EVALUATION OF VERMICOMPOSTING OF MUNICIPAL SEWAGE SLUDGES IN IRELAND

BY

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Abstract

From the research conducted, it is concluded that vermicomposting of dewatered municipal sludges in small rural wastewater treatment plants still has a number of technical and economic problems, before it could be considered a viable alternative to existing systems. The pilot scale unit designed in Bangor Erris indicated that heavy metal concentrations were low in the raw sludge, indicating that it's use as a fertiliser/soil conditioner is feasible. The trial indicated some earthworm stabilisation. There was no odours. There was a loss of phosphorous from the worm bed. Most of the research and development on vermicomposting has been conducted in, Australia and America where climatic conditions are quite different to Ireland. Therefore more research in an Irish context is necessary to evaluate the system. It is essential that critical parameters such as temperature, moisture content, bedding material and sludge loading to bed as well as earthworm application rates to bed are controlled. For the past decade, vermicomposting systems have been used in Ireland with very little success. Given this time frame and the number of failed attempts, we are still in the development phase of large scale vermicomposting.

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1.0 Introduction

The use of earthworms to breakdown and stabilise animal and vegetable waste is called vermicomposting (Hartenstein, 1981), or vermistabilisation (Loehr, Martin, Neuhauser, 1988). Many types of earthworms exist. Epigeic worms such as the species *Eisenia foetida* (the Brandling or Tiger Worm) are found in the superficial layer of the organic matter. It has been the focus of numerous research projects in the stabilisation of sewage sludges (Neuhauser, Loehr, Malecki, 1988; Hartenstein, Neuhauser and Collier, 1980). Due to its prolific growth and reproduction rates, and tolerance of a wide range of temperatures, it can be used in temperate climates such as Ireland. Other species suitable for sewage sludges in temperate climates include *Lumbricus rubellus*. In tropical countries the African Nightcrawler (*Eudrilus Eugeniae)* is used, which, due to its dependence on temperatures above 12°C, is not suitable for Irish conditions.

It is reported that worms obtain their nourishment both from micro-organisms that are involved in the decomposition process and from the organic matter that is decomposed, (Loehr, Neuhauser and Malecki, 1985). The end product that is excreted by the worms is called worm casting. It has been found to have excellent agronomic benefits when used as soil fertiliser or conditioner (Walsh, 1996).

Evidence in the literature suggests that vermicomposting may be suitable as a sludge treatment option. However, certain questions still exist in relation to factors such as physiochemical parameters, pathogen reduction, heavy metals, and the costs of employing such technology at rural wastewater treatment plants.

Legislation requires sewage sludge to be treated to remove pathogens. There is therefore a need to develop a low cost, sludge treatment process with minimal operator input at small rural wastewater plants.

1.1 Aim Of Research

Under the Sludge Management Plan for County Mayo (Fehily, Timoney & Co., 2000), vermistabilisation is proposed at three rural wastewater treatment works. The aim of this project is to collate all existing knowledge and research on the use of earthworms in waste management to:

- Review existing systems.
- Design and operate a pilot-scale trial.
- To examine factors that affect the performance of the vermistabilisation process.
- To assess design features relevant to small treatment works.

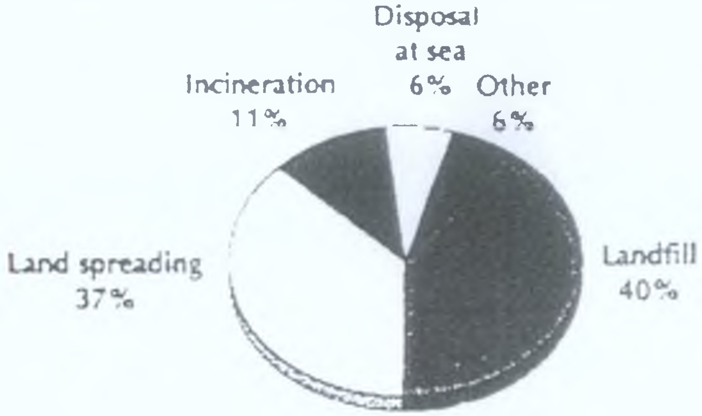
2.0 Literature Review

2.1 Background

2.1.1 Sewage Sludge Disposal

Changes in population size, structure and distribution add pressures to the environment. In particular, urbanisation has lead to increased additional housing stock (EPA, 2000). More housing requires more sewerage infrastructure. A report by OECD in 1999, showed Ireland as the world's leader in economic performance (EPA, 2000). This economic boom coupled with infrastructure aid from the EU and pressure from environmental groups, has lead to increases in the number of treatment plants. Sewage treatment produces large quantities of sewage sludge. It is estimated that Ireland will produce 112,133 tonnes of dry solid (tds) by the year 2005 with 129,795 tds by the year 2013 (Weston – FTA, 1993). Under the National Development Plan 2000 – 2006, on economic and social infrastructure, there will be £2,495 million pounds invested in water and wastewater infrastructure. Traditionally our towns and cities were built on large rivers or adjacent to the sea, this allowed wastewater to be discharged without treatment. The disposal of sludge is also a European problem. In 1994, (Graph 2.1) 40% of sewage sludge was landfilled, 37% landspread with 11% incinerated (Smith, 1996).

Graph 2.1 Disposal Of Sewage Sludge In the EU In 1994 (Smith, 1996)



2.1.2 Sewage Sludge Management In County Mayo.

Sludge arising from municipal wastewater treatment is the principal sludge managed by the Local Authority. Under the Sludge Management Plan for County Mayo (Fehily, Timoney and Co., 2000), the volume of sludge produced is 1,285 t.d.s per year. The "*Strategy Study on Options for the Treatment and Disposal of Sewage Sludge in Ireland*", (Weston-FTA, 1993), gives a projected sludge production of 1947 t.d.s per year in the year 2013. The Strategy Study divides Mayo in three regions. Region 6 in North Mayo, Region 7 in South Mayo and Region 8 in East Mayo. To assist County Councils in the implementation and planning of municipal waste water a number of reports were commissioned

- Inventory of Non-Hazardous Sludges in Ireland (Fehily, Timoney & Co, 1998).
- A Study of International Practice on the Use of Biosolids in Agriculture (Fehily, Timoney & Co, 1998).
- Code of Good Practice for the Use of Biosolids in Agriculture (Fehily, Timoney and Co, 1999).

All the reports indicate that the reuse of wastewater sludge in agriculture is seen as the most beneficial and sustainable method of sludge management. Due to the high pathogen presence the practice of disposal untreated by landspreading or injection into soil is not recommended (Fehily, Timoney & Co., 1998; Clark and Pebbles, 1999). The stabilisation or treatment of sewage sludge prior to land application is essential. In the larger towns of County Mayo, sludge management currently involves dewatering followed by landfilling to one of two authorised landfills.

Mayo County Council has applied to the Environmental Protection Agency for a Waste Licence under Council Directive 1999/31 EEC for the licencing of these two sites. Under condition 5.1 of the waste licence for Derrinumera Landfill site (Mayo County Council, 2001) "*no liquid or sludge waste shall be accepted for disposal at the landfill site*" until it undergoes some form of treatment. This condition will also apply to other landfill site, in due course. In a government report, a 65% reduction in biodegradable waste going to landfill, and the development of waste recovery facilities employing environmental friendly technology is envisaged (DoELG, 1998).

The Sludge Management Plan's main recommendation for large plants is thermal drying of sludge at a hub centre at Castlebar. This will involve transferring sludge from outlying satellite towns to Castlebar for treatment.

On small works the quantities of sludge are usually relatively small. The need for extensive sludge treatment is prohibitive, due to cost. There is therefore a requirement to develop a low technology, low cost sludge treatment process that can be operated on small sludge plants with minimal operator input. Presently 3% of sludge from small works is used by plant operators for their own fertilisation purposes (Fehily, Timoney & Co, 2000).

Under the Sludge Management Plan three sites are recommended for vermicomposting, these are semi-solid sludge at Achill Island (Continuous Flow Reactor system (CFR)), liquid sludge at a new plant at Belmullet Plant and liquid sludge at Louisburgh (see Appendix 1). Table 2.1 shows the projected volumes

Table 2.1: Treatment Option And Volume Of Sludge Arising From Wastewater Treatment Plant.

Municipal Wastewater Plant	Volume Of Sludge Arising	Treatment Option Proposed
Achill	72 t.d.s / yr	Vermicomposting Dewatered Sludge
Belmullet	55 t.d.s / yr	Vermicomposting Liquid Sludge
Louisburgh	26 t.d.s / yr	Vermicomposting Liquid Sludge

2.1.3 What Is Vermicomposting?

The use of earthworms to breakdown and stabilise human, animal and vegetable waste is called vermicomposting or vermistabilisation. It has the following advantages:

- Increasing the surface area for drying and microbial decomposition by fragmenting the sludge.
- Increasing the moisture holding capacity by decreasing particle size.
- The tunnelling action of earthworms improves aeration.
- The malodours produced by putrescible nitrogen and sulphur compounds are removed, with reduced forms of nitrogen and sulphur being oxidised by microbial composting (Neuhauser *et al.*, 1980).

The action of earthworms is mechanical, physical and biological. It involves substrate aeration, mixing, grinding as well as microbial decomposition of the substrate in the intestine of the earthworm.

The vermicomposting process involves the bioconversion of the waste stream into products which may be processed into earthworm meal or a high grade horticultural product (see Plate 2.1 and 2.2) (Sabine, 1988; Philip, 1988). Although the efficacy of vermicomposting is not in doubt, as laboratory and pilot scale projects have shown, actual large scale vermicomposting process using sewage sludge are few (Vermitech, 1999).

2.1.4 History Of Vermicomposting Worldwide

Over a hundred years ago Charles Darwin, in his book "*The Formation of Vegetable Mould Through The Action Of Worms*" (Darwin, 1881), established the importance of earthworms in the maintenance of fertilisation within the soil.

The most basic level of vermistabilisation, where worms are used to stabilise sewage solid, had been applied in the form of dry toilets in remote areas, or where septic tanks were inappropriate due to drainage problems e.g. *Dowmus* composting toilet in Australia (Walsh, 1996)

Scientific investigations have established that using earthworms as a treatment technique on various waste streams is potentially viable. This has been applied to pigs, (Chan and Griffith, 1988), cows, (Hand, Hayes, Satchell and Frankland, 1988), and paper mills (Butt, 1993). On a larger scale, scientific studies have helped establish the technical basis for vermistabilisation of sewage sludge.

Plate 2.1: Earthworm Meal Product

Plate 2.2: High Grade Horticultural Vermicompost Product

Research conducted at Cornell University and the State University of Syracuse, New York, has shown that aerobic sewage sludge can supply the necessary nutrients for the growth and reproduction of earthworms (Hartenstein, 1981; Neuhauser *et al.*, 1980; Kaplan *et al.*, 1980). At the Rothamsted experimental station in the United Kingdom extensive laboratory work by Clive Edwards led to development work on a field scale, and to a commercial working unit (Edwards, 1988).

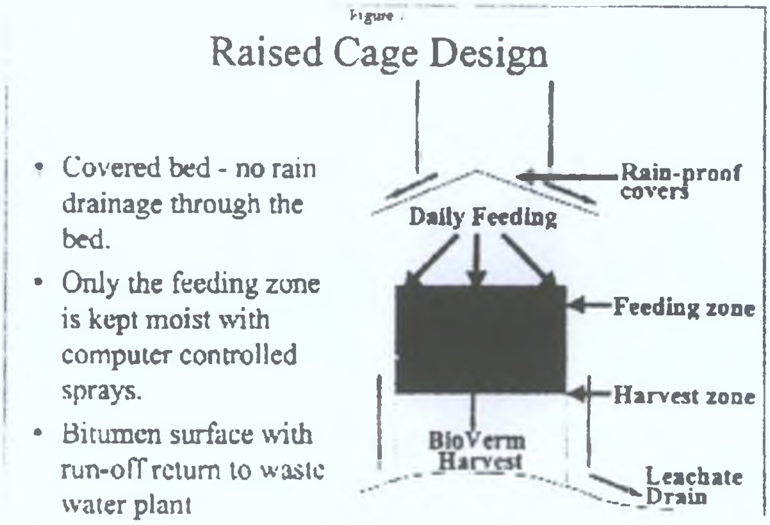
The main advances in vermicomposting were in America and Australia. There were very small-scale pilot tests run on liquid and dewatered sludge, but not until the 1970s did large-scale operations exist. The City of Lufkin, Texas in 1979, was the setting for large-scale vermicomposting of liquid sludge. 300 gal / day of liquid sludge at 4% dry solid was sprayed onto a 1900 square foot enclosed vermicomposting bed consisting of 8 inches of sawdust and the earthworm *Eisenia foetida.* Based on the conversion of the sludge at a rate of 0.08 lb / day / square feet, approximately 29,000 square feet was required at Lufkin (Green and Penton, 1981). Lufkin has a population of 15,000 people with approximately 1 tonne dry solid of sludge produced every day.

A similar operation was initiated in Keysville MD, in June 1979, where 300 lbs of aerobically digested sludge was dewatered to 12% dry solid and air dried to 18% dry solids. A two inch layer of sludge was placed on a 30 foot by 2.5 foot tray, followed by the seeding of earthworms at the rate of 2-3 lb per square foot (Pincince, Donovan and Bates, 1981). After forty eight hours the sludge is reported to be converted to casting.

In another plant at Fallbrook, California, aerobically digested sludge is pumped to drying beds for a period of 60 days to increase the solid content from 15% to 18%. A bulking agent is added. The static pile is allowed to compost for thirty days to reduce pathogen and weed seeds. Half the screened compost is sold and the other half is vermicomposted (Healion and Dick, 1996). In Australia a site run by Vermitech Pty, Ltd., was licenced by the Queensland Department of Agriculture, for the vermicomposting of municipal sewage sludge from four sewage treatment plants in 1997 (Plate 2.3, Figure 2.1).

Plate 2.3: **Vermitech Ltd. Site At Redlands, Australia, Using Continuous Flow System (adapted from Lotzof, 1999).**

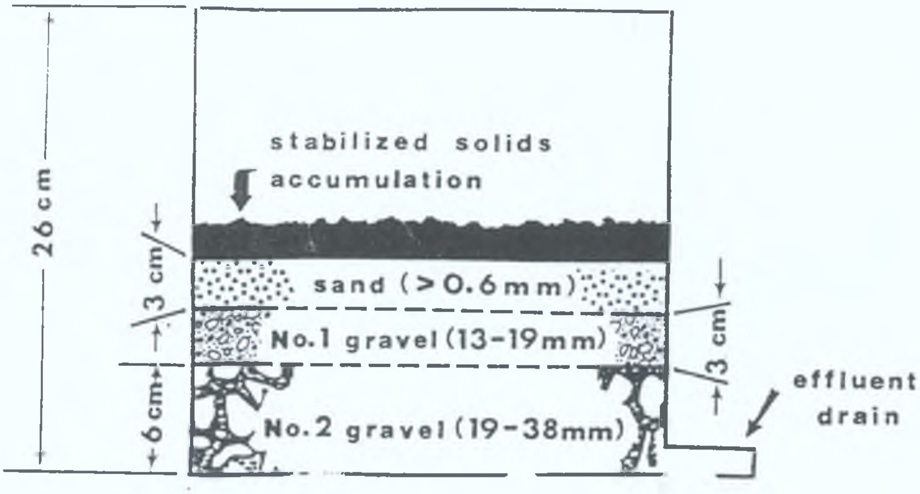
Figure 2.1: **Raised Cage Design At Redlands.(Adapted from Lotzof, 1999).**



- Covered bed - no rain drainage through the bed.
- Only the feeding zone is kept moist with computer controlled sprays.
- Bitumen surface with run-off return to waste water plant

The site at Redland is a raised cage system based on the continuous flow reactor. A total of fourteen beds, each 70m by 3.6m deal with a sewage sludge capacity of 400m^3/week (Lotzof, 1999). In New South Wales, Balhurst Wastewater Works uses a mixture of shredded green waste and solids at a ratio of 65%:35% respectively using earthworms. The final product is applied to forestry and site rehabilitation areas (Biogreen Casting, 1997). It complies with New South Wales EPA "Restricted Class 2" classification under the "Use and Disposal of Biosolid Products 1997".

Figure 2.2: Liquid Vermicomposting Reactor (adapted from Loehr *et al*, 1988).



A vermicomposting trickling filter system has been developed in Chile to treat domestic wastewater for a population equivalent of 1,000 people (Fig 2.2). The system involved wastewater applied to a composite vermicomposting and sand filter bed. The upper layer of the filter retains the solids in which the worm population reside, while the filtrate passes through the sand filter before being disinfected by use of an ultra violet light (Walsh, 2000).

2.1.5 Vermicomposting In Ireland

In Ireland, vermicomposting is still in its infancy. A small number of people are dedicated to its cause and aims. Vermicomposting began with the treatment of farmyard manure, with the product sold as a multipurpose organic compost called "Lettgro" (MacLochlainn, 1995). Some hospitals installed vermicomposting units for the treatment of food waste (MacLochlainn, 1995). Vermicomposting of fish waste is being investigated, with ongoing trials of approximately 300 tonnes of fish waste (Irish Earthworm Company, 2001).

Poultry waste at Shannonvale in Cork is presently under investigation (see Plate 2.4). A prototype vermicompost unit to deal with such waste has been designed by Flockhart (Mac Lochlainn, 1995) (Fig 2.3). Some local authorities are presently investigating the feasibility of using earthworms in sewage treatment. In County Donegal, ongoing trials are being conducted on sewage sludge / spent mushroom mix using an outdoor, enclosed windrow system (see Figure 2.4). Prior to vermicomposting, the pre-composting allows temperatures to reach 55-60°C to reduce pathogen and weed seeds. This is required so as to comply with existing national and pending European Union Regulations (Europa, 2000). The use of vermicomposting of sewage sludge can be looked at in three levels. It can be viewed as a single domestic tool (Applehof, 1988). On the larger scale as practised by Vermitech in Australia, the focus is on the production of castings for sale. This involves high capital outlay for the system but is off set by the excellent market value of the castings (Lotzof, 1999).

Plate 2.3: Vermicomposting Of Poultry Waste At Shannonvale, Co. Cork.

Figure 2.3: Continuous Flow Reactor System.(Adapted from MacLochlainn, 1995).

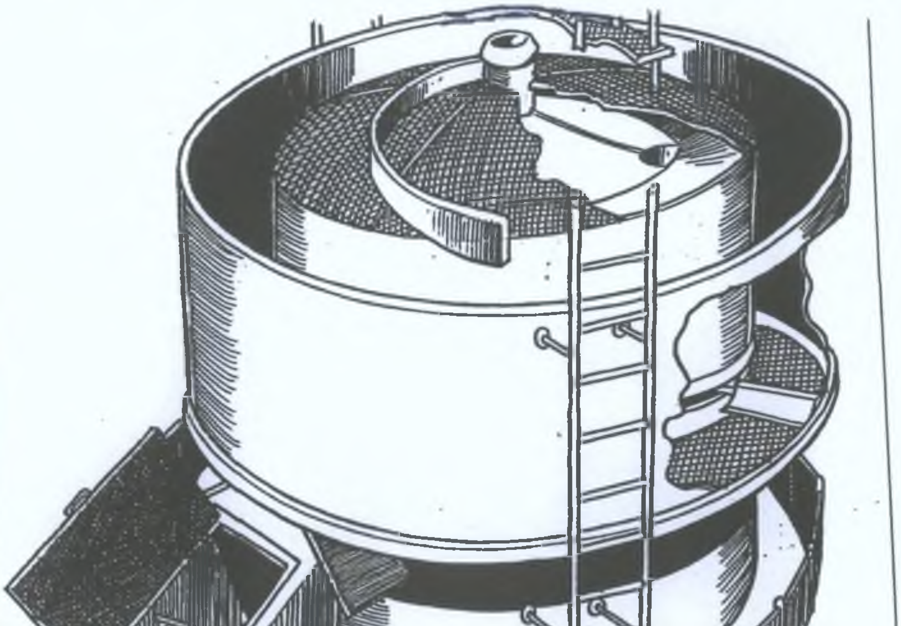


Figure 2.4: Outdoor Enclosed Windrow System.(Adapted from Irish Earthworm Company 2001).

On a smaller commercial scale, package units have been operated on very small wastewater treatment plants (see Plate 2.5) catering for populations of between 40 to 200 population equivalent. The system has been used at Moyvane, Co. Kerry, (see Plate 2.6 and 2.7) and Mullinahone, County Tipperary. More recently a purpose built unit, 75 foot by 15 foot was installed at Toomevara Wastewater Treatment Plant, Co. Tipperary. This enclosed unit with controlled conditions, deals with liquid sludge vermicomposting (See Plate 2.8 and 2.9).

Plate 2.5: Small Scale Vermicompost Units

Plate 2.6: Vermicomposting Unit At Moyvane STP, Co. Kerry

Plate 2.7: Vermicomposting Unit At Mullinahone, Co. Tipperary.

Plate 2.8: External View of Liquid Vermicomposting Unit At Toomevara STP, Co. Tipperary.

Plate 2.9: Internal View Of Liquid Vermicomposting Unit At Toomevara STP, Co. Tipperary.

In Ireland, unlike Australia, and America, environmental conditions are not optimal for worm growth. If it is to be used here, sub-optimal growth conditions will result in different process design and vermicompost characteristics (Clark *et al.*, 1999). Important process parameters and design features to be considered are:

- Solid concentration of the feed bed
- Frequency of feeding.
- Sludge solid loading ratio.
- Delivery mechanism for the liquid / dewatered sludge feed.
- Bed depth.
- Hydraulic loading rates.
- Worm population density.
- Temperature / moisture effects.
- Casting removal procedures.
- Light management.

The characteristics of the system that must be monitored are:

- Volume reduction.
- Pathogen reduction.
- Odour control.
- Chemical changes.
- Heavy metals.
- Nitrogen
- Phosphates.

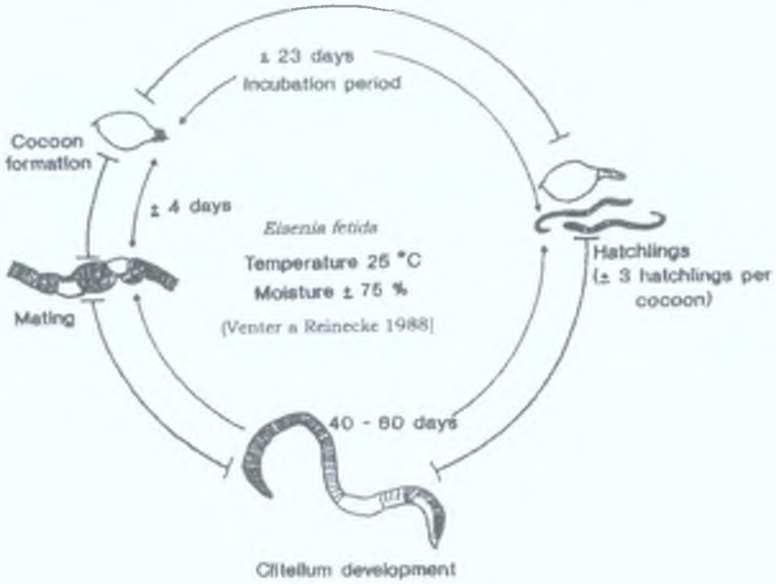
2.1.6 Brandling Reproduction Growth And Lifecycle Of *Eisenia foetida.*

Earthworms belong to the Phylum Annelida. Within this phyla are classes Hirudinea (leaches) and Oligocheata (worms with few bristles) (Edwards and Lofty, 1972). Earthworms in their natural environment are responsible for the turnover of large quantities of organic matter. There are in excess of 3,000 species but detailed knowledge is known of only 5% (Sabine, 1988).

The degradation of the organic matter is achieved by the worms passing organic matter (i.e. sewage sludge, municipal organic waste, potato, cattle or pig slurries) through their bodies and excreting it as worm castings. Certain species of earthworms can consume organic matter very rapidly and fragment it into finer particles by passing it through a grinding gizzard. The most common species in temperate climate like Ireland is the brandling or manure worm *Eisenia foetida* and the red worm *Lumbricus rubellus.* The earthworm derives it's nourishment from the micro-organism that grows upon the organic matter (Edwards, 1995). The faecal matter or casting that is produced is fragmented and is microbially active (Neuhauser, Hartenstein and Kaplan, 1980).

Eisenia foetida, a microbivorous earthworm, has been used to convert sewage sludge from a form with a relatively small surface area and a high potential for putrescence into faecal casting. The casting has a relatively large surface area and low potential for putrescence (Hartenstein *et al.*, 1981).

Figure 2.5: Lifecycle Of Brandling Worm Eisenia Foetida



2.1.7 Physiochemical Parameters that Affect Growth of *Eisenia.*

The physiochemical parameters affecting the growth of *Eisenia foetida* are well documented in laboratory and on-site testing (Neuhauser *et al.*, 1988; Edwards, 1988; Hartenstein *et al.*, 1980). These studies have shown that earthworms have well defined limits of tolerance to certain chemicals, with organic material being processed more efficiently under a narrow range of favourable chemical and environmental conditions. This is evident when excessive ammonia and salt concentrations are present. Neuhauser *et al.* (1988) found that *Eisenia foetida* survival declined once ammonia concentrations exceeded approximately 1mg NH_3 / kg and the conductivity content (measure of salt content) exceeded 3.5 mS/cm. There is evidence also that *Eisenia foetida* requires its minerals and vitamins in the form of microbial biomass, rather than as acellular soluble nutrients (Healion *et al.*, 1996).

The worm population requires a fresh, regular supply of faecal substrate in which to move. This is important since digested material casting is toxic and will suppress productivity. Optimum conditions are shown in Table 2.2

Table 2.2: Optimum Conditions for *Eisenia foetida*.

Conditions	Requirements
Temperature	15-25°C (limit of 0-35°C)
PH	7-9 (limit of 5-9)
Moisture conditions	84-90% (limit 60-90%)
Oxygen requirements	Aerobic
Ammonia content of waste	Low: <1mg / kg
Salt content of waste	Low: < 3.5mS/cm.

2.1.8 Other Earthworms For Breakdown Of Waste.

As stated above, the most commonly used earthworm for the degradation of organic waste is *Eisenia foetida*. There are a number of reasons for this. It is ubiquitous, with many organic waste becomes naturally colonised by it. It has a wide temperature tolerance and can live in wastes of various moisture contents (see Table 2.2). However other species of worms have shown potential in the treatment of sewage sludge. Suitable species include *Eisenia andrei*, *Lumbricus rubellus*, *Eudrilus eugenie* and *Perionyx excavatus* (see Table 2.3). These latter two species are from Africa and Asia and cannot withstand low temperature (Edwards, 1988; Edwards, 1995). The optimum temperature for these organisms is approximately 28°C (Clarke *et al.*, 1999; Datar, Roa and Reddy, 1997), with temperatures below 12°C lethal to survival (Healion *et al.*, 1996).

The difference between *Eisenia foetida* and *Eisenia andrei* are very small. *Eisenia andrei* showed uniform pigment while *Eisenia foetida* is banded (Sims, 1983).

Table 2.3: Comparison of Eisenia foetida with Other Types of Earthworms (Reinecke, 1991, 1992)

	Eisenia foetida	*Eudrilus eugenie*	*Perionix excavatus*	*Eisenia andrei*
Duration of life-cycle (days)	±70	±60	±46	
Growth rate (mg worm day)	7	12	3.5	
Maximum body mass (individual worm) (mg)	1500	4294	600	
Maturation attained at age (days)	±50	±40	±21	35
Start of cocoon production (days)	±55	±46	±24	
Cocoon production (worm day)	0.35	1.3	1.1	Comparable with E. foetida
Incubation period (days)	±23	±16.6	18.7	
Hatching success in water (%)	73	50	63.4	90.5
Mean number of hatchlings (cocoon)	2.7	2.7	1.1	3.3
Number of hatchlings from one cocoon	1-9	1-5	1-3	1-12

2.1 Characteristics Of The Vermicomposting Process

2.2.1 Introduction

Parameters such as temperature, moisture content, heavy metals, volume reduction, odour and chemical changes can affect the value of vermistabilisation as a treatment system for municipal sludge.

2.2.2 Odour Control

Anaerobic bacteria in sewage sludge can cause odours that attract disease vectors (flies and vermin). International experience has shown that the distinctive sewage smell characteristic of unstabilised sludge is rapidly eliminated in vermicomposting, and is replaced by an odour associated with well aerated soil (Edwards, 1998).

The surface area of the sludge is increased as it is converted to casting (Hartenstein, 1978). This also assists in microbial activity (Mitchell, 1978). Moisture and odour were shown in studies to be inextricably linked. In trials conducted on drying beds with high moisture content, earthworm faeces contained a higher ratio of malodorous sulfur gases than nondigested sludges (Mitchell, 1988).

2.2.3 Volume Reduction

The most distinctive characteristic of conventional composting is the large reduction in volume. In composting it is stated that approximately 20-30 per cent of the volatile solids are converted to carbon dioxide and water (Metcalf and Eddy, 1972). During the vermicomposting process, due to the combined action of the earthworms and the high concentration of aerobic microbes, accelerated organic decomposition is also significant.

Considerable quantities of carbon and water are also respired due to the aerobic conditions in the bed. This results in the conversion of considerable amounts of organic nitrogen and ammonia to nitrate (Walsh, 1996; Haimi and Hunth, 1988). Published results indicate dry weight reduction in well managed systems of 32% (Collier and Livingstone, 1981), while on a continuous flow reactor unit a volume reduction of 10% was achieved using dairy waste by Subler (Vermico, 2000). It was also stated by Subler that the more labile carbon available the greater the reduction occurring. Glas Aris Teo (2001) indicated that a 40-50% volume reduction is achieved using vermicomposting.

2.2.4 Pathogen Reduction

In conventional composting, the generation of temperatures in excess of 55°C is achieved. In vermicomposting, temperatures in excess of 30°C leads to earthworm mortality (Aston, 1988). In this respect there are concerns in relation to pathogen kill with vermicomposting.

However, there is considerable literature available to suggest that required pathogen reduction is achievable. The inhibitory effect of earthworms on pathogenic bacteria was shown in the case of *Pithomyces chatarum,* a fungus that causes eczema in livestock. The spores of this fungal species were rendered unviable after passsage through the gut of the composting worm *Lumbricus rubellus* (Keogh and Christensen, 1976).

Considerable applied research has been conducted in the 1990's, which indicated dramatic reduction in faecal microbes in vermicompost systems. Preliminary data obtained in small-scale vermicomposting systems indicated that human pathogens as faecal coliforms and S*almonella* may not survive vermicomposting after 60 days (Dominquez *et al.*, 1997). Data from windrow vermicomposting systems for sewage sludge operation showed no evidence of coliform bacteria (Harris, Platt and Price, 1990; Edwards and Bohlen, 1996).

Trials conducted in Australia also confirmed pathogen reduction. The plant operated by Vermitech Ltd at Redland in the Australia, based on a commercial continuous flow reactor system achieved stabilisation Class A final product.

The most compelling evidence was produced by the US EPA into a two year trial conducted in Florida. The pilot study was conducted to evaluate vermiculture effectiveness with biosolids on a small scale. It demonstrated a reduction in the four human pathogen indicators, faecal coliforms, *Salmonella* spp, enteric viruses and helminth ova in sewage sludge to Class A standard (Eastman, 1999) (USA EPA 5O3 regulations define Class A Biosolids as final pathogen concentrations not in excess of 1,000 faecal coliforms/g or 3 *Salmonella* per 4 grams).

The full-scale operation achieved the same values as those obtained in the pilot project (Eastman, Kane, Edwards, Trytek, Gunadi, Stermer and Hobley, 2001).

In Ireland unpublished work in relation to pathogen reduction in sewage sludge has also showed significant reduction (Walsh, 1996).

The mechanisms involved in pathogen reduction have not been fully elucidated to as yet. However as the earthworm digests the sewage sludge, it assimilates enterbacteroacea. It is reported that earthworms obtain most of their nourishment from the living microbial content within the food (Edwards *et al.*, 1995).

Furthermore, it is suggested that enzymes from the earthworms have an antiseptic effect on enteric bacteria during the digestion process (Lotzof, 1999).

2.2.5 Chemical Changes In Vermicomposting

The metabolism of organic waste by earthworms and aerobic bacteria will result in inevitable changes in the chemical composition of the final product as carbon and water is lost to the atmosphere and nutrients leached to drainage. Various studies are available in relation to chemical change within the earthworm system.

2.2.5.1 Phosphorous

Experimental results from the earthworm *Eisenia foetida* indicate that it was capable of utilising both micro-organisms and simple nutrients for growth (Edwards *et al*., 1995), but more detailed work is required to determine the mechanisms of nutrient uptake (Morgan, 1988). Trials conducted on available phosphorous on earthworm casts and surrounding soil reported that casts had more available phosphorous than soil without earthworms (Edwards *et al.*, 1995). Some studies suggest that the additional phosphate is found in the cast itself (Satchell and Martin, 1984), but others indicate that it is produced as a result of microbial activity (Park, Smith and , Besesi, 1992).

2.2.5.2 Nitrogen / Ammonia

In trials relating to nitrogen concentration, up to 50-60% nitrification rate observed (Dominquez *et al.*, 1997). It is reported that when earthworms consume organic matter with considerable amounts of nitrogen, much of the nitrogen is assimilated into the tissues and returned to the soil as casting (Lunt, and Jacobsen, 1944). While Needham suggested that little nitrogen is excreted in the casting (Needham, 1957).

Vermicomposting has shown low concentrations of ammonium nitrogen and high concentrations of nitrate nitrogen (Subler, Edwards, and Metzger, 1998).

2.2.6 Coccoon production .

Species of *Eisenia* are hermaphrodite with both male and female reproduction organs. The best growth and cocoon production occur at temperatures of 20-25°C (Loehr *et al.*, 1985). Cocoon production per worm depends on nutrition, population density and ambient temperature. On average earthworm produce two to four cocoons per week. Normally the average worm hatch per cocoon is 2- 3 every three weeks (Appelhof, 2000). Generation time i.e. egg to egg is as short as 9 weeks.

2.2.7 Moisture Content.

Both excessive and insufficient moisture can impact greatly on earthworm growth (Edwards *et al.*, 1972). Trials conducted on aerobically digested sludge indicated that the range for earthworm biomass and stabilisation was 84-91% moisture content at a temperature of 25°C (Neuhauser *et al.*, 1988). Above 80% moisture content, poor oxygen transfer interferes with worm feeding. It is necessary to add a bulking agent to liquid sewage sludge to increase aeration and to prevent anaerobic conditions occurring.

2.2.8 Temperature.

Trials conducted on *Eisenia foetida* showed optimum temperature at 25°C, but have a tolerance for temperature from 0-35°C (Edwards, 1988). Temperature below 10°C means lower growth and above 30°C leads to earthworm mortality (Price, 1987).

2.2.9 Ventilation.

Earthworms are aerobic organisms. It is essential that anaerobic conditions do not exist within a worm bed. Aeration is achieved by adding a bulking agent such as wood chipping or straw to increase porosity (Harris *et al.*, 1990). It is also achieved by raising the worm beds above ground level, so as to allow natural ventilation to circulate. The most modern organic digesters are designed to allow natural aeration to the bed, coupled with temperature control by the use of blower fans and a backup air conditioner system to ensure proper circulation (Vermico, 2000). Liquid slurries with low solid content can achieve sludge stabilisation by spraying onto active worm beds, provided proper drainage exists for the liquid components (Anon, 1984) (see Plate 2.10 and 2.11).

Plate 2.10: Worm Bed

Plate 2.11: Liquid Sludge Distributed By Splash Plate

2.2.10 Other Parameters.

Other parameters that affect the efficient use of earthworms for vermicomposting include pH, toxic chemical and sludge age. Studies have shown that as sludge age is increased, it nutritive value to earthworms decreases rapidly (Neuhauser *et al.*, 1988).

2.2.11 Food Loading Rate For *Eisenia foetida*.

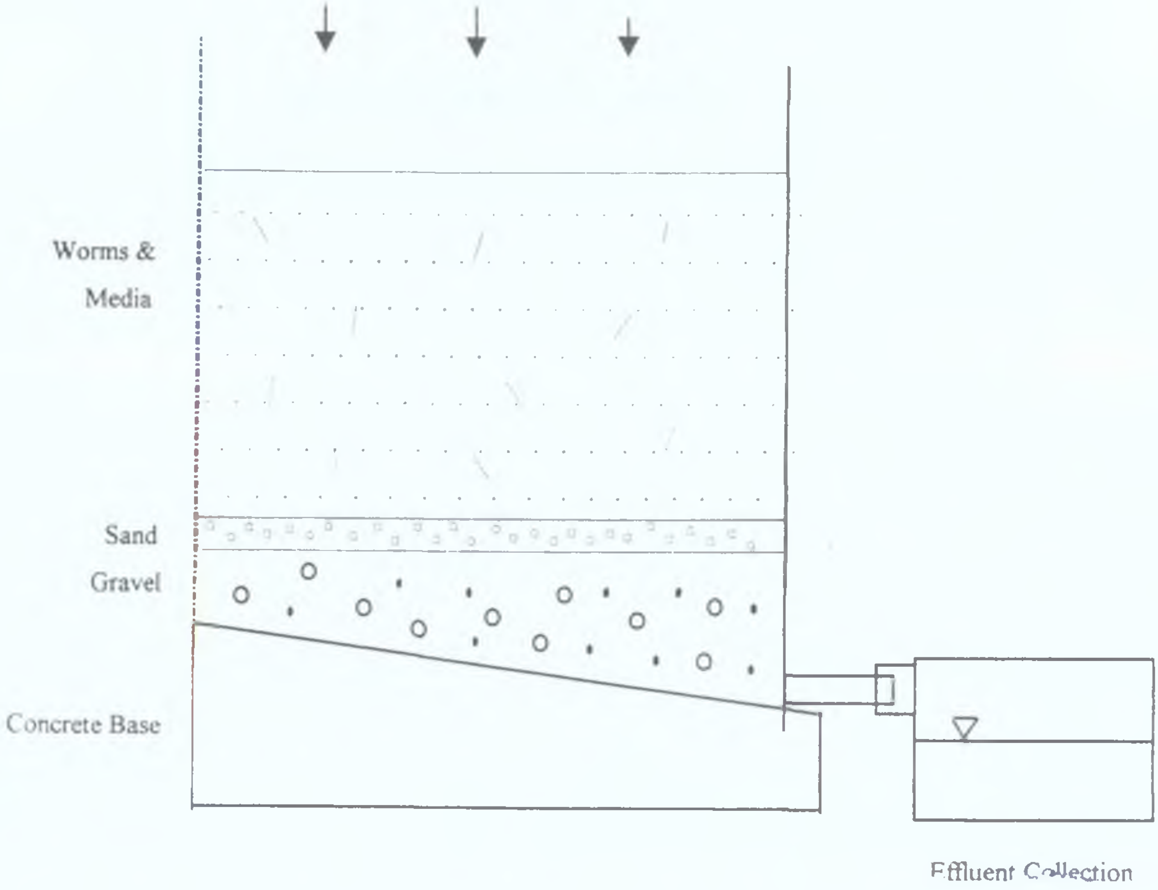
It is essential that the correct rate of food is applied to the worm bed. The earthworms feed throughout the day, but when their habitat becomes toxic (when it's casting accumulate beyond a critical point), feeding will cease (Hartenstein *et al.*, 1981). The disturbance of the earthworm in the bed may cause intermixing of casting with undigested organic matter leading to bed failure as earthworms will depart the environment. These two scenarios are overcome by feeding top down using systems such as closed or open windrows (Huntoon-Sherman, 2000) or mechanically operated system (Loehr *et al.*, 1985).

The feeding regime at Clayton West Sewage Plant in Yorkshire, England (Figure 2.6), using solid volume of between 1-2% dry solids established a daily average solid loading of 0.5kg/m^2/week (26 kg/m^2/year). At the Lufkin Plant sludge, loading rates of 0.13kg of dry sludge solid per m^2 per day (47kg/m^2/year) and 0.4 kg per m^2 per day (146 kg/m^2/year) were achieved (Pincince *et al.*, 1981). On dewatered feedstock to a continuous flow reactor with a square surface area of 1000 square feet, the recommended rate of addition to the reactor is to a depth of one inch (Edwards, 2000).

2.2.12 Earthworm Stocking Density

At Lufkin Water Pollution Control Plant in Texas, earthworm were stocked at a density of 2.4 kg per m^2 (0.5 lb per ft^2) to the worm bed. This resulted in stabilization of the sewage sludge of 1-2% dry solid content within 24 hours.

Figure 2.6: Cross Section Of Typical Segment of Vermistabilisation Unit At Clayton West.(Adapted from Clarke *et al*, 1999).



This seeding was based on initial trials conducted at the plant which indicated that 0.45kg (1lb) of worms would consume 0.056 kg (0.125lb) of dry sludge solid per day. At Fallbrook, California on sewage sludge with a bulking material using windrow system *Eisenia foetida* and *Lumbricus rubellus* was seeded at ¾ lbs/cubic foot (Harris *et al.*, 1990). A study conducted at the University of Georgia, established an optimal stocking density of 1.6 kg of worm/m² (1lb worm /3ft²) and a feeding rate of 1.25kg feed/kg worms / day resulted in the highest biomass. The best quality vermicompost was obtained at the same density with a feeding rate of 0.75 kg/feed/kg worms/day (Ndegwa, Thompson and Das, 1999).

2.2.13 Bedding agents

On windrow systems bedding material such as straw or sawdust are used (e.g. as in Lufkin) (Pincince, *et al.*, 1981). At Toomevara in County Tipperary wood chippings are used (Plate 2.12). In enclosed static beds, paper can be used.

Plate 2.12: Wood Chipping Used As Bedding Material At Toomevara STP, Co Tipperary.

2.3 Types of Vermicomposting Systems

2.3.1 Introduction

A number of biosolid disposal strategies have been adopted around the world to deal with the massive increase in biosolid production. No one solution has universal acceptance with each solution having benefits and limitations (Vermitech, 1999).

Vermicomposting has been adapted to deal with faecal material in a number of international applications. The application ranges from vermistabilisation of liquid sludge of approximately 1-3% to dewatered sludge at 12-25% dry solids. It is a new technology in the international context, with laboratory and field data available only since the 1970s. Early schemes involved large footprint designs and labour intensive techniques.

All the systems must control environmental parameters such as temperature, moisture and aeration. In addition the capital outlay is of major consideration (i.e. land and building costs). There are a number of systems which have been designed, including:

(a) Outdoor windrow system.

(b) Indoor static bed/invessel with controlled conditions.

(c) Continuous flow reactors.

2.3.2 Outdoor Windrow System.

This open system of vermicomposting involves placing organic matter in lines on a hard concrete base or field. Provided you have sufficient land capacity, the system could be financially viable. A number of large commercial vermicomposting systems are in operation throughout the world. The largest vermicomposting facility in the USA is operated by America Resource Recovery in California. An estimated 250,000 kilograms of earthworm processes 75,000 tonnes of material annually on 70 acres of the 320 acre farm. The feed consists of paper, manure and green wastes (Vermico, 2000). This system of processing organic waste is relatively slow, taking anywhere from 6 to 18 months (Edwards, 1995).

There is also evidence that a large proportion of the soluble nutrients are wasted away into the soil. The system of outdoor windrowing involves seeding a mixture of low solid sewage sludge and bulking agent e.g. sawdust and wood chipping, in rows approximately 8-10 feet wide and 2 feet high. If dewatered sludge is used a bulking agent may not be needed.

The bulking agent is mainly used to provide aeration to the system. If odour exists within the windrow it indicates that anaerobic conditions are present (Riggle, 1996). Occasionally a fresh organic mature bulking agent is added at 2-3 inches to the decomposed layers. The bottom layer, which contains the casting, can be harvested by removing the top layer. Due to unregulated control of aeration, shallow depths are required to dissipate heat, however shallow depth demands more surface area to vermicompost higher volumes of material (Jensen, 1993).

2.3.3 Indoor/ In Vessel System.

In temperature climates such as Ireland where rainfall levels exceed 2,800 mm and wind speeds averaging at 7 m/S, Agmet (1996), static beds should be indoor. There is the added problem of cold nights where frost is a problem. In order to fulfill vermicomposting in an Irish context, environmental conditions must be controlled. This involves temperature, aeration and moisture.

Overall the invessel unit devised by Eggan can take from 1 to 300 lbs a day for a 70 foot x 24 foot digestion unit with a harvesting period of two months. In his video (Vermico, 2000) Eggan stated that 100 lbs of organic matter will produce 5 lbs casting with a moisture content of 25%. Such a unit may be suitable to Ireland provided proper housing and labour is available.

2.3.3.1 Temperature

Worms raised from their hatchling to adulthood under controlled conditions have shown to feed and grow well (Reinecke and Kriel, 1981).

This is possible by providing underbed heating, a well insulated glass house, polytunnels or the fibre glassed design Glas-Tec unit as operated at Moyvane, County Kerry, and Mullinahone, County Tipperary. (see Plate 2.13 and 2.14).

Plate 2.13: Glas-Tec Unit At Mullinahone STP, Co. Tipperary.

Plate 2.14: Glas-Tec Unit At Moyvane STP, Co. Kerry.

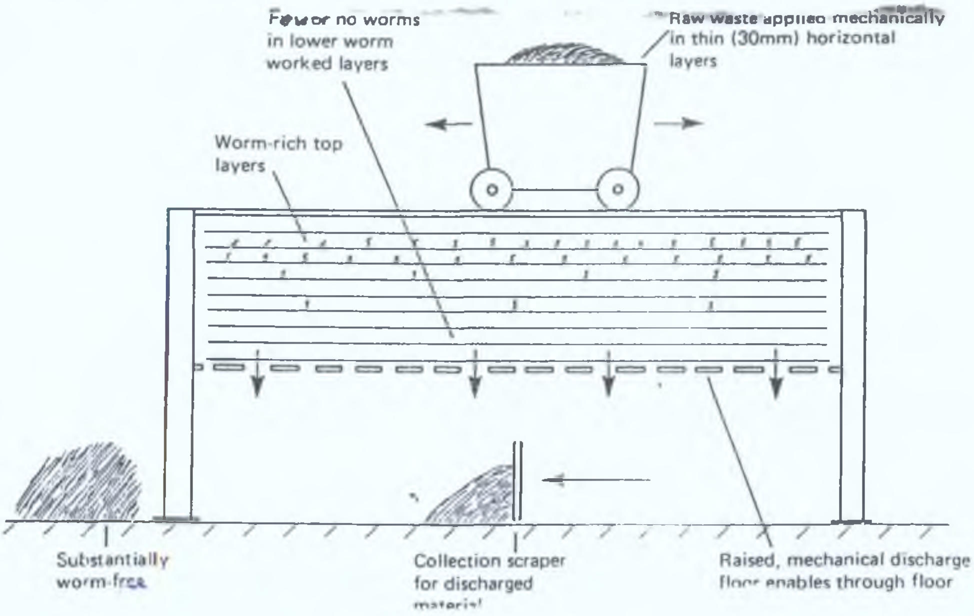
2.3.3.2 Moisture Content

In nature the greatest number of worms can be found in soils of 12 – 30% moisture (Edwards *et al.*, 1972). The optimum range of moisture from vermicomposting is between 50-90%. Automated misting systems set on timers are used in warmer climates. The bottom of the bed should be 40% moisture content (Martin, 2000).

2.3.4 Continuous Flow Reactor

The continuous flow reactor (see Figure 2.7) has the advantage over static bed design in the surface to volume ratios, as all sides allow dissipation of heat compared to static bed which only dissipates on three slides, (Subler, 2000). Earthworm mortality is subsequently reduced.

Figure 2.7: Continuous Flow Reactor System (adapted From Price, 1987).



The continuous flow system is based on adding feedstock at the top from modified spreader or gantry and collecting the casting mechanically at the bottom through mesh floors using breaker bars.

The raised unit provides stability and control over areas such as temperature, moisture and aeration, as previously mentioned. Such a method was devised and tested at the National Institute for Agricultural Engineering in Silsoe, England, and is currently being used around the world.

Pacific Garden Centre in the USA process dairy waste on a unit 120 foot by 8 foot by 3 foot high (Vermico, 2000). The system is operated by pre-conditioning the dairy waste for three days at 100°C to kill weed seeds and possible pathogens. Organic matter is fed onto the unit at approximately one inch layers, Subler (2000), or 1 lb square yards per day (Edwards, 2000). The optimum feeding density and density rate varies according to food type, reactors used and general environmental conditions prevailing. Price (1987), using a pilot scale reactor, operated over a twelve month period, where the worms are inoculated at 2kg / m² with separated cattle solids, while, Jensen (1993), showed a lower rate of 0.5 to 1 lb feedstock per l kg of worm biomass per day.

2.4 Legislation Governing Vermicomposting Of Sewage Sludge

2.4.1 Introduction

European Directive 91/156, set the general parameters for waste management. In Ireland, currently, vermicomposting is not defined as an organic waste destruction process. However, under the Waste Management Act, 1996, the composting of waste at a facility where there is greater than 1000m³ of compost and waste held is licensable (EPA, 1997). If a smaller amount is produced, a permit from the functional Local Authority is required.

2.4.2 Legislation In Ireland

Directive 91/271/EEC, enacted in Ireland by the Urban Wastewater Treatment Regulations 1996, regulates the collection and treatment of urban wastewater. It encourages the reuse of wastewater sludge, where appropriate, and recommends that disposal of wastewater sludge should be minimised, where possible (EPA, 1996).

The Dumping at Sea Act, 1996, eliminated disposal of sludge at sea after 31st December 1998.

Council Directive 86/278/EEC, *On the Protection of the Environment and in Particular of the Soil when Sewage Sludge is used in Agriculture* and the Waste Management (Use Of Sewage Sludge In Agriculture) Regulations 1998 govern the proper reuse of Biosolids in agriculture in Ireland.

The Directive applies standards in relation to heavy metal concentrations, treatment process requirements to kill pathogenic organisms, plant nutrient levels and prohibits sewage application to crops at specific times of the year.

Directive 86/278 is currently being amended. One important aspect of the proposed Directive is the definition of advanced and conventional sewage sludge treatment (Spinosa, L., 2001). The current proposal also requires stricter limits on heavy metals with new values proposed with reference to phosphorus value.

To comply fully with the proposed Directive will cost water companies in the United Kingdom an extra £50-£60/tonne dry solids (TDS) with an overall bill of 40 million pounds per year (Davis, 2002). Vermicomposting only allows temperatures to reach 30°C maximum, while the present treatments in the Directive insist on a minimum temperature of 55°C with conventional or advanced treatments. However, Annex 1 of the working document allows member states to list other processes which may achieve the same results as the listed treatments.

2.4.2.1 Other Legislation Affecting Vermicomposting In Ireland

The production of vermicompost and its subsequent use in agriculture is governed by a Code of Good Practice For the use of Biosolids in Agriculture (Fehily, Timoney & Co., 1998). The Code sets guidelines for the treatment and use of wastewater sludge.

The code is designed to reflect the requirement of relevant legislation at both national and European level. This legislation includes:

- Directive 76/464/EEC on pollution caused by dangerous substances discharged into the aquatic environment.
- Directive 80/68/EEC on the protection of groundwater against pollution caused by certain dangerous substances.
- Directive 91/676/EEC concerning the protection of water against pollution caused by nitrates from agriculture
- (SI No 258) on Water Quality Standards for phosphates.

Vermicomposting should be required to comply with all above relevant legislation on volume reduction, heavy metals, nutrient reduction, odour, vector attraction and pathogen neutralisation.

2.4.3 Legislation In America

The main body of legislation which governs the third working document on sludge, originated in the USA from 40 CFR part 503 Biosolid Rule, the *Standards for the Use or Disposal of Sewage Sludge*. Land application requirements ensure that any Biosolid that is land applied is below specified limits on pathogen and heavy metals, so as to protect human health, plants and animals. There are requirements in relation to the correct agronomic rate of Biosolid application, vector attraction, and it describes the treatment required to meet specific application standards. The rule divides Biosolids in Class A and B. Class A can be applied to land without any restrictions provided it undergoes treatment that reduces pathogen below undetectable levels. It can also be bagged for sale. Vector attraction and heavy metals are also required to be below certain limits. Class B Biosolids ensure that pathogens in Biosolids have been reduced to levels that protect human health. Land restrictions uses apply to this class (USEPA, 1999).

2.4.4 Legislation In Australia

Legislation in Australia is similiar to that in America. Stabilisation Classes A or B are used. These classes are classified according to New South Wales EPA Guidelines "*Use and Disposal of Biosolids Products 1997*".

The classes describe the end result for Biosolids by restriction use 1 or 2, or unrestricted. Unrestricted use is for residential premises, while public sites can use restriction 1. Restriction class 2 allows use on forestry and agriculture (Biogreen Casting, 1999).

2.5 Cost Of Vermicomposting

2.5.1 Introduction

There are considerable amounts of scientific literature available on vermicomposting as an alternative sludge treatment option but there is very little data on the costing involved. This is largely due to limited large-scale commercial operations.

2.5.2 Vermicomposting Cost Worldwide

It is only in the last thirty years that vermistabilisation of municipal sludge began as a sludge treatment option. Most of the research in the early 1970s was based on laboratory studies to determine the viability of earthworms in sludge treatment, with very little emphasis on costing. The capital costs of vermicomposting projects will vary significantly depending on the extent of investment in equipment and land, while operating costs will depend significantly on the amount of labour required. Operating and capital costs will vary on the type of operation (i.e. low technical system to high technical automated systems). Most of the low technical systems are used for domestic use to treat municipal solid waste. Large sewage sludge systems vary from windrow systems to continuous flow reactor systems.

The city of Lufkin in Texas constructed twelve 1,900 square foot enclosed vermicomposting beds, each capable of treating three hundred gallons per day of liquid sludge at 4% dry solids. The sludge is sprayed onto a bed of sawdust and worms. The cost analysis at Lufkin showed capital costs varied from 140,000 dollars to 680,000 dollars depending on the type of structure used, while operating costs were approximately 20,000 dollars per annum. This included labour, maintenance and sawdust. The total annual operating costs varied from 38,000 to 86,000 dollars or about 105 to 235 dollars per dry tonne processed (Pincince *et al.*, 1980).

At a pilot facility at Keyville, MD, sludge of 18% dry solid was vermistabilised on trays. However due to high labour costs involved in loading and unloading the trays in the process, labour costs alone amounted to three hundred dollars per dry tonne processed (Green *et al.*, 1978).

With a population of 17,000, Fallbrook, California, developed a vermicompost process to stabilise half of its sludge production of 0.6 dry tonnes per day. Operating costs were 330,000 dollars per year with the bulking material of straw accounting for one third of costs (Healion *et al.*, 1996).

In America, an automated invessel vermi-organic digestor based on the continuous flow reactor can handle from 50 to 850 lb per day. Capital costs been reported were 43,000 dollars (Eggan, 2000).

Very large-scale vermiculture is a capital intensive activity. A development on a site in Redland, Australia, involved capital costs in the order of 3 million dollars. This facility will process 20,000m³ of sludge waste each year with a finally produced end product of 7,000m³ of vermicompost. The total wholesale value amounted to 1.7 million dollars (Lotzof, 1999).

2.5.3 Vermicomposting Costs In Ireland

It is only in the last ten years that vermicomposting has been developed in Ireland. Vermistabilisation in Ireland centred mainly on research and development (Walsh, 2000). A number of pilot studies were conducted to assess and evaluate vermicomposting as a viable option for sludge treatment in Ireland. Cost implications were not discussed in most of the research. Detailed research conducted in County Carlow in 1993 showed capital costs of £200,000 excluding vat. This involved tunnel costs, worm bed construction and tunnel services, while net operating costs totalled £120,000, with labour costs accounting for £36,000. This relates to two operators working on the vermistabilisation site. This net present cost of the vermistabilisation project amounted to over six hundred and fifty thousand pounds with a net present cost per tonne of dry sludge solid disposed of £394. The costs are based on a population equivalent of 28,230 with a sludge production rate presently of 429 tonnes of dry solid per year and a projected sludge production rate of 1,050 dry tonnes per year. Furthermore it is estimated that capital costs of one million pounds are required to build a 70m by 20m vermistabilisation system with controlled environmental conditions (Healion *et al*., 1996).

2.5.4 Vermicomposting Costs In Mayo

2.5.4.1 Economics of Sludge Treatment In Achill Island.

Under the Sludge Management Plan (Fehily, Timoney and Co., 2000) capital costs of £215,000 are estimated for Achill Island. This is based on a population equivalent of 2,500 pe. However, as the system is not fully developed in Ireland, operational costs are not available on this system. The requirement for bed and unit maintenance, harvesting and sludge conditioning, necessitates a requirement for an extra labour unit on a flexible part time basis. As land area is not limited at Achill, capital costs are reduced.

2.5.4.2 Economics of Sludge Treatment At Belmullet and Louisburgh

The sludge plan as outlined recommends liquid vermistabilisation for Belmullet and Louisburgh. Capital costs are estimated at £60 to £100 per population equivalent. With a population equivalent of 2,000 people anticipated for Belmullet, extra vermicomposting units are required to deal with the extra volumes of sludge produced. The present vermicomposting units deal with a population equivalent of approximately 200 pe. This may require the installation of ten units in Belmullet by the year 2005. The operational costs to deal with the extra units would increase to £25,000. This is based on a routine maintenance contract of £2,500 per year. The same situation would exist in Louisburgh where operation costs would increase to £12,500 by the year 2005. There is also a cost requirement to deal with the extra workload such as the casting and the earthworm maintenance in the vermicomposting unit.

In general, pilot scale applied research should seek to document the capital and operating costs of vermicomposting including structural requirements, labour and the purchase of earthworms. The overall costing should involve bedding material, labour and the disposal of the vermistabilised products. In comparison to alternative methods of sludge disposal in Australia, vermicomposting costs are shown to be comparable with other technologies (Vermitech, 1999).

2.5.5 Economic Value of Vermicomposting

The annual fertiliser market in Australia exceeds 2.5 million tonnes. There is now growing recognition that vermicomposting or earthworm biomass can replace a certain fraction of inorganic fertiliser. Vermicomposting product in Australia, which is produced to the highest standard, can command a price exceeding 250 Australian dollars per cubic metre (Lotzof, 1999). In a facility in Albuquerque, New Mexico, screened worm castings retail at a premium price in half gallon containers (Block, 1999). Many soil scientists also recommend that the casting be used as supplements with other soil supplements, such as compost, rock powders and minerals (Jensen, 1997).

Vermicompost can be used in Mayo to rehabilitate cut away bog (Fehily, Timoney & Co., 2000). In Yelm farm Washington, vermicomposting retails at three times the price of other compost. It also has developed a market for live worm sales (Edwards and Steele, 1997).

The effluent from the vermicompost by Bathurst City Council, New South Wales is also sold (Biogreen Casting, 1999). In Ireland, production quantities of vermicomposting product are very small, as the sludge volume being treated is minimal. The end product for earthworm biomass includes road and housing, landscaping, golf courses and final landfill covering.

3.0 Materials and Methods

3.1 Introduction

The Sludge Management Plan for County Mayo recommends that vermicompost units should be installed at three locations. In this study, a small pilot system was designed to give initial, indicative data, for comparison with literature sources. The practical work undertaken was designed to:

- Evaluate the capacity of a vermicomposting to treat sludge that has been dewatered with the aid of a Polyelectrolyte.
- To monitor solids reduction, moisture, and temperature.
- Quantify changes in sludge composition.

The trial was for a period of twenty days.

3.2 Trial System Design

A pilot test was conducted at Bangor Erris Sewage Treatment Plant operated by Mayo County Council. As the author is currently employed on the site it was appropriate to conduct the trial at this site.

The unit was constructed at the plant without any capital requirement. The equipment and materials were available on site. An enclosure was constructed, three metres long by three metres wide giving a gross area of $9m^2$ (Plate 3.1). The enclosure had a concrete base with timber supports. The unit was covered by a robust radon barrier covering. The unit was divided into two compartments (Plate 3.2), giving a control bed and worm bed. The gross area for each bed is three square metres.

A stocking density of 10,000 worms per metre square was suggested in the literature (a sewage/grease sludge in Toulouse) (Healion *et al.*, 1996), while Walsh (1996) seeded 120kg of worms (*Eisenia foetida*) per 1.5 cubic metres. 10kgs of worms were purchased from the Irish Earthworm Company in County Cork at a rate of 19 euro per kilogram.

The 10 kgs of worms were seeded to the worm bed. Sewage sludge was not applied for the next three days. This allowed the worms to acclimate to the worm bed and secondly allowed the worms to decompose the paper substrate that accompanied their shipment to the site. Retaining a portion of worms was considered, in case of shock loading to the system. Due to the history of the effluent for the last 6 years, this was not believed to be necessary.

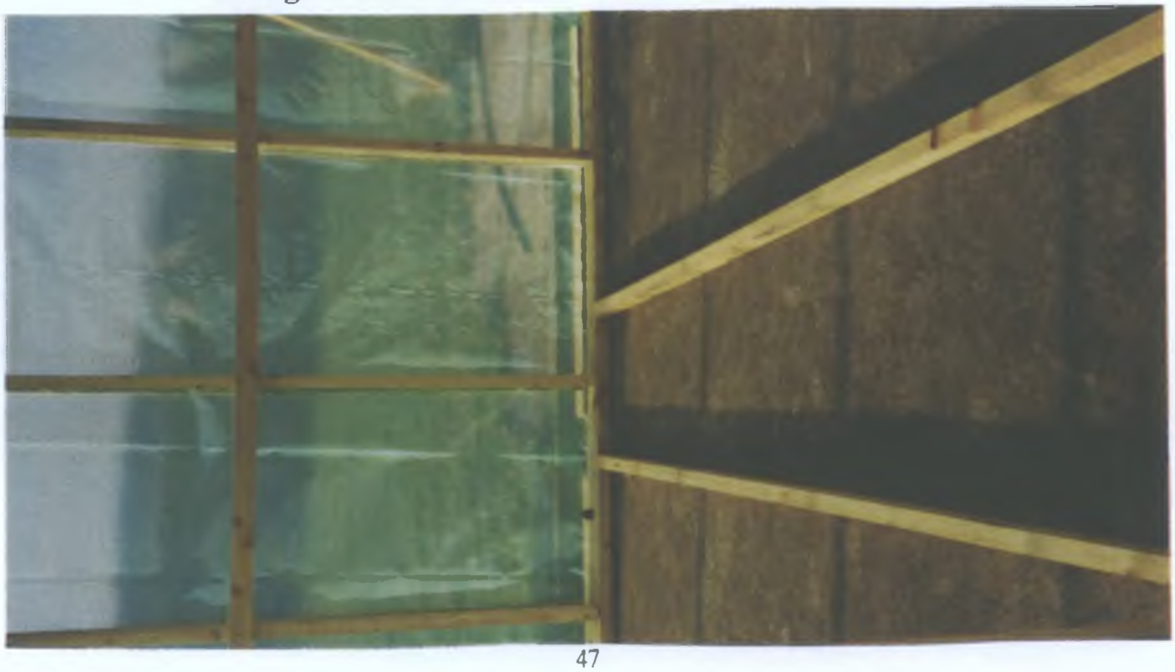
The bedding material option depends on the following factors:

- *Cost*
- *Local availability*

A local saw dust/wood peeling was selected as the bedding material. It was free.

Plate 3.1: External View Of Vermicomposting Pilot Building At Bangor Erris Sewage Treatment Plant

Plate 3.2: Internal View Of Vermicomposting Pilot Building At Bangor Erris Sewage Treatment Plant.



To enhance drainage and aeration, perforated six inch drainage pipes were installed under the saw dust/wood peeling layer. To provide easy access and due to the nature of the substrate, a central walkway was installed. It also provided maintenance access if required.

The work was conducted in summer months, and, as a result, supplementary heating was not required. Shorter nights in May resulted in shorter cold periods. A light source was used within the unit. It had two functions

- It provided a heating source at night when the temperature dropped.
- Earthworms are very sensitive to light. Artificial light prevented the earthworms from leaving the bed at night thus preventing destocking to occur.

Moisture was maintained at 80 to 90%. Approximately 50kgs at 14% dry solid content was spread on the worm bed. A control bed of 50kg of dewatered sludge without worms was also used.

3.4 Analysis Undertaken

3.4.1 Introduction

As vermistabilisation is bioconversion of organic matter into worm casting, there is the requirement to monitor and analysis the physical, chemical and biological characteristics obtained within the worm bed.

Plate 3.3: Sludge Added To A Sawdust Bedding Material

Plate 3.4: Sludge Added To Control Bed (left) And Worm Bed (right)

3.4.2 Parameters Measured

Parameters measured were as follows:

- Moisture Content/Total Solids
- Temperature
- Heavy metals e.g. Lead (pb), Copper (Cu), Cadium (Cd).
- Phosphates
- % Dry matter
- Volatile solids
- Humidity

Analysis of heavy metals was carried out at the Environmental Protection Agency Laboratory in Castlebar and Dublin.

Temperature was monitored by the use of handheld temperature probe which was read visually once during the day. Humidity within the unit was measured by a DELTA OHM HD 9216, a combined moisture and temperature meter. These parameters were read once per day.

In normal operation of the main wastewater treatment plant, sludge of 2% from the picket fence thickener is fed onto a series 825 Solid Technology Double Press where a polyelectrolyte is added to enhance dewatering. The dewatered sludge is forwarded to a screw conveyer, and then to a 12 cubic yard bin. This was the sludge that was used in the trial.

1kg of grab sample was obtained at two locations within each bed at day zero, day ten and day twenty for analysis.

4.0 Results

4.1 Introduction

The results obtained are an indication of the ability of earthworms to stabilise organic matter under Irish field conditions. The results were produced over a period of 20 days under semi-controlled conditions.

4.2 Principal Parameters Monitored

There was a visual difference between the two beds. On the control bed, it could be seen that the sludge did not undergo any significant decomposition (Plate 4.1). The sludge appeared undigested there were crusts in the upper area of the bed. In contrast, the worm bed appeared to have stabilization to some degree, with the formation of worm castings (Plate 4.2). The bedding of sawdust provided aeration, which is essential for the vermistablisation process. Conditions within the polytunnel were observed, including light and drainage.

The results of the solids and phosphorous analysis are shown in Table 4.1 and results for heavy metals are shown in Table 4.2.

TABLE 4.1: Changes in the solids and phosphorous parameters of the Control Bed and Worm Bed

Parameter %Total Dry Solid	Units	Day 0	Control at Day 10	Control at Day 20	Worm Bed at Day 10	Worm Bed at Day 20
Total Solids	mg/kg	131700	158171	142000	170264	211000
% Dry Weight	%	13.2	15.8	14.2	17.0	21.1
Volatile solids (d.s)	mg/kg	745000	734000	739000	792000	836000
Total Phosphorus	mg/kg	2136	1956	2207	1356	1174

Plate 4.1: Control Bed

Plate 4.2: Worm Bed

TABLE 4.2: Comparison of the concentration of heavy metals in worm bed to the control bed

Parameter Dry Solid	Units	Day 0	Control at Day 10	Control at Day 20	Worm Bed at Day 10	Worm Bed at Day 20
Copper	mg/kg	74.8	41.2	67.7	38.2	63.6
Cadmium	mg/kg	0.12	0.12	0.11	0.10	0.11
Lead	mg/kg	6.9	6.5	7.8	6.0	6.7

4.2.1 Phosphorous

From Table 4.1, it can be seen that phosphorous values varied from 0.21% at day zero to 0.22% in the control bed and 0.12% in the worm bed at day 20. At day 10 the phosphorous level in the control bed was 0.19% while in the worm bed it was 0.13%.

4.2.2 Heavy Metals

Heavy metals results are shown in Table 4.2. Copper values at day zero were 74.8 ppm, reducing to 38.2ppm at day 10 and 63.6ppm at day twenty in the worm bed. The control bed levels were 41.2ppm and 67.7ppm at day 10 and day 20 respectively. Cadmium levels were low through the trial period, with values of 0.10 to 0.12mg/kg dry weight in all beds. Lead values varied from 6.9ppm at day zero to 7.8ppm in the control bed to 6.7ppm in the worm bed.

4.2.3 Temperature

A comparison of temperature in the worm bed is shown in Table 4.3 and Figure 4.1. A comparison of the worm bed and the polytunnel is illustrated in Table 4.4 and Figure 4.2. The bed temperatures were relatively consistent. The polytunnel atmosphere showed significant variation.

4.2.4 Relative Humidity

As can be seen from Table 4.5 and Figure 4.3, a comparison was made of temperatures within the polytunnel and percentage relative humidity. Temperature ranged from a low of 13.7°C to a high of 28°C while humidity ranged from 41.8% RH to 83.7% RH.

Table 4.3: Comparison Of Temperature in the Control Bed And Worm Bed

DAY	WORM BED	CONTROL BED
0	11	10.9
1	11	11.1
2	13.2	13.5
3	13.5	13.6
4	14.2	14
5	13.5	13.1
6	13.3	13.1
7	16.2	16.3
8	16.3	15.9
9	14.9	15.8
10	16.2	15.9
11	15.4	14.6
12	14.3	13.7
13	13.6	13.8
14	15.6	14.8
15	15.5	14.7
16	14.5	13.7
17	14.6	15.2
18	15.4	16.1
19	15.5	15.3

Figure 4.1: Comparison Of Temperature in the Control Bed And Worm Bed

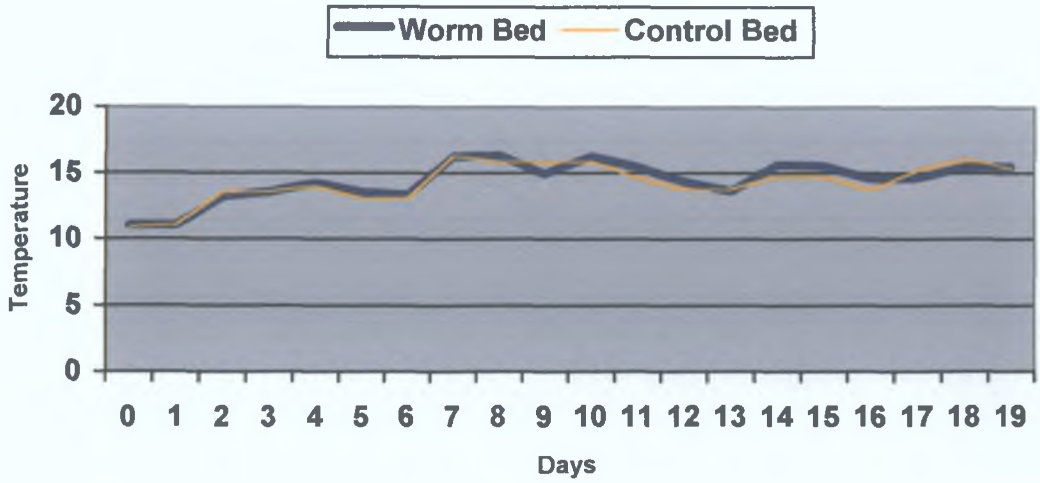


Table 4.4: Comparison Of Temperature In Worm Bed and Polytunnel

DAY	WORM BED TEMPERATURE	TEMP WITHIN POLYTUNNEL
0	11	18.3
1	11	17.5
2	13.2	16.6
3	13.5	17.3
4	14.2	17.2
5	13.5	21.1
6	13.3	22.4
7	16.2	24.8
8	16.3	16.7
9	14.9	25
10	16.2	24.6
11	15.4	22.1
12	14.3	13.7
13	13.6	16.6
14	15.6	28
15	15.5	20.6
16	14.5	14.8
17	14.6	16.2
18	15.4	25.4
19	15.5	19.2

Figure 4.2: Comparison Of Temperature In Worm Bed and Polytunnel

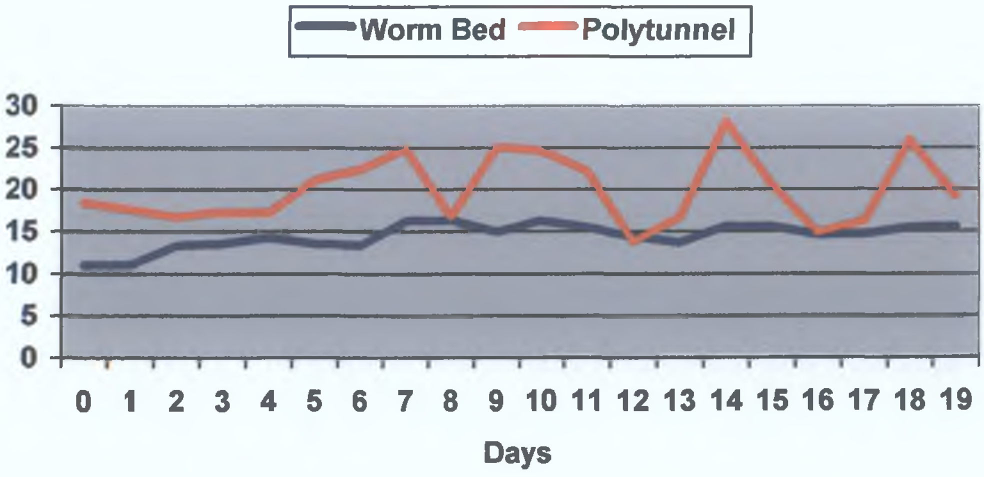
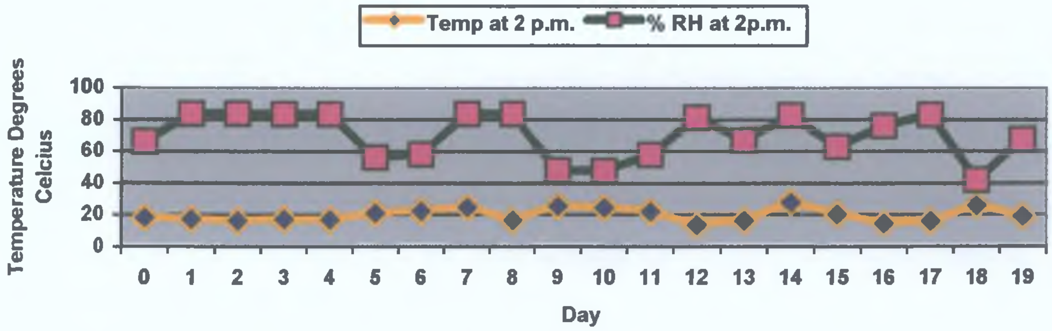


Table 4.5: **Temperature Within Polytunnel Compared To Percentage Relative Humidity**

DAY	*Temperature at* 2 P.M.	% RELATIVE HUMIDITY at 2 P.M.
0	18.3	66
1	17.5	83.5
2	16.6	83.7
3	17.3	83.2
4	17.2	83.1
5	21.1	55.9
6	22.4	58
7	24.8	83.4
8	16.7	83.7
9	25	48
10	24.6	47.8
11	22.1	57.8
12	13.7	81.3
13	16.6	66.7
14	28	82.4
15	20.6	62.8
16	14.8	76
17	16.2	83
18	25.9	41.8
19	19.2	67.3

Table 4.5: **Temperature Within Polytunnel Compared To Percentage Relative Humidity**



5.0 Discussion

5.1 Introduction

The experiments were conducted in the polytunnel under semi-controlled conditions. The results show aspects of the vermistabilisation process in an Irish context. The results indicate what may occur under field conditions.

5.2 Trial Process

5.2.1 Light

Light was provided for two reasons. It acted as a heat source at night-time, to offset the decrease in temperature. Earthworms in general are sensitive to light, but if exposed for a period to strong light they do not react to any sudden changes in light intensity (Edwards *et al.*, 1972). Also it was essential in the trial that a light source was on continuously. The worms tend to migrate in periods of darkness. Having continuous light prevented the worms in the worm bed gaining access to the control bed, or generally leaving the confines of the polytunnel. The requirement for light would also be necessary in a fully operational reactor unit.

5.2.2 Bedding Material

The bedding material that was used was obtained locally from a sawmill. The saw dust/wood peeling was suitable for the trial. However, it was necessary to add water once a day, at approximately 5 litres per bed. This was necessary to keep the bed moist, due to high absorption rate of the bedding material. The bedding material used did not show any visible effect on the earthworm population.

In trials conducted at Ohio State University on a range of bulking agents, the sewage/ sawdust mix using *Eisenia andei* showed the smallest growth rate compared to a sewage/food waste mix (Dominquez *et al.*, 2000). The good result obtained in studies into sewage/food waste in Sovadec in France, Healion *et al.* (1996) showed that municipal solid waste can be combined with sewage sludge. The end result is the removal of two organic wastes from the waste hierarchy.

5.2.3 Temperature

It is important in vermistabilisation to use the temperature at which population growth is most rapid, or at which the efficiency of conversion of substrate to worm tissue is highest (Aston, 1988). Controlling temperature is one of the critical parameters in the Irish situation. Many of the studies conducted on vermicomposting relate to countries like America and Australia, where ambient temperatures are suitable to vermistabilisation. In general, conditions that promote the most rapid feeding and conversion of waste to casting are found in the temperature range of 13°C to 22°C (Pincince *et al.*, 1981). In the study conducted at Bangor Erris Sewage Treatment Works (Plate 5.1 and 5.2) temperatures within the worm and control bed ranged from 11°C to 16.3°C. However, to obtain the highest yield and conversion of substrate, cocoons should be produced at a constant temperature of 20°C to 25°C (Reinecke *et al.*, 1981). A comparison of worm bed temperatures and polytunnel temperatures showed increases in temperatures in the worm bed with a corresponding increase in polytunnel temperature.

If possible, twenty four hour readings would give a true reflection of bed temperatures throughout the day and night and these results would be critical in designing a full scale unit. The lower temperatures in the bed in the first five days may be due to the high ratio of cooling surface to waste volume (Price, 1987). The addition of underbed heat would benefit the overall system. The energy costs involved would need to be investigated in an overall full scale project.

Plate 5.1: **Overview of Bangor Erris Sewage Treatment Works**

Heat cables are used at Toomevara, in County Tipperary. Health and safety aspects need to be addressed in relation to heating cable in the vermicompost unit as rodents can expose electrical cables by chewing on them. It was noticeable in the morning after a cold night that earthworms were deeper into the bed in comparison to the afternoon, where increased temperature moved the worms to the top of the bed.

Plate 5.2: View Of Dewatering Building And Thickening Unit

5.2.4 Humidity

Humidity values were taken daily. A comparison of temperature and relative humidity shows no significant trend. There is some indication from Table 4.5 and Fig 4.3 that as temperature increases humidity values decrease. The inconsistent values from the figure may be partially due to the addition of water periodically to the trial beds. The significance of water is a increase in moisture content within the beds. This causes a subsequent decrease in humidity values. Various reports indicate an optimum relative humidity of 50% to 60%. High humidity levels cause increased evaporation from the beds leading to drying to occur. This may lead to damage to the skin of the earthworm with possible mortality. Its effect on earthworm biomass and organic conversion needs attention on a full-scale operation.

5.2.5 Heavy Metals

A number of authors have reported changes in the heavy metal composition of vermicomposted waste. To date, there are recordings of increases, decreases and no changes. The three heavy metals, that were investigated on the trial showed varying results.

5.2.5.1 Copper

The Copper results showed decreases in day 10 and increases in day twenty in both beds. However, Cadium and Lead remained constant over the twenty days. In general, metals in sludge are less toxic to worms than are metals in soils, where copper concentration in sludge up to 1500 ppm has been shown to be not toxic to *Eisenia foetida* (Beyer, 1981), although 2,500 ppm of copper sulphate was lethal (Hartenstein *et al*., 1980). The effects of heavy metal accumulation were investigated by Malecki *et al*. (1982) over an eight and twenty week trial. Results showed that copper concentration in excess of 500 ppm was necessary before growth rates were affected, while a concentration of 2000 ppm inhibited reproduction rates.

The levels obtained in this trial agree with previous Irish trials, which indicated that metal concentration is low in Irish sewerage systems (Gray, 2001). The decrease in copper concentration in day ten in the control and worm bed may indicate leaching of the metals to drainage pipeline. Walsh (1996), showed that copper was definitely accumulated in the worms.

An hypothesis for the increase in copper values at day 20 is that it may possible be due to microbial actively which allows extractable metals such as copper to become soluble within the worm bed (Hartenstein, *et al* 1980).

5.2.5.2 Cadmium

The Cadmium level results in the trial showed levels that did not vary across the twenty days. The values are very small in comparison to the legal value of 20-40 mg/kg dm under the Directive 86/278/EEC on the Use Of Sewage Sludge in Agriculture and the pending third draft document on sludge (Europa, 2000).

Cadmium may accumulate in worm tissues if concentrations are in excess in the sludges (Hartenstein *et al.*, 1980; Beyer, 1981). However, Collier (1978) suggested that it required a period of a half a year exposure of the worms to the sludge before accumulation occurred. The suggested reason why Cadmium accumulates in worms is reported to be related to the metabolism of micro-organisms which release the Cadmium from the sludge (Neuhauser, 1978). However over the period of the trial at Bangor Erris, results obtained contradicted those findings. No changes occurred in either bed over the twenty days.

5.2.5.3 Lead

The irregular values through the study for lead are very difficult to interpret. No significant changes occurred between day zero and day twenty.

In some other studies, it was suggested that Lead levels are reduced in worm beds, and that the mechanism is possibly the translocation of metals within the sludge, causing it to be diluted and carried deeper in the bedding material (Hartenstein *et al.*, 1981).

In general, lead accumulates in the epithelial cells of both the body wall and the alimentary canal of earthworms (Beyer, 1981). An hypothesis could be proposed that the bedding material may affect the uptake of heavy metals such as lead. In a trial conducted at Fallbrook District in California on the vermicomposting of sewage sludge and bulking agent, Harris *et al.* (1990), found that worms prefer the sludge with straw bulking material over the sludge with wood chipping. Consequently it was consumed more readily, which showed higher levels of metal reduction and bioaccumulation.

It is concluded that a lot more research is required in heavy metal accumulation in casting and worms to determine the benefits of vermicomposting as a soil conditioner/fertiliser. In the Irish context generally, heavy metal concentration in municipal sludge is low, but constant monitoring is necessary if industrial complexes are discharging their effluent to municipal sewage systems.

5.2.6 Phosphorous

The concentration of phosphorous was measured in the control bed and worm bed. The results indicate that, in the worm bed, the phosporous is transferred to the worm biomass or, secondly, it was leaked to drainage.

However leakage is unlikely, as the control bed remained constant. As the leachate was not measured, it is difficult to comment as to the balance of loss. In further trials a comprehensive look at the chemical content of vermicomposting, especially nitrogen, phosphorous and potassium is necessary in order to evaluate and assess their potential as a fertiliser in vermicomposting.

5.2.7 Total Solid / Moisture Content

Initial total solid content of the sludge was 13.2%. From the result it showed a slight increase in the control bed, while a significant increase in total solids was seen in the worm bed. Moisture and total solid content are linked to the performance of the vermicompost bed. It has been shown that, for cocoon and bioconversion of biomass into casting, a range of 9%-16% total solid content is optimum (Neuhauser, 1988). This was the range used in the current trial.

To facilitate the separation of the casting from the live worms, it is necessary to have the moisture less than 80% moisture content. This is necessary to reduce balling of the vermicompost (Price and Phillip, 1990). Research trials have shown that liquid vermistabilisation can occur provided proper drainage and correct bedding is available. This can be viewed at facilities at Toomevara and Mullinahone in County Tipperary and at Moyvane in County Kerry. Other considerations that affect reduction in total solid increase are earthworm density (Ndegwa *et al.*, 1999).

As in Plate 4.2, there was visual evidence of stabilisation of the worm bed, when compared to the control, Plate 4.1, which showed crusting of the sludge and a soggy texture.

5.2.8 Volatile Solids

Volatile solids reduction is a measure of stabilisation in the vermicomposting process. Neuhauser *et al.* (1988) stated that maximum reduction of volatile solids is the goal of any sludge stabilisation system. The probability of putrefraction occurring in the sludge, due to anaerobic conditions is reduced. The result of the trial showed no volatile solid reduction in the worm bed indicating no organic stabilisation by the earthworms. The results showed the volatile fraction of the dried sample increased from 74.5% at day zero to 83.6% at day twenty. An eight week trial conducted in the University of Georgia, on biosolids and paper waste, showed a volatile solid reduction of 12%, while trials at Redland in Australia, on the undigested biological nutrient removal sludge, it was established that in excess of 50% reduction was recorded (Rogella, 2002).

A possible reason for the initial decrease in volatile solid is that the earthworm casts contained a higher organic fraction which was accessible and available to micro-organisms. In contrast the control bed showed no significant reduction indicating no stabilisation.

5.2.9 Odour Reduction

Over the twenty day period, there was no evidence of odour from the control or worm beds. Trials have shown that the increased surface area of the worm beds allows the micro-organisms and malodorous molecules to come into contact with each other, thus eliminating odour (Hartenstein, 1978). Hartenstein, *et al.* (1981), showed odour elimination is due to high oxygen levels within the sludge, due to the action of earthworms.

However, on a mixture of 50% Biosolids and 50% chipped green waste, it was observed that production of offensive odours were noticed when the material was disturbed (Biogreen Casting, 1999).

5.2.10 Volume Reduction

Due to the short period of the trial significant volume reduction was not noticed. Much of the literature presented has very little data on volume reduction, but according to Subler (Vermico, 2000), a 10% volume reduction on dairy waste was achievable using the continuous flow reactor system, while DATAR *et al.* (1997), showed a 40% reduction by volume and weight.

A lot more research is necessary to prove that vermicomposting of municipal is viable as a useful sludge technology. In this trial, there was some visual evidence of stabilization, but this was not borne out in the analysis. The polyelectrolyte on the worm bed appeared to have no adverse effect on earthworms growth or reproduction rates.

Further research and development of vermicomposting is recommended. Firstly basic research should investigate the rate of sludge conversions, the earthworm breeding rates, and to look at the development of other earthworm species in vermicomposting. Other important parameters to be researched and addressed include heavy metals and the rate of pathogen reduction during vermicomposting.

Unless pathogen reduction is proved successful in vermicomposting, precomposting will be necessary, in order to comply with existing and pending European Union Directives.

Secondly, large-scale applied research is required to document capital and operating costs involved in vermicomposting. There is the need to develop mechanical methods of loading and unloading the worm bed both with dewatered and liquid sludges.

6.0 Conclusion

- The literature shows a wide variation in vermicomposting systems and reported effectiveness.
- Heavy metals were low in the sludges studied in the trial. Vermicomposting had little effect on metal concentration.
- Total solids were increased, but there was no significant reduction in volatile solids.
- Odour was not found in the trial.
- Literature has shown that liquid vermistabilisation is possibly viable but cost factors need more research.

7.0 Recommendations

1. The practical work at Bangor Erris should continue.

2. A full-scale pilot vermistabilisation trial plant should be developed.

3. A variety of bedding materials, including municipal solid waste, should be investigated.

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APPENDICES

County Mayo

Legend

🟥 Waste Water Treatment Plants

◆ Bio-Disc/ Septic Tanks

Location of Wastewater
Treatment Plants
In County Mayo (2020)