# VERMICOMPOSTING AND LAND UTILISATION OF BIOSOLIDS BLENDED WITH PULPMILL SOLIDS

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## ABSTRACT

New Zealand's central north island economy is dominated by intensive dairy farming and forestry operations. The soils are young, porous, shallow, and are lacking of soil humus. To mitigate nutrient losses, farmers are increasingly opting to replace mineral fertilisers with humus rich organic fertilisers. The region is producing approximately 50,000 tonnes of biosolids and 200,000 tonnes of carbon rich fibrous by-products from pulp and paper mills per year. Until recently, these had been sent to landfills with dramatic negative effects on New Zealand greenhouse gas emission balance. From 2007 these waste streams have been blended and processed in industrial scale vermicomposting operations established within the region. In 2013, greater than 100,000 tonnes of organic wastes have been vermicomposted including 35,196 tonnes of municipal biosolids and 68,746 tonnes of pulp mill solids. From this approximately 30,000 tonnes of vermicast has been produced and has been land applied. The local vermicomposting industry is currently establishing its third industrial vermicomposting operation in the North Island to process 150,000 tonnes per year and positions New Zealand as the global leader in vermicomposting technologies.

## KEYWORDS

**Vermicomposting, biosolids, sewage sludge, pulp mill solids, vermicast, land utilisation, industrial scale, economic viable.**

## 1 INTRODUCTION

In New Zealand 5 pulp and paper mills plus 2 recycled paper mills are producing 203,000 tonnes of organic wastes (McGrouther et al., 2013). The main organic by-products of the pulp and paper mills are primary pulp mill solids separated at the first stage of the wastewater treatment plant usually through a clarifier. Applying polymers and screening of the solids fractions separate from the effluent and with further technical dewatering results in a product that has an approximate 20 to 25% solids composition. In some alternative processes, clarifier sediments are pumped into dewatering ponds where the sludge is dewatering slowly by draining of excess water back into the wastewater treatment plant. This type of sludge contains some 15 to 20% solids content. These primary solids are generally high in carbon and low in plant valuable nutrients. If primary solids are applied to farmland, nitrogen and phosphate fertiliser application have to be increased to avoid nutrient immobilisation (Vasconcelos & Cabral, 1993). Land application to New Zealand forest has been trialled at small scale with little success (Garrett & Wang, 2006) thought the relatively young volcanic soils as are typical in New Zealand are low in organic matter and would benefit from organic soil conditioners. There are instances of small-scale direct application of pulp and paper solids having been applied to land under controlled conditions to assess the potential risks on soil and water ecosystems (Bostan et al., 2005).

Until now the primary solids originating from the pulp and paper mills have either been disposed of in landfills and where no landfill capacity is available have been combusted for electricity production but with negative energy gain due to the high water content and which still requires the boiler ash to be disposed of to landfill.

Biological sludge from oxidation ponds, also known as secondary pulp mill solids, has slightly higher nitrogen and phosphate concentration and a lower carbon concentration. This narrower C/N ratio makes secondary pulp mill solids more suitable for land utilisation (Garrett & Wang., 2006).

Sewage sludge is defined in New Zealand as municipal biosolids (NZWWA, 2003). The guidelines for the safe application of biosolids to land in New Zealand (NZWWA, 2003) require stabilisation treatment to reduce pathogens and testing on contamination to achieve an AA-grade classification prior to unrestricted land application. Most of the produced municipal biosolids would not meet the a-grade contamination classification and would require a blending agent for diluting heavy metal concentrations. Stabilisation such as drying, composting and liming (high pH) are cost intensive, resulting in most of the biosolids produced in New Zealand being land filled.

Vermicomposting of pulp mill solids has not been previously conducted at any significant scale, as the wide C/N ratio of pulp mill solids is not suitable for vermicomposting. Laboratory trials have shown best reproduction of earthworms when the C/N ratio is adjusted at about 25 with nitrogen rich waste streams (Elvira et al., 1996; Elvira et al., 1998; Ndegwa & Thompson, 2000). Various industrial organic wastes have been studied for four decades using vermicomposting technology to produce a high quality soil conditioner or fertiliser (Edwards & Neuhauser, 1988). Paper wastes with a C/N ratio of up to 200 and higher, were used as a carbon rich blending agent for nutrient rich wastes such as biosolids, food wastes (Edwards, 1988), manure (Arancon et al., 2005), and other industrial wastes (Tucker, 2005). Since the 1990's solids from pulp and paper mills were used as carbon rich fibre for blending with nutrient rich wastes in vermicomposting processes (Butt, 1993; Elvira et al., 1996; Elvira et al., 1997; Lazcano et al., 2008a; Quintern, 2009; Tucker, 2005). In recent years Quintern and his team (Quintern, 2011; Quintern et al., 2013) have been demonstrating that a sub-optimal C/N ratio in the earthworm feedstock can be successful in commercial vermicomposting operations and nitrogen sources captured from the wastewater treatment plant of a pulp mill can be used as nitrogen source for blending with primary pulp mill solids (Quintern et al., 2009; Quintern et al., 2013).

## 2 MATERIALS AND METHODS

The characteristics of pulp mill solids tend to vary considerably. Variations are also found between different pulp mills, as well as between different types of solids originating from individual pulp mills. In addition, further variations are also noted as the age of the solids increases. This paper focuses on Quintern's work at two pulp and paper mills, which have identified inconsistencies within their waste solids.

Our operation at the Kinleith pulp and paper mill at Tokoroa in New Zealand's North Island is vermicomposting a mix of primary and secondary solids producing an organically certified Vermicompost (Quintern et al., 2013). A part of the operation operates on leased land contained within an organically certified dairy farm and which requires all inputs onto the worm farm to be a certified organic input for vermicomposting on an organic certified worm farm. Table 1 shows the characteristics of the pulp mill solids originating from the Kinleith pulp and paper mill (Photograph 1) compared to the specified limits for organic certification (AsureQuality, 2013).

*Photograph 1: Dewatered primary pulp mill solids in sedimentation pond.*

At the Tasman pulp and paper mill situated at Kawerau in the Bay of Plenty region (Glasner & Quintern, 2011) of New Zealand North Island, the Vermicompost we produce comprises primary pulp mill solids in combination with municipal biosolids from Rotorua city. Characteristics of both sludge's are shown in Table 2 and compared against the limits for the safe application of biosolids to land in New Zealand (NZWWA, 2003).

# 3 INDUSTRIAL VERMICOMPOSTING OPERATIONS IN NEW ZEALAND

The journey of establishing two industrial scale vermicomposting operations at the largest pulp and paper mills in New Zealand started in 2007 with laboratory batch trials to combine industrial produced organic wastes streams produced in the region on their suitability for vermicomposting. The favourable initial results quickly led to large-scale field trials intended to evaluate the vermicomposting process under real climatic conditions. These trials were crucial to establishing proof of concept and to establish the operational costs and wider economic benefit data as well as demonstrating environmental impacts to regional environmental authorities and similar organisations responsible for the granting of operational resource consents. A significant consideration throughout these trails was to engage closely with the indigenous tribes (iwi) for social and cultural acceptance of the technology. These trials required numerous process adjustments as the process was moved from a controlled and closed lab environment to an open-air situation.

*Table 1: Characteristics of primary, secondary, and recycled paper solids from Kinleith Pulp, Paper Mill compared to specified limits for organic certification.*

| Parameter | Primary Solids | Secondary Solids | Limits organic Certification |
|---|---|---|---|
| Dry Matter (%) | 17.8 | 18 | |
| Total Carbon (%) | 37.6 | 17.0 | |
| Total Nitrogen (%) | 0.5 | 0.53 | |
| C/N ratio | 75 | 32 | |
| pH | 7.4 | 8.5 | |
| Total Phosphorus (mg/kg) | 509 | 1,203 | |
| Total Sulphur (mg/kg) | 3,200 | 5,000 | |
| Total Potassium (mg/kg) | 1,060 | 1,203 | |
| Total Calcium (mg/kg) | 24,200 | 42,000 | |
| Total Magnesium (mg/kg) | 2,440 | 863 | |
| Total Sodium (mg/kg) | 1,130 | 1,582 | |
| Total Boron (mg/kg) | 0.28 | 0.12 | |
| Total Arsenic (mg/kg) | 1.0 | <0.021 | 20 |
| Total Chromium (mg/kg) | 2.9 | <0.011 | 15 |
| Total Cadmium (mg/kg) | 0.1 | nt | 1.0 |
| Total Copper (mg/kg) | 9 | <0.011 | 60 |
| Total Lead (mg/kg) | 1.72 | <0.0021 | 250 |
| Total Mercury (mg/kg) | 0.04 | nt | 1.0 |
| Total Nickel (mg/kg) | 1.3 | <0.011 | 60 |
| Total Zinc (mg/kg) | 43 | 1.2 | 300 |

nt: not tested

Typically, organic wastes, pulp mill solids, municipal biosolids and kiwi fruit wastes are received at a centralised reception area. These wastes streams are characterised, quality checked and volumes monitored prior to being blended by standard agricultural mixing technology. The blended material is then laid out in windrows directly onto the soil without any sealing or covering following the best practice standards for vermicomposting in New Zealand (NZS, 2005). Width and length of the windrows depend on the site dimension but are usually 24 m by up to 240 m. Compost worms are migrating into the feedstock after a maturing period of 2 to 4 weeks and start breeding immediately (Photograph 2). Maturity of the vermicast is generally achieved after 12 months and is determined by monitoring product characteristics (analysis) or according to prescribed standards (AsureQuality, 2013) (Table 2).

*Photograph 2: Compost worms (Eisenia foetida) feeding on mixed pulp mill solids and biosolids.*

*Table 2: Characteristics of primary solids from Tasman Pulp, Paper Mill, Rotorua municipal biosolids compared to limits of New Zealand biosolids guidelines (NZWWA, 2003).*

| Parameter | Primary Solids | Rotorua municipal biosolids | Limits NZ biosolids guidelines |
|---|---|---|---|
| Dry Matter (%) | 58.9 | 14 | |
| Total Carbon (%) | 34.2 | 42 | |
| Total Nitrogen (%) | 0.43 | 7.6 | |
| C/N ratio | 80 | 5.5 | |
| pH | 7.4 | 6.1 | |
| Total Phosphorus (mg/kg) | 717 | 3,700 | |
| Total Sulphur (mg/kg) | 1,292 | nt | |
| Total Potassium (mg/kg) | 2,060 | 2.210 | |
| Total Calcium (mg/kg) | 78,3 00 | nt | |
| Total Magnesium (mg/kg) | 1,260 | nt | |
| Total Sodium (mg/kg) | 2,030 | nt | |
| Total Boron (mg/kg) | 9 | 44 | |
| Total Arsenic (mg/kg) | 2.1 | 7.0 | 20 |
| Total Chromium (mg/kg) | 34 | 26 | 600 |
| Total Cadmium (mg/kg) | 0.16 | 0.4 | 1.0 |
| Total Copper (mg/kg) | 16 | 134 | 100 |
| Total Lead (mg/kg) | 4.9 | 21 | 300 |
| Total Mercury (mg/kg) | 0.04 | 1.7 | 1.0 |
| Total Nickel (mg/kg) | 5.5 | 14 | 60 |
| Total Zinc (mg/kg) | 43 | 250 | 300 |

nt: not tested

The fibrous structure of the pulp mill solids has a high water holding capacity, which allows for the operation of the worm farms without irrigation or coverage of the windrows. The height of the windrows depends on the structure of the feedstock, but should enable processing of the whole depth within 12 months without leaving anaerobic zones active within the windrow, which signifies remaining non-vermicomposted organic material.

**Tasman** was our first commercial operation started in 2008 with approximately 2,000 tonnes of pulp mill solids and 900 tonnes of municipal biosolids per year. By 2011, this operation was processing a total of 25,000 tonnes of combined pulp mill solids and municipal solids. This wormfarm operates on two sites with a total footprint of 17 ha and an additional 30,000 to 40,000 tonnes of material will be realised in the current year following successful research and development resulting in combining both primary and secondary pulp mill solids.

**Kinleith** vermicomposting operation commenced with an intensive program of breeding compost worms (*Eisenia foetida*) in November 2008. From April 2009 primary solids were delivered to the worm farm on a regular basis. Since January 2010 all primary solids originating from the Kinleith pulp and paper mill have been vermicomposted at the MyNOKE® wormfarm since January 2010 and all secondary solids since October 2010.

In 2011 Kinleith worm farm had reached a footprint of 19.8 ha. For minimising transportation costs, all worm farm sites are located within a 6 km distance to the dewatering ponds. 10.8 ha are operated on old log yard sites and a 9 ha block is located on a nearby organic certified dairy farm. Since early 2013 a 15 ha forest block has been leased for processing approximately 14,200 tonnes of municipal biosolids (Table 3) with close to 30,000 tonnes of pulp mill solids per year. First products will become available early 2014.

*Table 3: Pulp mill solids, municipal biosolids and other industrial wastes processed at New Zealand's central north islands vermicomposting operations in 2012 and 2013.*

| **Organic waste** | **Tasman Mill** | | **Kinleith Mill*** | | **Maketu**** | |
|---|---|---|---|---|---|---|
| | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 |
| Primary pulp mill solids (t) | 23,346 | 16,380 | 38,641 | 43,670 | 70 | 300 |
| Secondary pulp mill solids (t) | - | 8,396 | | | - | - |
| Municipal biosolids (t) | 9,346 | 11,398 | - | 14,200 | 42 | 252 |
| Kiwi fruit wastes ($m^3$) | - | - | 1,094 | 812 | - | - |

* Primary and secondary solids are mixed before dewatering
** Maketu is a small community with a centralised wastewater treatment plant receiving pulp mill solids from Tasman Mill started in November 2012.

The locations of the vermicomposting sites are determined where potential integration into crop or forest rotation is possible in a similar approach to studies of outdoor pig ranging in agricultural production (Quintern & Sundrum, 2006). After two to three years a rotation process results in windrows being established on new land or forestry block and the old sites are replanted with catch crops or trees after harvesting the vermicast. This way any potential enrichment of nutrients in the underlying topsoil are utilised by crop and potential hot spots for nutrient leaching are avoided.

# 4 RESULTS AND DISCUSSIONS

Industrial scale vermicomposting of pulp and paper mill solids has been proven to be economically viable, environmentally safe, culturally embedded and socially accepted and supported (Quintern, 2014b; Quintern, 2014a). Crucial for the success is a bottom up approach looking from the end-user demand for a high quality product at a comparable price. Therefore, nutrient content of the vermicast should be high enough to achieve a contribution of plant growth while mitigating contamination issues resulting from heavy metals. This is achieved by eliminating the need for costly infrastructure and unnecessary handling, exacting quality control and monitoring and balancing the C/N ratio to mitigate nutrient losses from vermicomposting while still producing a high quality soil conditioner.

The blended feedstock (mixed pulp mill solids) is applied on the wormfarm in windrow technology vermicomposting. The volume reduction incurred during vermicomposting is between 78 and 85%. During the 2012-13 summer, a record 75-year drought did not require irrigation of the windrows. The C/N ratio achieved of the mixed pulp mill solids is higher than that suggested for successful vermicomposting (Aira et al., 2006). A higher C/N ratio of the feedstock leads to a reduction in nitrogen losses during vermicomposting, as nitrogen will remain limited for microbiological growth. The requirement for groundwater monitoring as specified under the conditions of the resource consent for our wormfarms where pulp mill solids are vermicomposted with municipal biosolids is not showing any significant increase of nitrogen concentration or metals. The vermicast produced from feedstock with a wider C/N ratio remain with a relatively wide C/N ratio of 29 (Table 4) and is seen as a more stable soil conditioner and therefore most favourable for most purposes such as potting mix substitute or land applied in areas sensitive to nutrient leachate (Ndegwa & Thompson, 2000).

*Table 4: Characteristics of organic certified and non-organic certified vermicast from Kinleith Pulp, Paper Mill compared to limits for organic certification and limits of New Zealand's biosolids guidelines.*

| **Parameter** | **MyNOKE organic certified vermicast** | **NOT organic certified vermicast** | **Limits Organic Certification** | **Limits NZ biosolids guidelines (NZWWA, 2003)** |
|---|---|---|---|---|
| Dry Matter (%) | 40-49 | 41.35 | | |
| Bulk density (kg/m$^3$) | 745 | 750 | | |
| Organic matter (%) | 33.6 | 43.6 | | |
| Total Carbon (%) | 19.5 | 25.3 | | |
| Total Nitrogen (%) | 0.65 | 1.14 | | |
| C/N ratio | 29 | 22 | | |
| pH | 7.04 | 7.0 | | |
| Total Phosphorus (mg/kg) | 1,310 | 5,830 | | |
| Total Sulphur (mg/kg) | 4,430 | 2,560 | | |
| Total Potassium (mg/kg) | 804 | 1,659 | | |
| Total Calcium (mg/kg) | 71,300 | 109,700 | | |
| Total Magnesium (mg/kg) | 3,420 | 1,633 | | |
| Total Sodium (mg/kg) | 869 | 1,443 | | |
| Total Manganese (mg/kg) | 259 | 198 | | |
| Total Boron (mg/kg) | 8 | 12 | | |
| Total Arsenic (mg/kg) | 7.0 | 19 | 20 | 20 |
| Total Chromium (mg/kg) | 26 | 26 | 150 | 600 |
| Total Cadmium (mg/kg) | 0.50 | 0.52 | 1.0 | 1.0 |
| Total Copper (mg/kg) | 53 | 48 | 60 | 100 |
| Total Lead (mg/kg) | 38 | 12 | 250 | 300 |
| Total Mercury (mg/kg) | 0.12 | 0.25 | 1.0 | 1.0 |
| Total Nickel (mg/kg) | 14.2 | 6.0 | 60 | 60 |
| Total Zinc (mg/kg) | 127 | 140 | 300 | 300 |

Currently some 32,000 tonnes of vermicast (Photograph 3) are produced per annum from pulp and paper solids. Of this, 10,000 tonnes are organic certified vermicast for premium application such as required by kiwifruit orchards. The remainder is produced in combination with municipal biosolids (Table 5).

*Table 5: Produced volumes of vermicast at New Zealand's central north islands vermicomposting operations in 2012 and 2013.*

| **Vermicast /-compost** | **Tasman Mill** | | **Kinleith Mill** | |
|---|---|---|---|---|
| | 2012 | 2013 | 2012 | 2013 |
| Vermicast – not organic certified (t) | 12,000 | 14,500 | - | 7,500 |
| MyNOKE organic certified vermicast (t) | | | 10,000 | 10,000 |

*Photograph 3: Screened (5 mm) MyNOKE® organic Wormicast produced form pulp mill solids coming off a conveyor.*

The application rates of vermicast vary according to purpose and demand. These can vary from approximately 2.5 to 5.0 tonnes per ha on pasture to 20 tonnes per ha to maize. For details see Table 6. On average 8.4 tonnes of vermicast are applied per ha across all sectors. In total approximately 2,740 ha of agricultural and horticultural land is currently benefitting from vermicast originating from our wormfarms in the region.

*Table 6: Land application rates of vermicast and areas of land application with vermicast to primary industries in 2013.*

| **Primary sector** | **Application rate (t/ha)** | **Total area applied (ha/a)** |
|---|---|---|
| Pasture | 2.5 to 5.0 | 600 |
| Cropping | 5.0 to 20.0 | 1,500 |
| Kiwi fruit orchards | 5.0 | 600 |
| Others (landscaping, turf, | 5.0 to 75.0 | 40 |
| Average land application | 8.4 | - |
| Total area land applied | - | 2,740 |

# 5 CONCLUSIONS

Vermicomposting of pulp and paper mill solids in combination with organic wastes originating from food processing industries or biosolids from municipal biosolids is an economic and environmental technology to convert organic wastes into high quality soil conditioners and organic fertilisers. There is a growing demand for vermicompost products in the primary sectors such as agriculture, forestry and horticulture. Primary industries within close vicinity of the wormfarms will derive additional benefit from reduced transportation costs. Where hog fuel or wood chips are delivered to pulp and paper mills, the backload capacities of trucks can be highly cost beneficial in the supply of vermicompost to more remote customers.

Beneficial uses of vermicompost to various crops and forests on different soils have been documented widely (Joshi et al., 2013; Hidalgo & Agricultural, 1999; Lazcano et al., 2008b; Lazcano et al., 2011; Lazcano et al., 2010; Arancon et al., 2006; Arancon et al., 2004; Atiyeh et al., 2002; Arancon & Edwards, 2005). Little is known on continuous application of vermicast in intensive dairying especially on pasture and intensive monoculture maize cropping systems. Intensive dairy farming is currently criticised to leading to increases in nitrate leaching and phosphate runoff, whereas intensive maize cropping may lead to a reduction in soil organic matter and therefore a carbon loss from these soils. Vermicast has the potential to increase root growth (Canellas et al., 2010; Zandonadi et al., 2007; Canellas et al., 2008) and a regular application to farmland increases topsoil quality. As a result, vermicast has the potential to mitigate nitrate losses, increase soil organic matter directly as a carbon source and indirectly by increasing root production.

Vermicomposting of combined industrial and municipal organic wastes offers multiple positive effects on the carbon footprint for industry, the community and for the primary sectors. Of significance is the reduction in greenhouse gas emissions originating from land filling of organic wastes and the avoidance of the high economic penalties associated with the design, construction and on-going monitoring of landfills. For the farming and horticulture sectors, soil carbon would be increased and higher carbon sequestration by increasing root mass and crop yields. Potential fertiliser reduction would reduce the carbon footprint and a better soil structure could reduce laughing gas emissions from pastoral soils.

### ACKNOWLEDGEMENTS

The authors gratefully acknowledge the outstanding support from the Carter Holt Harvey Kinleith Pulp mill environmental team and the wider management team for their constructive support throughout the start-up phase of the vermicomposting operation. Special thank Jonathan Stevenson for transforming the "worm farm" into full-scale commercial operation.

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