1.3 million tonnes of industrial and municipal organic waste vermicomposted in New Zealand

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Industrial vermicomposting integrated into farm management for cost-efficient, regional organic waste management and sequestering carbon in soils

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Abstract

Vermicomposting is generally considered to be a small-scale activity, of benefit only in smallholdings or gardens. This paper will show that industrial-scale vermicomposting is not only possible but also offers significant benefits to a wide range of stakeholders.

This paper will describe how industrial vermicomposting of approximately 200,000 t/a of organic waste is currently being carried out in New Zealand. Studies have demonstrated that vermicomposting of industrial organic waste such as pulp mill solids, paunch, food processing waste, and biosolids (sewage sludge) can be vermicomposted successfully.

Vermicomposting has the potential to divert more than 80% of solid organic waste including paper waste and biosolids from landfills. Only 20 to 25% of the organic waste remains as vermicast (vermicompost), which has multiple environmental benefits over compost and digestate from anaerobic digestion. Some benefits are mitigation of nitrogen leaching, improving utilisation of mineral fertilisers and increasing soil humus levels with a high potential for carbon sequestration in agriculture.

By integrating vermicomposting into farm management, capital expenditure, operational costs and environmental effects outperform thermal composting and anaerobic digestion.

The potential of using vermicomposting at an industrial scale and for a much broader range of organic waste is often rejected as an alternative technology for organic waste recycling.

Understanding the barriers to implementing vermicomposting will help decision-makers to evaluate the best technology for their organic waste management.

Introduction

Vermicomposting of organic waste has seen an enormous uptake globally [1] and is rapidly growing in New Zealand [2] over the last two decades (Fig. 1). Even though thousands of research papers and books have been published on vermicomposting, the vermicomposting technology is not recognised or even considered viable for processing industrial and municipal organic waste streams commercially. Vermicomposting is still often believed to be a niche technology only capable of processing small volumes of organic waste. This is despite there being several industrial vermicomposting sites in New Zealand with processing capacities of organic waste between 100,000 and 1500,000 t/a that have been operating for over a decade.

The organic waste is converted into earthworm castings during vermicomposting, commonly known as vermicompost or vermicast. Depending on the vermicomposting process and the types of organic waste used as inputs, the product will vary in its characteristics. Vermicompost and vermicast can be classified as soil conditioners, fertilisers, plant growth promoters, and others, depending on product quality and national regulations or standards. One key factor for classifying vermicompost and vermicast is the nutrient content. Vermicompost or vermicast with high nitrogen or phosphate content will generally be classed as fertiliser. High carbon content paired with low nutrient content is characteristic of a vermicompost or vermicast as a soil conditioner with higher carbon sequestration potential in soils. In New Zealand [3] and Australia [4] the national standards for composts differentiate between vermicast, where more than 90% of the product is earthworm casting and vermicompost, which can contain organic materials unprocessed by earthworms.

In New Zealand, industrial-scale vermicomposting has grown steadily over the past 14 years, with over one million tonnes vermicomposted in total. Starting in 2008 with 5,000 t/a of organic waste vermicomposted, vermicomposting has been receiving a tremendous increase in demand for processing organic waste in 2021 across the waste-producing sectors and exceeding 200,000 t/a of organic waste for vermicomposting in 2022

(Fig. 1). New Resource Consents are submitted or in preparation to triple the capacity across New Zealand by the end of 2023.

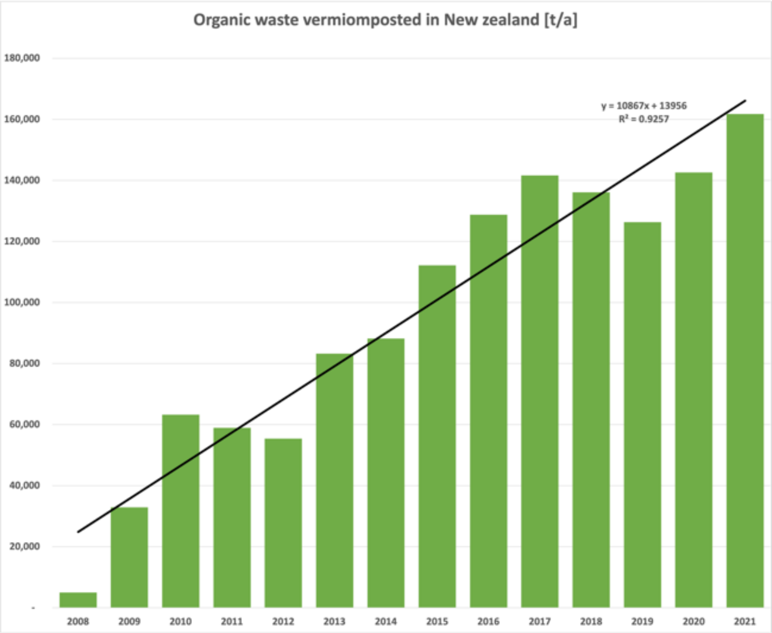

Fig. 1 Annual organic waste vermicomposted in New Zealand from 2008 until 2021

Vermicomposting technology

In this paper, the term vermicomposting, commonly known as worm farming, is used as the technical term for processing organic wastes into earthworm casting. While vermiculture is more frequently understood for businesses producing special earthworm species for bait, feedstock for animals, and fish farming, or providing compost worms for domestic worm farms. In vermiculture, only limited types of organic waste are suitable for breeding earthworms often peat and grain are used as bedding and feedstock.

Vermifiltration is a technology for filtrating effluent where compost worms maintain an organic filter medium such as sawdust to keep it permeable for the effluent. Vermifiltration generally does not utilise any solid organic waste.

Integration of vermicomposting into farm management

Of the currently produced 45,000 t of vermicast produced in New Zealand, farmers, market fruit growers, and orchard managers are the main customers purchasing the bulk of the vermicast. Transport of organic waste to the vermicomposting site and transport of vermicast to the end-user are costly and requires regional vermicomposting sites to reduce transportation. The New Zealand-wide growing demand for a regional vermicomposting service led to the integrated vermicomposting model. Herein farmers became critical stakeholders and are now a crucial element in the regional vermicomposting module.

Over the past decade, the new vermicomposting system has become highly flexible to regional organic waste inputs: it is best described as windrow technologies [5] improved in recent years from a basic windrow technology described [6] by optimising the following key elements (Fig. 2): (i) the central organic waste reception and processing site and (ii) multiple decentralised vermicomposting sites fully integrated into crop rotation in farm management and located on farmland within proximity of the reception and processing site. By integrating vermicomposting sites into crop rotation, the demand for permanent ‘processing’ land becomes obsolete as hosting a vermicomposting site has been shown to improve soil fertility and productivity. Technically the footprint of a vermicomposting operation is reduced to the organic waste reception and processing site. By reducing transportation costs, an increasing number of farmers are participating in the vermicomposting model, leading to a waiting list for future vermicomposting sites. This concept makes vermicomposting a fully scalable technology with processing capacities of organic waste varying from 5,000 to 150,000 t/a per site producing approximately 2,000 to 35,000 t vermicast.

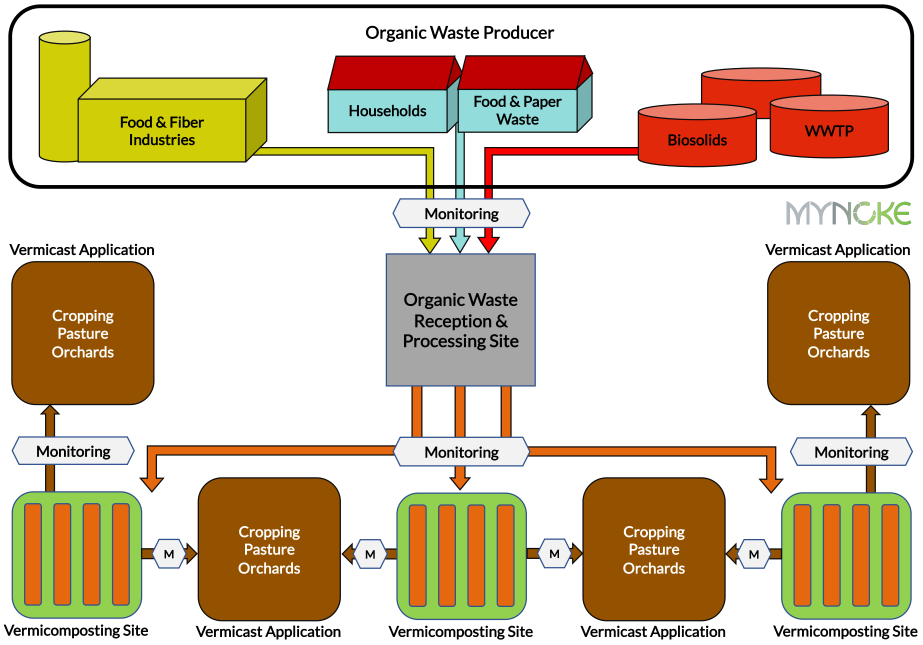

Fig. 2 Diagram of integrated vermicomposting into farm management with centralised organic waste reception and processing site and multiple vermicomposting sites on farmland

Organic waste inputs and feedstock preparation

Organic waste inputs for vermicomposting, either un-mixed or a mix of various organic wastes, are hereafter described as feedstock. Evaluating if any feedstock is suitable for commercial vermicomposting on farmland requires the feedstock to pass all the following three criteria:

1. An earthworm population can be established, and earthworms reproduce in the feedstock. Earthworms are converting all feedstock into vermicast in an adequate time. Note: In an open-air vermicomposting operation the feedstock must be highly suitable for earthworms. In laboratory trials, earthworms are often forced to feed on certain feedstocks. Publications on vermicomposting of certain types of organic waste should be reviewed carefully.
2. The vermicomposting process must meet cultural, social, and environmental standards regarding land, groundwater, and air discharge. In New Zealand, these are regulated in the Resource Management Act and require consultation and approval by the local Maori community (iwi) to comply with their cultural, environmental and social rules.
3. The vermicast or vermicompost must meet national [7] and when exported, international, standards for a safe application to land or in potting mixes. This includes reducing pathogens and, where required, the production of a seed-free vermicast [8].

Error! Not a valid bookmark self-reference. gives an overview of the organic waste (feedstock) sources successfully vermicomposted in New Zealand in the period from 2008 to 2021. Feedstock is grouped in classes of carbon-rich and nitrogen-rich organic waste. Non-organic feedstock, for example, are wood ash, lime, and gypsum. Nitrogen-rich organic waste requires blending with a carbon-rich resource such as pulp mill solids, paper waste, cardboard and others. Feedstock can generally be substituted within each group with certain limitations to planning feedstock requirements and other operational parameters for new sites or expansion of existing sites. Combinations of feedstocks must be reviewed and tested to ensure combinations are safe and meet all the above criteria. Limitations are, for example, combining two feedstocks with the same elevated metal (e.g. zinc or copper). Other limitations can be related to the pH or water content of the feedstocks.

Adding more carbon-rich waste helps to mitigate nitrogen losses mainly through leaching, volatilisation, and potentially some nitrous-oxide emission. Hemicellulose fibres function as an absorbent for nitrogen-rich moisture in the organic waste as well as a carbon source for immobilisation of nitrogen. During the vermicomposting process, earthworms take up the nitrogen of the feedstock and convert it into protein-rich worm tissue with a high market value as a sustainable protein source for animal feedstock. Nitrogen is effectively exported from the organic waste stream, and the remaining nitrogen is predominantly organically bound in stable soil humus-like vermicast. Compared to thermal composting and anaerobic digestion, vermicomposting is the only process where nitrogen is removed from the process without further technical nitrogen-removal processes. Vermicomposting is a sink for nitrogen from organic waste.

Other inputs such as wood ash and lime are nutrient-neutral but act as pH buffers and a ‘grinding’ medium for earthworms’ digestive systems. New organic waste sources such as animal skins from the abattoir industry have been successfully tested under commercial vermicomposting operations. A patent is pending, and some of the estimated 800,000 t of organic waste from this primary industry sector will be vermicomposted in the near future.

Table 1 Classes and volumes of organic waste received at industrial vermicomposting operations in New Zealand from 2008 until 2022

Class	**Type of organic waste / feedstock**	**Volumes**	**References**
Carbon-rich	• Pulp mill solids • Paper waste (including food packaging) • Cardboard (including food packaging) • Food wastes including bread, pastries, dairy • Sediments from wood processing plants, bark fines, rejected fibre, knots, sawdust and fines • Crop residues	870,492 t	[9] [10] [11]
Nitrogen-rich	• Municipal biosolids (sewage sludge) • Waste Activated Sludge (WAS) (e.g. from milk plants and abattoirs) • Dissolved Air Flotation (DAF) sludge (e.g. from milk plants and abattoirs) • Farm manure and effluent • Green wastes (after wooden material has been removed) • Paunch, wool, hair • Fruit processing waste such as onion, fruit packhouse wastes etc. • Lake weeds • Food wastes such as vegetables and fruits including meat, dairy, and fish • Grease trappings	425,400 t	[12] [5]
Other inputs	• Wood ash • Sediments from rivers, lakes, and stormwater ponds • Lime (e.g. from pulp and paper mills)	40,500 t	[13 - 16]
Total volume		**1,336,393 t**	

Vermicomposting versus thermal composting and anaerobic digestion

The two most common organic waste processing technologies are thermal composting and anaerobic digestion, while vermicomposting is often not considered a viable option. The review of the feasibility of organic waste technology depends on knowledge of latest information and assumptions about the sector's future development.

Key benefits of vermicomposting compared to commercial thermal composting and anaerobic digestions are described in Table 2. Rural green waste windrow composting is not included as this technology is not considered suitable for food waste and industrial organic waste such as waste activated sludge.

When integrated into crop rotation and applied to farmland, vermicompost has the lowest capital expenditure and operational costs. Commercial thermal composting and anaerobic digestion plants are planned and constructed on estimated maximal volume intake. The efficiency of these two technologies relies heavily on operating at optimum or maximum capacity. We find that organic waste volumes are often not measured accurately in industries or municipalities before making such an important decision. Predictions are usually made on small numbers of samples over a limited period. In addition, organic waste volumes may vary seasonally, for example, in regions with tourism or food processing industries. Fluctuating unknown organic waste volumes bears an enormous economic risk when planning the capacity for commercial composting plants or anaerobic digesters. Oversized thermal composting plants are not uncommon, leaving communities with high operational costs. The life span of these plants usually exceeds 20 years. Uncertainty of energy prices either for operating the composting plant or as revenue for an anaerobic digester needs to be understood and predictable for calculating the best scenarios for the organic waste producer.

A large scale modern thermal composting or digestion plant requires at least 70,000 tonnes of clean organic waste per year over its lifetime. As with all large investment projects, it can potentially create lock-in effects that may lead to plant overcapacity and hamper efforts to reduce organic waste production.

The most common organic waste processing technologies are thermal composting and anaerobic digestion, while vermicomposting is often not considered a viable option. Reviewing the feasibilities of organic waste stream technologies depends on access to vital information and assumptions about the sector's future development.

Table 2 Comparison of vermicomposting versus commercial thermal composting and anaerobic digestion

Criteria	Vermicomposting	Commercial thermal composting	Anaerobic digestion
Capital expenditure	Very low	High	High
Operational costs	Low	High	High
Scalability	Highly scalable	Limited	Not scalable
Volume reduction	Up to 80%	30 to 40%	10% (potentially volume increase)
Nitrogen export during processing	High, immobilised in earthworm tissue / protein	Very low; nitrogen is concentrated (risk for leaching)	Very low; high risk of N volatilisation and leaching from liquid digestate
End-product	Vermicast, very stable humus fraction, soil conditioner	Compost, bulky, partly unprocessed material	Slurry high storage and land application costs
Process suitability for paper waste	Yes	Limited	No
CO_2 sequestration	Stable soil humus, vermicast increases root growth	Potentially	Indifferent finding

Finally, the market for end products such as compost and digestate needs to be evaluated. With a volume reduction of up to 80%, vermicomposting offers a more reliable demand for the vermicast. In many regions, the land application of compost and more critical digestate is limited due to nitrogen loading and restrictions for land application. This often leads to unplanned and costly incineration of compost or additional treatment of digestate such as solid separation, thermal composting of solids, treatment of liquids in municipal wastewater treatment plants, or (as seen in North Germany) resulting in long transport distances of the digestate to suitable farmland for disposal.

In comparison, earthworms remove nitrogen from the organic waste during vermicomposting, leaving a stable humus product with less than 1% nitrogen concentrations. Low total nitrogen concentration classifies the vermicast as a soil conditioner, not as a nitrogen fertiliser. Vermicast with low nitrogen content can mitigate nitrogen losses from intensive farmland and is significantly safer when applied in nutrient-sensitive areas such as drinking water catchments.

Carbon sequestration

Carbon sequestration during vermicomposting

Under certain conditions, vermicomposting can sequester carbon by generating stable humus, described by Zhang et al. [17] as an earthworm-mediated ‘carbon trap’ in soil when provided with fresh organic matter. The same principle would occur in windrows during vermicomposting, where earthworms will contribute to net C sequestration by generating stable castings.

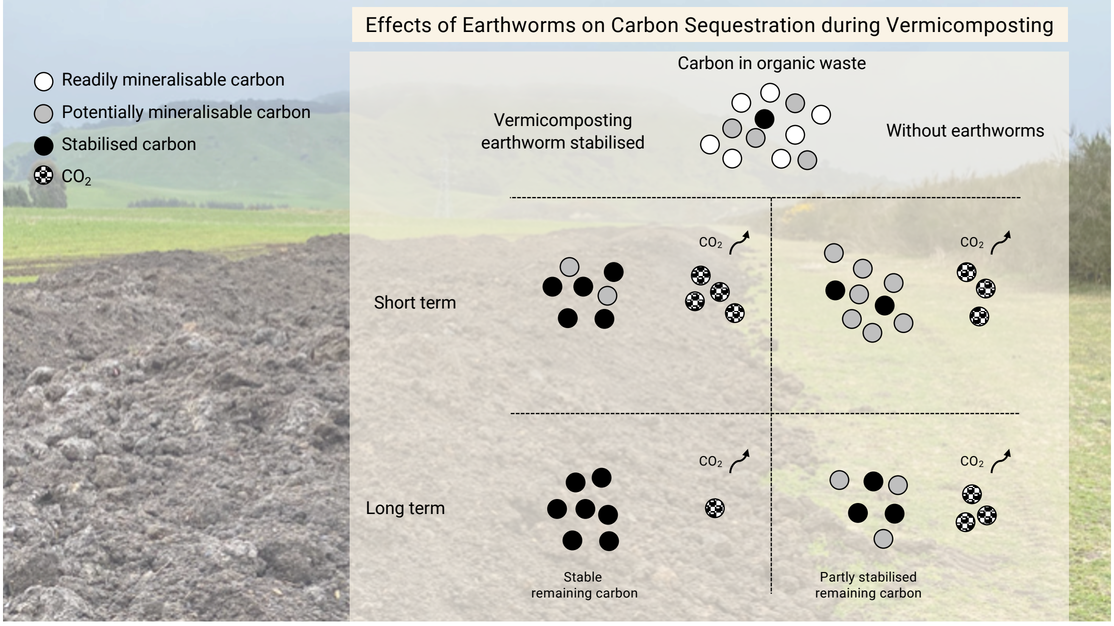

Fig. 3 Timescale-dependent contrasting effects of earthworms on C-sequestration during vermicomposting in windrows generating stable vermicast for land application; modified from [17]

Carbon sequestration with vermicast application

Several authors have found that vermicast application increases yields and root growth [18, 19, 20] of various crops and plants. While the increased yield of crops increases carbon uptake but usually does not contribute to sequestration, the increase in root dry matter production would result in a higher soil carbon content equilibrium and thus would be accounted for as carbon sequestration.

In addition to the carbon sequestration from crops, the regular application of vermicast could lead to a higher carbon pool in the soil. Long term trials are required to validate the effect of vermicast application on soil carbon and other soil parameters.

Benefits of vermicomposting

Organic waste producer's benefits

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Benefits to farmland, orchards, and vineyards

Vermicast has been proven to increase yields [21], and product qualities, mitigate nutrient losses [22], runoff, soil erosion, and improve soil humus and carbon levels. Mineral fertiliser application can either be reduced, or the fertiliser is used more efficiently. GHG emissions from the application of mineral fertiliser are reduced, and the described carbon sequestrant can reduce the overall carbon footprint of the business.

Despite the multiple benefits of applying vermicast onto land, crops, orchards, vines, and nurseries, long-distance transportation of bulk vermicast can make it less economical for farmers and growers. A regional vermicomposting site in proximity will reduce vermicast transportation costs to end-users and avoid unnecessary GHG emissions from transport.

Higher soil humus levels and increased root depth improve the storage and the access of plant available water for crops. Where climate change is causing more extended periods without rainfall, the natural water-holding capacity of soils will reduce water stress to crops and irrigation costs. Where access to irrigation water is limited, access to vermicast can keep farming viable.

National and global benefits

Vermicomposting of organic wastes can contribute to the national goal of reducing GHG emissions. Especially for countries with a robust agricultural sector and with associated food processing industries. Agriculture is recognised as one of the most significant contributors to GHG emissions. With vermicomposting, a low cost, scalable technology for organic waste processing is available which can be integrated into land management. At the same time, organic waste, including paper waste, is diverted from landfills meeting national zero waste targets, extending the demand for building new landfill capacity, and mitigating GHG emissions from landfills. By removing organic waste from landfills, the main contributor of leachate at landfills is removed, and so are the costs for leachate treatment.

Barriers and outlook

When comparing technologies in the light of their economic, environmental, social, and cultural effects, it is also important to understand barriers and potential underlying conflicts for the successful establishment of industrial vermicomposting.

Unbiased evaluation of new strategies for organic waste requires the latest knowledge of the available technologies and the long-term necessary market and capacity. Organic waste producers regularly seek advice from professional consultants who might not be familiar with industrial vermicomposting. Suppose the waste producer chooses the same professional consultant to supervise the building and its commercialising (first years of operating the plant). It can create a conflict of interest as the consultants' fees are linked to the project's total costs: recommending a low price and quick solution versus a long-term lucrative service agreement is a clear conflict of interest and sets up a client-consultant-dilemma.

The barrier to establishing new vermicomposting sites or including additional organic waste streams in existing areas is often a lack of information on the economic and technical facts on industrial-scale vermicomposting. While thermal composting and anaerobic digestion are reasonably well-understood technologies by regulators and consultants, vermicomposting technology at an industrial scale is broadly unknown. Applying for resource consent for vermicomposting can be challenging. In some countries, organic waste processing is strongly regulated and using a resource consent can become highly difficult and even impossible. Vermicomposting is mainly seen as a variation of thermal composting. Regulators tend to apply the same environmental effects of thermal composting, such as generating high concentrated leachate, odour emissions, or the risk of self-ignition of unmatured compost to vermicomposting. Conditions are then copied from thermal composting consents which are either unnecessary and thus expensive or not practical.

Industrial vermicomposting is either not taught at universities or tertiary education facilities or is not up to date. The next generation of environmental consultants leaving colleges and universities will be less competent. Where organic waste providers must meet specific GHG-reduction targets, GHG emissions are unavailable for all vermicomposting organic waste streams. Reliable data for carbon sequestration from vermicast application to land are needed to compare competing technologies accurately. With the production of large, consistent volumes of vermicast, more farmers, market fruit gardeners, growers, and orchard managers are already replacing mineral fertilisers with vermicast creating instant positive results on yields and soil parameters but without reliable data to model long term effects. Regional field studies are required to maximise the beneficial economic and environmental effects, and results can then be communicated to the agricultural and horticultural sectors.

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