in plant available forms otherwise soil quality and crop performance will decrease to low levels, and the form in which nutrients are applied (e.g., mineral vs organic) can have an effect on soil and crop responses, but these effects are mostly short lived, e.g., a few weeks to years.

Again to reiterate, it is essential to get truly expert and independent advice in this area, and when consulting the literature only secondary level sources (e.g., text books) of the highest quality should be used, e.g., (Brady & Weil, 2008).

4.1.2. Researching the effects of fertilisers and organic soil amendments

The above indicates that researching the effects of fertilisers and especially the addition of organic matter to soil is not straight forward. The scientific literature is littered with examples of broad / general conclusions unjustifiably drawn from often highly reduction experimental situations. To reliably and accurately determine the effect of any particular fertilisation and especially organic soil amendment regime requires care, expertise and time. Soil properties change very slowly so experiments need to run for several years, ideally a five or more, to generate really solid results. Some long term agricultural experiments have been running for more than a century, e.g., (Anon., 2006). Often the results from the first few years are the opposite of the long term trends. Pot experiments often bear no relationship to field results at all and should be treated with considerable scepticism.

Many experiments studying the effects of different types of organic soil amendments, such as compost vs 'surface mulching', or with mineral fertilisers, suffer from having multiple uncontrolled variables, e.g., the amount of the major nutrients in the mineral fertilisers and compost vary widely, or the amounts of compost used is much greater than surface mulch. Therefore to study the comparative effects of compost vs ferment, it is vital that exactly the same starting material is used to create the compost and ferment, using randomised replicates and that the randomisation and replication are carried through the whole experimental chain. It is also essential that soil processes are analysed as part of such experiments, based on solid theoretical understanding of soil, rather than solely relying on crop performance (e.g., yield) data.

Fortunately, the theoretical understanding of soil processes is now sufficiently developed to be able to undertake a broad system-level analysis of compost vs ferment treated soils and to use this to frame experimental hypothesises.

4.2. A system level comparison of the use of compost vs. ferment on land / soil

A considerable number of the fundamental differences between compost and ferment made from the same starting material can be worked out at a theoretical level. The key system level differences between compost and ferment include:

- The total amount of the atmospheric nutrients carbon, oxygen, hydrogen and nitrogen, and chemical energy based on the dry weight of the feedstock, will be higher in ferment than compost (as these are all lost to the atmosphere during composting);
- The concentration of lithospheric nutrients (phosphorus, potassium, magnesium, calcium, etc.,) in compost (dry weight equivalent) will be higher than ferment, but the total amount of lithospheric nutrients in compost and ferment made from the same amount of feedstock will be identical;
- The water content of ferment will be considerably higher than compost;
- The proportion of rapidly decomposable material, e.g., sugars, simple starches, proteins, will be considerably higher in ferment than compost and vice versa, the proportion of highly complex stable organic compounds, such as cellulose, lignin and humus, in compost will be much higher;
- Ferment is likely to have a considerably greater amount / proportion of biologically active chemicals such as organic acids, as it is these that are in a large part responsible / and the products of fermentation;
- The pH of compost is typically around 7, while ferment is typically around 4;
- The microbial species / communities of compost and ferment are likely to differ considerably, as will biologically active compounds, such as antibiotics. However, there will also be considerable variation within the two types of materials, e.g., high C:N open windrow compost is likely to be quite different to lower C:N closed vessel compost;
- The level to which unwanted / deleterious materials such as animal pathogens, plant pathogens, weed seeds, and agrichemical pesticides are degraded in the ferment is unclear;
- There is likely to be considerable variation in the attributes of both compost and ferment due to variations in starting material, variations in the production process, e.g., temperature, types of inoculant, duration, etc., therefore, this variation must be empirically measured and incorporated into lifecycle assessments / analysis.

Taking these general / system level differences between ferment and compost and applying the well established theoretical understanding of soil functions (from physics to ecology) some general estimations (i.e. a level of uncertainty is unavoidable) of the relative effects on soil and crops between the two can be made.

4.2.1. A theoretical analysis of the relative effects of ferment and compost on soil

To restate, the correct comparison between ferment and compost is on an equal amount of feedstock (starting material), not equal amounts of compost and ferment.

The most important difference between ferment and compost in regard to the effect on soil and crops is the extra C, O, H, N and energy and the amount of easily decomposable compounds in ferment. From the few studies (e.g., (Morgan, 1992)) that have compared compost with undecomposed plant residues, and an understanding of the functioning of the soil food web / soil ecology, it would be expected that ferment would have a greater benefit to soil ecology, as compost is close to becoming humus, which is the end product of soil ecology, i.e. it is not good food for most soil organisms, as the start of the soil food web is undecomposed biological material, mostly plant residues. Ferment would therefore provide more food (energy and nutrients) to soil ecology than compost and therefore allow larger increase and activity of soil organisms. However, this effect will be transitory and only last as long as there is material to decompose.

The extra nitrogen in ferment, providing that it is not rapidly lost to the atmosphere during land application and incorporation, would be expected to significantly increase crop yields, where soil N is limiting. The same N is also partly responsible for the greater activity of the soil food web, N also being the limiting nutrient for soil biology in temperate climates and agriculture.

The effects of the extra carbon are not so clear cut. While it will help to boost soil biology, the same as the extra O, H, N and energy, most of the additional C is expected to be part of easily decomposable compounds, and therefore quickly converted back to CO_2 and returned to the atmosphere. The effect on soil organic matter levels (soil 'carbon') over the longer term are unclear, as there are very few studies comparing the effect of fresh plant residues and the same material after composting on organic matter levels. At a theoretical level long term stable organic matter i.e. humus, is formed from complex organic compounds mainly lignin (woody material), therefore as neither fermentation or composting can create lignin, only avoid destroying it, there may be no difference. However, the organic acids produced in fermentation and low pH, may help break down such compounds faster than composting. This is probably a completely uncharted research issue.

The extra water content of ferment is immaterial from the soils perspective as the extra water is trivial compared to that added to the soil by rain or irrigation. However, the extra water is a significant issue in regards to its application to land due to the extra weight of the ferment.

The lower pH of ferment is also likely to be of little effect, also due to the very large differences in the amount of ferment applied compared with the soil, and also the soils inherent buffering ability and the low pH is due to organic acids which will themselves be decomposed, and therefore only have short residence times. This however needs to be confirmed empirically.

The presence of organic acids, different microbial communities, bioactive compounds etc., is likely to have only a short term effect, e.g., days to weeks, as, unless the amount of compost or ferment added to the soil is truly huge, e.g., 200 $tonne.ha^{-1}$ a year (dry weight), the amount of added material would at most only represent a few percent of the mass of soil and existing soil organic matter present in the plough layer (top 30 cm of soil where biological activity is highest) therefore the introduced material and microbes would be in the minority and most likely be over whelmed by the existing soil microbe communities. However, it is possible for introduced organisms to be sufficiently competitive to establish themselves and become dominant, at least for a while, just as a few of the plants introduced to New Zealand have become weeds, e.g., gorse and broom. However, while the long term effects are likely to be minimal, the short term effects could be significant, e.g., effects on plant or animal pathogens in the soil. These could be both positive and negative, i.e. there could be a positive short term benefit on crops due to beneficial compounds or microbes in ferment and there could also be negative effects for the same reason. This also and equally applies to composts and also to many biological amendments. However, the golden rule with predicting the behaviours of ecosystems is, the rules are broken all the time, i.e. the effects may well be different every time. As both ferments, composts and the soil they are applied to may well vary considerably, unpredictability may be the only predictable effect.

While the effect on soil is, and should be the primary concern in regard to the comparative effects of compost and ferment, it is also vital that wider environmental effects are considered and verified.

4.3. A system level comparison of the use of soil applied compost vs. ferment on the wider environment

The key effects the application of biological / organic materials to land can have are:

- Nutrient leaching to ground water and waterways (streams and rivers) with N and P being the nutrients of most concern;
- Nutrient loss to the atmosphere in harmful forms, principally N as ammonia (acidification / acid rain) and nitrous oxide which is a GHG;
- Other GHGs i.e. methane;
- Direct pollution of ground water and waterways with organic materials (e.g., though poor application practices).

Compost, being mostly stabilised biological material is considered low risk of environmental pollution, except for loss of ammonia if storage piles re-heat, e.g., after transport, and leachate from piles, both of which can be controlled. Ferment is more of an unknown due to its higher levels of water and nitrogen and easily decomposable content. Similar biological 'wastes' such as slurry which have high water contents and soluble nutrient loads, especially of nitrogenous compounds, need careful handling and application if pollution is to be avoided, and the best use made of the materials, This may also apply to ferment. While no GHGs or other harmful gasses can be released during production of ferment as the process is fully closed, the same is not true of application to land. This needs to be clarified.

4.4. A system level comparison of the use of compost vs. ferment for farming and growing production systems

4.4.1. Higher total nutrients especially Nitrogen

The key benefit for farmers and growers from the use of ferment rather than compost is the higher levels of nitrogen ferment will contain, and therefore which should boost crop yields where N is limiting or allow smaller amounts of synthetic nitrogen fertiliser to be used. The general boost to soil biology may also be beneficial, but the linkages between soil biology and crop performance are many, complex, poorly understood and sometimes capricious. If ferment created a greater increase in stable soil organic matter / humus compared with compost that would be of benefit as this would improve soil structure and nutrient holding capacity, though the difference may be small from an agronomic perspective.

4.4.2. Introduction of harmful microbes, weed seeds and agrichemicals

A key concern for producers would be the potential for introduction of harmful materials, such as animal and plant pathogens, viable weed seeds, and pesticides, especially residual herbicides which can be active at very low concentrations. Of the limited research on fermented food 'wastes' and particularly fermented animal manures including dog faces (Truesdale & Green, 2010), fermentation appears able to eliminate many harmful faecal and animal pathogen organisms. It could be expected that the same would also apply to plant pathogens. However, there are significant differences between plant and animal pathogens, e.g., their optimum active temperatures and the environments they are 'at home' in, e.g., animal intestines vs. soil. Also there are some harmful materials, e.g., some sclerotinia and the herbicide Clopyralid that can survive hot composting. Therefore extrapolating the effects of composting on harmful materials to fermentation and the effects of fermentation on animal pathogens to plant pathogens, is not possible and these need to be empirically verified over a wide range of conditions / situations. These should start on known problem pests and pesticides that could be expected to be problematic, e.g., Clopyralid and onion white rot (a sclerotinia).

As this reports is focused on a comparison of compost and ferment, it is assumed other issues of concern to farmers and growers, such as the presence of plastics and glass contaminants in compost will equally apply to ferment, so they are not addressed.

4.4.3. Introduction of beneficial microbes

Composts, compost teas, vermicompost and their by products have all been shown to have beneficial and rapid effects on plant grown and control of plant pathogens beyond that expected from their nutrient analysis. Also negative results have also be found, e.g., addition of biological materials has reduced crop growth. This is to be expected as such materials are the products of complex webs of microbes, many of which are the original sources for materials such as antibiotics, and the organisms themselves may be biological control agents. However, the nature of such biological / organic materials is to be highly variable, and the natural system, such as soil and plant leaves, to which they are applied are also very variable, therefore one of the more consistent results of tests of growth enhancement and biological control is the inconsistency of results. Therefore while there are experiments that show a beneficial effect of adding ferment, these need to be replicated across a wide range of conditions, e.g., soil, weather, crops, pests, etc., to determine the reliability of these effects, before more general claims can be made.

4.4.4. Possible nutrient leaching issues

If ferment contains high levels of inorganic nutrients (mineral salts) and soluble organic compounds, there is potential for the material to pollute ground water and waterways. This is a well recognised issue with slurry which shares a number of properties with ferment, therefore application may well need to be restricted to times when there is no soil drainage, and not applied close to, e.g., 5-10 meters, surface water channels. With the hotter dryer climate in NZ this is not considered likely to be a significant hindrance to the use of ferment.

4.4.5. Land application issues

As fermenting results in little decrease in bulk and no change in weight, the practicalities of land application may be significant. For example the bulky nature of compost can be a deterrent to its use by farmers and growers as transport costs are often a considerable part of the total cost, and field application requires multiple passes across fields to deliver sufficient material. While the total amount of nitrogen in ferment will be higher than compost from the same starting material, the concentration of nutrients will be lower on a wet basis (i.e. as transported and applied) due to the higher water content of ferment and the higher amounts of C O and H. Therefore a greater, possibly much greater, weight / volume of ferment will need to be land spread to deliver the same amount of N and lithospheric nutrients as compost. This will have cost and other implications. A range of mechanical de-watering technologies are used to reduce the water content of slurry where it needs to be transported more than a short distance. Such dewatering technology may be of considerable benefit for de-bulking ferment prior to transport. However, the liquid fraction may contain considerable amounts of in-organic nutrients and dissolved organic compounds which are also both a valuable resource and potentially make the liquid hazardous.

Ferment is also considered likely to have different handling characteristics to compost, and therefore compost application machinery may not be able to spread it. Most mineral fertiliser applicators cannot handle / apply compost and so are expected to be completely unable to handle ferment. Ferment is expected to have a consistency somewhere between cattle slurry and farm yard manure (FYM). It is considered that slurry applicators may be best suited to ferment application because ferment is probably too liquid for most FYM spreaders to handle, and more importantly, if there is a significant amount of volatile nitrogen compounds, i.e. ammonia, then FYM spreaders will not be suitable due to their violent discharge systems, i.e. smashing the FYM up and flinging it out across the field Figure 2 which can result in the release of large quantities of ammonia to the atmosphere.

De-watering ferment may mean that existing FYM spreaders are able to cope with ferment, but the issue of loss of ammonia and other volatile compounds still needs to be addressed.

Figure 2. Rear discharge FYM spreader.

However there is a lot of variation among different slurry application methods and considerable work is being undertaken in northern EU countries to determine the best application approaches. This work shows that surface application (trailing shoe) or soil 'injection' are the best approaches to minimise odours and maximise the retention of volatile nutrients Figure 3.

Figure 3. Equipment for injecting slurry into soil and pasture.

Trailing shoe and injection slurry applicators are substantial machines using pressure vessels and are therefore the most expensive means of applying biological / organic fertilisers. Also carrying the considerable amounts of ferment in tanks across fields can cause significant compaction. Umbilical spreading systems may therefore need to be used (Figure 4).

Figure 4. Umbilical system spreader

5. Fermentation and Bokashi

Bokashi is one of a range of Effective Microorganisms (EM) products. EM is a technology developed by Prof. Teruo Higa where a diverse range of microbes extracted from natural decomposition systems such as compost and forest leaf litter layers, are combined into a single water based product (EM-1). The main types of microbes in EM are:

- Lactic acid bacteria;
- Photosynthetic bacteria;
- Yeasts;
- Actinomycetes;
- Fermenting Fungi.

EM has been widely promoted globally as having a multitude of beneficial effects, for example increasing yields, improving plant and animal health. It has been financially supported by, and extensively used in, Kyusei Nature Farming, as a benevolent cause. Its global distribution, promotion and availability as a beneficial tool rather than a purely commercial product, add considerably to its attraction.

However, some of the claims made for EM are not supported within the peer reviewed scientific literature, though some claims have been substantiated. Care is therefore required when analysing claims made for EM and its derivative products such as Bokashi. EM is probably best therefore analysed on a case by case basis to establish its efficacy.

Bokashi is produced by adding EM-1 to a high carbon substrate, originally rice bran, but sawdust is now commonly used, often along with some additional nutrient sources, such as molasses, and then fermenting it. This provides a stable, easy to handle material. This can be done under quite low-tech conditions, e.g., by farmers in barns, but for a more consistent material commercially produced Bokashi is likely to be best.

As described in section 2.2.1 most fermentation processes require inoculation with suitable microbes to ensure fermentation occurs as required. Most fermentation processes take often relatively homogeneous aseptic starting material while food ‘waste’ by its nature is heterogeneous and will be pre-colonised by a diverse range of microbes, including many decomposers. Inoculating such material with suitable fermentation microbes is therefore a not an insignificant task, especially as one species on its own may not be enough. One of the interesting aspects of EM is the general stability of the cultures and their consistency, even though where samples of EM are taken at point of use and analysed for the presence of the microbes that went into EM, not all of the types of microbes are present (Yamada & Xu, 2000). Therefore the reports from the literature demonstrating the ability of EM to consistently ferment materials, such as food ‘wastes’, is both impressive and consistent with general experience with EM. Also there are a few reports looking at fermenting food ‘waste’ using the naturally occurring microbes or with single species cultures, none of which fermented as well as when Bokashi was used (Yamada & Xu, 2000). This is also consistent with theory.

Bokashi therefore appears to be very well suited as the starter culture for fermenting food preparation ‘waste’ and it ready availability and comparatively low cost means there is little value in considering other starter cultures, at least initially or if problems are found.

6. Next steps - further research

As the management of food preparation 'wastes' by fermentation and then land application is a relatively new phenomenon and there is little peer reviewed literature on the subject, there is a clear need for research. The topics are almost endless, so a clear and organised approach will be required if resources are to be used wisely.

The issue of GHG and other undesirable gasses produced during fermentation and their release during application clearly needs to be addressed, as this may well be a make-or-break issue. This can be done at a small scale, i.e., 'bucket' size and with hand manual application to soil. Engagement of a GHG expert to consider the issue from a theoretical / chemical level would be wise.

Deeper theoretical consideration and empirical testing of the potential for environmental pollution of all types, especially from land application, needs to be undertaken.

The ability of fermentation to neutralise harmful materials, such as herbicides and especially plant pathogens will be essential. It is recognised that there are unlikely to be large amounts of pesticides in food preparations wastes, but if fermentation is expanded to include other high nitrogen green 'wastes' e.g., lawn clippings then this will be an issue of concern to growers and farmers. This can also be done using small scale experiments.

Practical issues of 'waste' collection, treatment, storage and transportation need to be considered. Management of the 'people' aspect, especially in a domestic setting may be critical, especially if Bokashi needs to be applied in the home to ensure timely inoculation, rather than after collection.

Long term trials on comparing the effects of ferment, compost and ideally anaerobic digestate on soil and crop production are required. Short term trials looking for harmful effects on crops may be useful - which may also show beneficial effects.

Devising practical and reliable land application methods is also considered to be essential.

7. Conclusions

Fermenting food preparation 'wastes', such as domestic kitchen scraps, as an alternative to composting has a considerable number of benefits. The key benefits are:

- A simpler, potentially cheaper, and shorter processing cycle post-collection;
- The return of greater amounts of carbon, oxygen, hydrogen, nitrogen and energy to land compared with compost, with potentially useful improvements in soil quality and/or crop growth.

However, due to the limited peer-reviewed scientific literature on fermenting food 'wastes' especially using Bokashi fermentation and the almost non-existent literature on application of large amounts of fermented biological materials to land, there is a clear need for further research. Also there may well be issues with the greater land application rates of ferment required compared with compost, and the effects of fermentation on materials such as weed seeds, plant pathogens and pesticides needs to be established.

Therefore, with an increasing understanding of the utter importance of creating closed nutrient cycles, and returning all biological materials back to the soils from which they originated, fermentation could be a valuable addition to the current options of composting and anaerobic digestion. It is recommended that fermentation of food preparation 'wastes' should be actively pursued and compared with the alternatives of composting and anaerobic digestion using lifecycle assessments.

8. References

Anon. (2006). *Rothamsted research: Guide to the classical and other long-term experiments, datasets and sample archive*. Harpenden, UK: Laws Agricultural Trust Co. Ltd

Brady, N. C. & Weil, R. R. (2008). *The nature and properties of soil* (14th ed.). Upper Saddle River, New Jersey: Pearson Education Inc. http://wps.prenhall.com/chet_brady_natureandp_14/

King, F. H. (1911). *Farmers of forty centuries, or permanent agriculture in China, Korea, and Japan*: Mrs. F.H. King

Morgan, T. (1992). *The effect of organic mulches on soil bio-physical and chemical properties under an apple orchard.* Lincoln University, Christchurch. http://www.merfield.com/sol-morgan/

Truesdale, K. & Green, L. (2010). *An efficient cost effective alternative organic waste treatment pilot study supporting sustainable farming practices and soil restoration*. Retrieved February, 2012, http://www.bokashicycle.com/canada/Armstrong_Pilot_Sep012010_No_AS09012010_Summary%20Report_web.htm

Yamada, K. & Xu, H.-L. (2000). Properties and applications of an organic fertilizer inoculated with effective microorganisms. *Journal of Crop Production, 3*(1), 255-268.