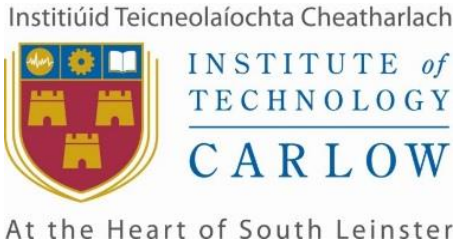
Analysis of the vermicomposting process and its implications for plant growth promotion under Irish conditions



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Dedication

To Eileen and Anton

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Abstract

Waste is an ongoing issue, especially in Ireland. Current waste management treatments are becoming unsustainable; therefore, research on alternative methods is being conducted. This project investigates the use of vermitechnology as a possible treatment method for food waste. It involves the use of earthworms to degrade food waste in an environmentally safe manner. A system was built on-site using the earthworm species *Eisenia fetida* to break down food waste over a 65-day period. This work was successful in reducing the volume of food waste added to the system in a clean, economically feasible way. On the other hand, a liquid by-product produced from this technology is called 'vermitea'(VT). Physio-chemical analysis, including pH and electrical conductivity, was carried out on VT produced on-site and from commercially sourced vermicompost (VC) prepared from a protocol designed in the lab for this project, along with nutritional analysis for potassium and phosphorus determined by UV spectroscopy. Results indicated a significant presence of physio-chemical content; after nine weeks, pH was 6.6 ± 0, electrical conductivity (EC) resulted in 755µS/cm ± 2, a salinity content of 4.3 *PSU* ± 0 and finally a total dissolved solid concentration of 292 mg/L ± 1. The nutritional content of the VT samples was interesting, with potassium levels increasing from approx. 500 mg/L initially to 1000 mg/L after nine weeks, compared to the control which decreased over the same time period. With respect to VT from commercially sourced VC, smaller amounts of VC may be soaked to prepare VT for sufficient nutrient concentration.

Finally, the plant growth promotion potential of VT was studied through the application of VT against a leading chemical fertiliser, Miracle Gro® to a variety of arable, horticultural and pasture crops. Two types of experiments were designed, *i.e.* seed germination and early seedling development experiments. Overall water was seen to be the best treatment for growth in barley in germination tests with 34% germination, a root length of 1.5 cm ± 1.8 and a shoot height of 0.7 cm ± 1.1. Oat benefitted primarily form VT treatment, with 64% germination, a root length of 2.3 cm ± 1.4 and a shoot height of 1.4 cm ± 1.0. For the above crops in soil, a combination of VT and MG for barley, while VT for oat could be used. With respect to horticultural crops, VT could be added to aid in the growth of cauliflower and pea, while a combination of water and VT added to aid carrot and turnip and possibly a combination of 20 % MG and VT for tomato. Finally, in

relation to a pasture crop, clover, VT aids in the germination of seeds in the initial growth stages, while MG then contributes to growth in the following growth stages in soil.

Overall this technology can help in the reduction of food waste currently sent to landfill, in a safe, cost-effective manner, while producing an organic solution which may be used to aid the germination of a variety of plant species

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List of Abbreviations and Units

%	percentage
°C	Degrees Celsius
µS	micro Siemens
BMW	biodegradable municipal waste
CH_4	methane
cm	centimetres
EC	electrical conductivity
EU	European Union
g	grams
K	potassium
L	litres
Mg	milligrams
mg/L	Milligrams per litre
ml	millilitres
MSW	municipal solid waste
N	nitrogen
N_2O	nitrous oxide
P	phosphorus
PSU	practical salinity unit
SD	standard deviation
SE	standard error
t/ha	tonnes per hectare
TDS	Total dissolved solids
UV	ultraviolet
VC	Vermicompost
VOC	Volatile organic compounds
VT	vermitea
χ^2	Chi-squared

Chapter One

General Introduction

1.1 Introduction

Food waste is an addressable problem and may be an alternative for efficient use of limited agricultural resources, while global population is set to rise from 8 billion in 2030 to 9.2 billion by 2050 (Department of Agriculture, Food and the Marine, 2015) and the requisite quantity of food rises also. Current food waste management, largely landfills, have been in use for the last few decades. Food waste issues include; landfill restricted capacity, environmental pollution and reduction in greenspace, especially habitats for native wildlife. It is important to manage waste in a manner that is more productive and less benign to the environment. This project investigates a novel treatment, vermitechnology, which has been researched previously by other researchers for a variety of wastes including municipal and domestic.

1.2 Waste in world and Ireland

The definition of waste under Article 3(1) of the new Waste Framework Directive is;

'any substance or object which the holder discards or intends or is required to discard'

(European Commission, 2012), and according to the Environmental Protection Agency *"One-third of the food we buy ends up in the bin. This can cost the average household up to €1,000 per year"* (2015).

One form of waste is Biodegradable Municipal Waste (BMW), *i.e.* waste including commercial and household materials, which will degrade or rot in time in aerobic conditions. The main elements of this form of municipal waste are paper, cardboard, food waste, textiles and garden waste (grass cuttings and leaves) (Environmental Protection Agency, 2015).

In the European Union, 89 million tonnes of food waste is generated annually, while Ireland generates over 1 million tonnes per year, which including household, business and food production waste. It is interesting to note that much of the food waste occurs without any consumption of food at all.

Ireland is a relatively small island with a total area of 84,409 km^2. In April 2017, the population of Ireland was estimated at 4,792,500 people, having increased by 52,900 people since the former census (Central Statistics Office, 2017b). Although small in comparison to many EU countries, Ireland produces notable quantities of waste.

An average of 367 kg household waste is produced per person annually, of which 25 % is food waste (Environmental Protection Agency, 2015), having increased from 2013 when household production was 304 kg per person (Environmental Protection Agency, 2014). This attitude towards food results in the following question: 'Where does all this food go?'

1.3 Food Waste Regulations

Legislation is always changing in order to compete with the growing food waste issue. In December 2009, in Ireland, the Minister for the Environment, John Gormley signed the Waste Management (Food Waste) Regulations 2009 (S.I. No. 508 of 2009; Environmental Protection Agency, 2015). These regulations encourage both the segregation of food and food recovery from food waste arising from the commercial sector (Minister for the Environment, Heritage and Local Government, 2009). They also enforce the requirement on major sources of food waste in this country including State buildings, hotels and supermarkets to separate foodstuffs and to allow them to be available for distinct collection. These regulations also state that:

"*They will facilitate in particular the achievement of the targets set out in Directive 99/31/EC on the landfill of waste for the diversion of biodegradable municipal waste from landfill sites to composting and to other forms of authorised treatment*"

(Waste Management (Food Waste) Regulations 2009)

The above regulations were amended in 2015 by S.I. No. 190 of 2015. Some amendments include; the introduction of 'The European Union (Household Food Waste and Bio-waste) Regulations' in 2013.

1.4 Food waste treatment in Ireland

Currently, there are two main options regarding the disposal of waste; landfill and incineration. Recycling of food waste in this country has only become apparent in recent times.

1.4.1 Landfills

The construction of landfills can be very costly and the area of land required is vast. There are different types of landfills in Ireland. The Landfill Directive 1999/31/EC of 26 April 1999 classifies landfills by waste type: inert waste, hazardous and non-hazardous waste (Environmental Protection Agency, 2014).

The landfills in Ireland include the category of municipal solid waste (MSW) landfills (Environmental Protection Agency, 2014) under which food waste falls. According to the Environmental Protection Agency, MSW landfills can be described as accepting *"predominately household and commercial waste, and lesser quantities of industrial waste"* (2014), therefore MSW landfills may accept food waste. In 2016, three hundred and forth thousand tonnes of biodegradable municipal waste was sent to landfills in Ireland (Environmental Protection Agency, 2017). The waste is packed into the landfills and covered, where it will degrade over time.

Landfills can be referred to as either ***open*** (landfill is accepting or open to accepting waste for disposal during a certain time period) or ***closed*** (the landfill has permanently ceased accepting waste for disposal) (Environmental Protection Agency, 2015).

While there are important advantages of landfills, their negative effects are far more dangerous and are harmful for the environment and human health. The emissions from these landfills occur in different forms: volatile organic compounds (VOCs), gaseous form, leachate and airborne particulate matter (Slack, 2004), which are all seriously harmful, especially toxic gases that include toluene and xylene along with other greenhouse gases like nitrous oxides (N_2O) and methane (CH_4). These gases are extremely harmful to the health of both humans and animals. There needs to be an alternative way of waste disposal, including our food waste. As landfills have been used for every form of waste, they are filling up to capacity and may soon face closure.

In Ireland, there has been a reduction in the number of landfills accepting municipal waste from twenty-five (in 2010) to only seven (in 2016) (Environmental Protection Agency, 2017). As the only method of disposal, for both hazardous and non-hazardous waste, the environmental repercussions of this strategy only begin to properly present itself in the coming years.

1.4.2 Incineration

As it stands, Ireland currently has only one regional facility for incineration in Dublin, Poolbeg, which took almost twenty years to plan and build. There are also a number of small industrial incinerators which concentrate mainly on the incineration of pharmaceutical products along with chemical waste (Corrigan, 2011). Incineration is not a problem-solving waste disposal tool. Although there is a consensus that when waste is burned, it disappears, this is not the case. Incineration only reduces waste to around 30-50 % of the original waste volume that was compressed and added initially and this reduced mass is then converted to ash.

An important issue is how this ash/toxic residue is disposed of. If any of these residues were to seep out and in turn pollute waterways and sources of water in areas of habitation, it would be a severe danger to health. The composition of emissions released from incinerators varies depending on the type of waste that was burned and the type of pollution control measures available.

1.4.3 Anaerobic Digestion

Anaerobic digestion is a new technology which is being implemented. The aim of this technology is to break down waste under anaerobic conditions (no oxygen available) using micro-organisms who can tolerate an oxygen-free environment, resulting to the production of a 'biogas' A paper by Holm-Nielsen *et al.,* (2009) discussed the possible use of anaerobic digestion for animal wastes and slurries in the future.

1.5 Vermitechnology

As current waste treatment methods are becoming unsustainable, alternative techniques are being pursued. One such method is the use of Vermicomposting as a safe, sustainable approach for treating organic waste that is becoming increasingly popular as a management strategy for organic waste (Manyuchi *et al.,* 2013). Vermitechnology can be defined as the process which combines the techniques of both vermicomposting and of vermiculture (Board, 2004). This technology is now emerging as an "economically viable" and "environmentally sustainable" approach of food waste treatment which has been accepted socially worldwide (Sinha *et al.,* 2010). Vermicomposting is a technique which is used to divert waste from landfills. It is defined by Suthar (2008) as: "*The decomposition of complex organic waste resources into odour-free humus-like substances through the action of earthworms".* It is being commercialised all over the

world in countries like China, U.S. and Australia (Sinha, 2015). However, there is some food waste that should be avoided in this practice to ensure an optimum working vermisystem. This includes waste from food products with high salt content, large volumes of citrus fruits (with an acidic pH) and finally meat and dairy products initially until there is a large number of earthworms present in the system (Sinha *et al.*, 2015).

Previous research has been conducted using vermitechnology to treat waste. Examples include:

- Suthar (2008) studied vermicomposting of vegetable-market solid waste
- Mishra, *et al.*, (2014) used *Eisenia fetida* to treat municipal solid waste
- Saxena, *et al.,* (1998) looked at vermicomposting of fly-ash from coal-driven power plants
- Sinha *et al*., (2009) used earthworms for vermistabiliztion of bio-solids
- Vig *et al.,* (2011) researched the treatment of tannery sludge using vermitechnology

1.6 Earthworms

Earthworms are tube shaped, segmented animals belonging to the Phylum Annelida. They live in the soil, feeding on organic matter. Around three thousand described species of earthworms occupy ecosystems which can be divided in terrestrial, marine and freshwater environments as noted by Huang *et al.,* (2007). Ninety percent of the invertebrate biomass of soil is made up of earthworms which can be termed as "*important ecosystem engineers*" (Huang *et al.,* 2007). Interestingly, Brown *et al.,* (2010) state that *"many societies continue to fear insects and disregard earthworms, and this may explain why aggressive practices against soil biota have been so widespread until fairly recently."* An example given within that chapter is a survey which was taken among 163 farmers in Veracruz, Mexico. With regard to the role of earthworms in soil fertility, 55 % ignored this fact while 11 % considered earthworms to be harmful due to the simple fact that these farmers actually confused earthworms with intestinal parasites.

Figure 1.1: An adult earthworm (Weedtechnics, 2015)

Earthworms are oligochaetes, meaning ‘few bristles’. They have permeable skin and also require a moist environment to avoid desiccation. If an earthworm resided in a dry environment, it would eventually die. Understandably, different species behave differently. Some species can live in permanent burrows deep in the soil while others prefer to live in compost. Earthworms can be classified due to their behaviour in their natural environment. These three classifications are; anecic, endogeic, and epigeic (Sherman, 2015).

1.6.1 Anecic

Anecis earthworms construct vertical permanent burrows in the soil and convert organic debris on the soil surface, producing and distributing plant available nutrients. If these species of earthworms lose their permanent burrows they stop breeding and cease to grow. An example of such an earthworm species is *Lumbricus terrestris* (the ‘Common nightcrawler’) (Sherman, 2015).

1.6.2 Endogeic

Endogeic earthworms build mainly horizontal burrows which are wide in range. They reside in these burrows most of the time while feeding on mineral particles in the soil along with decaying organic matter. An example of such an earthworm type is *Aporrectodea calignosa* (Sherman, 2015).

1.6.3 Epigeic

Epigeic earthworms are found in areas of rich organic matter such as under leaves or forest floors but they do not build permanent burrows. Due to the fact that they consume

this organic matter, these worms can adapt easily to vermicomposting. An example of such an earthworm is *Eisenia fetida* ('Common redworm') (Sherman, 2015). Epigeic earthworms can accelerate the process of composting, and therefore produce an enhanced quality compost (Gupta *et al.*, 2007).

There are certain earthworms known as 'composting worms' and this term can cover a multitude of species. Previous vermitechnology research has been conducted using the following earthworm species: *Eisenia fetida* (Mishra *et al.,* 2014; Gupta *et al.,* 2007; Manyuchi and Phiri, 2013a), *Perionyx excavatus* (Hatti *et al.,* 2010; Reinecke *et al.,* 1992) and *Eudrilus eugeniae* (Reinecke *et al.,* 1992), *Eisenia andrei* and *Drawida willsi* (Manyuchi and Phiri, 2013b). In another paper these authors Manyuchi and Phiri, (2013a) noted that *Eisenia fetida* could be the earthworm of choice for the vermicomposting process as this species is adaptable to changing conditions and also due to the lower chances it has of compromising on this process. However, some species are not suitable for the composting process for example *Lumbricus terrestris.*

1.7 Vermicompost

Vermicompost (VC) is becoming a popular form of compost in use today. It is produced through a process which utilises vermitechnology, whereby earthworms are used to break down organic matter to produce compost. The process consists of these composting worms transforming organic matter into worm castings using their natural digestive function. This, in turn, leads to the production of vermicompost as the worm castings combine with some partially processed organic matter to produce this rich medium. Sinha *et al.,* (2009) state that it is the earthworm species and the nature of raw material can modify the nutrient content and quality of VC, along with temperature and pH range.

Previous work has been conducted on vermicompost, such as the work of Pramanik (2012) who studied the chemical along with the biochemical properties of soils amended by VC. This research noted that the application of VC to soil caused an increase in available phosphorus. In addition, VC produced from garden wastes was the best treatment for lateritic soil, as it influenced phosphorus-solubilising factors which led to a higher phosphorus content in the soil.

The benefits of vermicompost add to those already associated with compost, such as the presence of macro and micronutrients and the buffer action of soil for nutrient availability. Lekeshmanaswamy and Yasotha (2012) referred to the research carried out by Buchanan

et al., (1998) who showed that vermicompost had a higher level of nutrient content compared to the waste it derived from. Research conducted by Purakayastha and Bhatnagar (1997), state that vermicompost is, in fact, a source of necessary nutrients for plants, growth hormones and also vitamins; this form of compost is identified as possessing antagonistic action against fungi and bacteria. Other work has studied the effect of VC on plants, such as for example VC effect on wheat yield reported by Roberts, *et al.,* (2007), who found that VC on its own could not act as a substitute for inorganic fertilisers without negatively affecting wheat yield. However Suthar (2005), who also investigated VC effects on wheat, noted that VC added to soil produced better yield and growth of wheat. Work has also been done on tomatoes by Gutierrez-Miceli *et al.,* (2007) who reported that VC may increase the nutritional quality of the tomato plant, while Atiyeh *et al.,* (1999) found that low concentrations of VC may promote the growth of tomato crops. In addition, Peyvast *et al.,* (2008) researched the application of various VC concentrations on spinach and found similar findings to Atiyeh *et al.,* (1999), with 10% VC treatment producing the highest plant height in spinach.

Sinha *et al.,* (2009) noted other important properties of VC including:

- Significant levels of bioavailable nutrients for plant and beneficial soil microorganisms
- A state free from the presence of pathogens and harmful chemicals
- Its ability to repel plant pests and aid in the suppression of plant diseases.

1.7.1 Vermitea

Vermitea, which is also known as 'worm tea' or 'vermiwash' is an organic fertiliser which is becoming popular with garden enthusiasts. Not much is known about it as it is a material which has only been used in recent years. Ismail and Ismail (2009), described vermitea as "*a liquid fertiliser produced by passing water through columns of vermiculture beds".* However, some confusion can arise in differentiating between worm cast and worm leachate.

Research has been carried out mostly based on topics such as physicochemical properties, microbial work and earthworms themselves. Some research has been done on fruit and vegetable waste. Research conducted by Huang *et al.,* (2014) found that vermicomposting caused a sharp decrease in electrical conductivity, along with nitrogen and total carbon concentrations early in the process. In addition, they concluded that the presence of

earthworms aids the activity and number of fungal and bacterial species present in the system. Suthar (2008) also reported on a loss in carbon concentrations during vermicomposting while there was an increase in nitrogen, phosphorus and potassium concentrations. Also, in conclusion, this research found that vermicomposting could be effective on very small volumes of vegetable waste when mixed with bulking materials. Research carried out on vermicomposting sludge using *E. fetida* showed that there was a decrease in pH and an increase in electrical conductivity levels in the VC (Yang *et al.*, 2014). Some work has also been conducted on the use of VT on plants, mostly through a spraying application. An example of such work includes Hatti *et al*., (2010) using VT from the earthworm *Perionyx excavatus* on *Vigna mungo* (mungo bean), who reported that vermiwash had high nutrient levels of potassium, manganese, phosphorus and calcium. These nutrients aided the significant increase in biomass along with root and shoot height on this plant. Gutiérrez-Miceli *et al.,* (2011) investigated the application of both VT and VC on radish seeds and reported that a combination of the lower concentrations of VC and worm bin leachate resulted in higher seed germination and larger leaf number. However, they also noted that higher concentrations of both treatments can inhibit growth.

1.8 Chemical Analysis

Certain chemical parameters are analysed when examining vermicompost and vermitea:

pH - It is important to have a suitable pH so as to allow optimum environmental conditions to occur. Work by Mahmoud and Ibrahim (2012) found that on addition of VC (from rice straw combined with animal wastes) to soil, the soil pH decreased, especially when high quantities of VC were added. Nath *et al.,* (2009) also noted a decrease in pH when studying vermicomposting of kitchen, animal and agro wastes.

Electrical Conductivity (EC) – Work on EC in VC and VT has been done by Yang *et al.,* (2014), who reported an increase in EC levels of VC produced from sewage sludge; Mahmoud and Ibrahim (2012) noted that soil EC decreased due to the application of VC alone. Finally, Nath *et al.,* (2009) also found that vermicomposting resulted in a decrease of EC.

Phosphorous - Phosphorus is an important nutrient for plants as it is essential for optimum growth and maturity of plants (Farah *et al.,* 2015; Suthar, 2012; and Businelli *et al.,* 1984), as it is a participant in the following processes of plant physiology:

photosynthesis, cell division, respiration and energy storage and transfer. Orthophosphate is the main available form of phosphorus which the plant can take up (International Plant Nutrition Institute, 1999). Therefore, orthophosphate is also known as the 'plant available phosphorus'. Adhikary (2012) noted that phosphorus is converted to the plant available form when passed through the gut of an earthworm.

Potassium - Potassium is an essential nutrient for plant growth. Plants need potassium in large amounts for optimum growth and for reproduction (Zhang & Sun, 2015; Suthar, 2009; Pramanik *et al.,* 2007).

1.9 Use of vermitechnology by-products on plants

In recent years, a significant topic of interest in crop production is the importance of sustaining the growth of plants and crops without harming the environment. In modern practices the use of fertilisers plays an important role in this aspect. However, the types of fertilisers which are predominantly used are of chemical nature. These are also termed as 'artificial fertilisers'.

The nutrition of plants is an important factor in improving agricultural productivity and quality (Savci, 2012). An important aspect is the nutritional value of substances available to plants along with the nutrients in soil, which affect the quality of yield (Savci, 2012). A solution to the provision of such nutrients is through the application of fertilisers. However, the application of such chemicals has disadvantages, such as the severely negative impacts on the environment, *e.g.* eutrophication of freshwaters, along with the financial costs associated with the acquisition/purchase of these chemical fertilisers.

An alternative to this approach could be the application VC and VT. The use of earthworms as a treatment option for organic biosolids (termed as 'vermicomposting'), is a cost-effective, sustainable approach (as it is a cheaper system to run) as well as an ecological tactic for effective management of biodegradable solid waste. Moreover, the end product of this technique is considered an organic fertiliser for agricultural applications which is environmentally friendly (Huang *et al.,* 2014).

Research has been done on the use of vermitechnology products on plants. The difference between compost and vermicompost on the yield of maize and tomato in greenhouse conditions was investigated by Doan *et al.,* (2013). This research showed that both VC and mineral treatments produced the highest growth of both maize and tomato when compared to compost. The effects of vermicompost deriving from food waste on the

production of peppers were also studied in greenhouse conditions (Arancon *et al.*, 2004). These researchers noted that a combination of 40 % food waste VC and 60 % potting medium produced a better yield than potting mixture alone. It is possible that microorganisms present in the VC produced plant growth-influencing-substances which may have contributed to higher pepper yields. Singh *et al*., (2010) compared the use of chemical fertilisers and vermicompost on tomato yield and found that a combination of VC with NPK fertiliser produced a better tomato quality when grown in the field in a mild-tropical agro climate. Work conducted by Abduli *et al*., (2011) looked into the efficiency of vermicompost on tomatoes and reported an increase in tomato plant growth when the VC ratio in the soil increased.

As discussed in this literature review, some research has been conducted to investigate the feasibility of the vermicomposting process on organic crop production in India and other countries such as Australia. A number of tests carried out in India by Flores (2009) showed that a continuous application of VC at 5 t/ha, reduced the need for the use of chemical fertilisers up to 50 % for banana, coconut and ginger crops.

Additional research is needed in order to analyse this composting process further, along with the analysis of 'vermitea' as an alternative form of fertiliser. Research is also needed to be carried out within the context of the Irish climate.

The aim of this project was to explore the potential of vermitechnology as a possible alternative waste management solution. It also aimed to analyse the physico-chemical and nutritional properties of VT, sourced from both an on-site system and from a preparation of commercially acquired VC. Finally, VT was compared to a chemical fertiliser, as treatments to various species of plants to investigate the possible role of VT as a plant growth promoter.

Chapter Two

Investigation of the biodegradation of food waste using vermitechnology and chemical analysis of vermitea

2.1 Introduction

Due to an ever-increasing world population, food consumption and thus food waste is of increasing concern over recent times. Food waste includes materials deriving from the preparation of meals (fruit and vegetable wastes) as well as food remainders from homes, restaurants *etc.,* (Othman *et al.,* 2012). Currently available treatments for food waste are limited, with the most popular being landfill. However, due to population expansion and the need for more land, space for landfills is becoming limited, not to mention the environmental and economic issues associated with these sites. Therefore, alternative food waste treatment options are needed. One such treatment, currently under research is vermitechnology.

Vermitechnology, also known as vermicomposting, is a process of utilising earthworms to reduce varied sources of organic waste. It has been defined as *"the digestion of organic materials by earthworms to produce excreta, known as casts"* (Chaoui *et al.,* 2003). It differs from other forms of composting at the presence of worms digesting the organic material (Chaoui *et al.,* 2003). Compost derived from this type of system is known as 'vermicompost' and is presumed to be *"a highly nutritive organic fertiliser"* (Sinha *et al.,* 2009). The process of vermicomposting of these types of wastes is *"encouraged to avoid the loss of energy"* (Majlessi *et al.,* 2012). Some research has already been carried out worldwide, using vermicomposting to treat various forms of wastes, for example Saxena *et al*., (1998) who used earthworms to compost 'fly-ash' from plants such as coal plants. Vermicomposting has also been used to stabilise biosolids (sewage sludge) (Sinha *et al.,* 2009). Many of these composted wastes may contain nutrients which play an essential role in crop production and soil fertility (Garg *et al.,* 2012).

Earthworm species such as *Eudrilus eugeniae* (Lekeshmanaswamy and Yasotha, 2012) and *Perionyx excavatus* (Hatti *et al.,* 2010; Sunitha, 2011), have been used in vermitechnology research. However, *Eisenia fetida* (commonly known as 'Tiger Worm') is the most common species of earthworm to be utilised for vermicomposting (Majlessi *et al.,* 2012; Rajpal *et al*., 2011). *E. fetida,* is a eurythermal species, (Reinecke *et al.,* 1992)

in that they can withstand an extensive temperature range, which makes them a popular choice for vermicomposting.

As mentioned previously, ‘cast’ is a term used for the liquid extract from vermicompost, and is also known as ‘vermiwash’ or ‘vermitea’. Vermiwash has been defined as “*a leachate that is produced during the vermicomposting process and is dark brown in colour”* (Manyuchi and Phiri, 2013b).

Vermicompost and vermiwash can be analysed for physio-chemical and nutritional content. pH and electrical conductivity (EC) are common physico-chemical parameters studied (Manyuchi and Phiri, 2013b; Nath *et al.*, 2009). EC can also be used to measure the age or ‘maturity’ of compost, including vermicompost (Majlessi *et al.*, 2012). A far as it concerns potassium, it plays an important role in many plant growth parameters, including the activation of plant enzymes as well as photosynthesis (International Plant Nutrition Institute, 1998). On the other hand, orthophosphates is the main form of phosphorus that the plant can take up (International Plant Nutrition Institute, 1999), and is also known as ‘plant available phosphorus’. Potassium and phosphorus content has been measured in VC and VT (Nath *et al*., 2009; Pramanik *et al*., 2007).

2.2 Preparation of vermitea

2.2.1 Materials and Methods

2.2.1.1 Preparation of vermitea from vermicompost commercial one

The objective of the experiment was to determine i) a procedure for producing vermitea from vermicompost and ii) determine the optimum vermicompost initial quantity and the optimal length of vermicompost soaking time. Two commercial sources of VC were used for this experiment. The first source outlined was Plagron® VC (supplied by The Hydroponics Store®). Three tubs of Plagron® VC were used for this trial. The VC in each tub was thoroughly mixed by hand. 1 g aliquots were soaked in 200 ml of deionised water for 1 to 5 days. This was repeated using 5, 10, 15 and 20 g samples, taken randomly from the tubs.

2.2.1.2 Preparation of vermitea from vermicompost commercial two

Secondly, independent vermicompost samples were provided by a commercial unknown source. However, these samples originated from different locations and sample weights were quite small. Therefore, a blind experiment was carried out to produce vermitea from the five bags of vermicompost samples using the procedure described in section 2.2.1.1. It is important to note that although five bags of VC were supplied, only bags one, two, three and five were tested, as bag four had an insufficient amount of VC for sampling and analysis. Due to a limited amount of VC provided in each bag, the samples were soaked for a single time point only, for 5 days.

2.2.1.3 Preparation of vermitea from topsoil

The same procedure (see section 2.2.1.1) was used for the control samples using commercially sourced topsoil (Woodies DIY Garden Centre).

2.2.1.4 Chemical analysis of samples

2.2.1.4.1 Analysis of samples for acidity and/or alkalinity (pH)

All samples were centrifuged at 3500 rpm for 5-8 minutes to remove any debris. The pH of all samples was measured in triplicate using a WTW pH 3210® pH meter.

2.2.1.4.2 Analysis of samples for conductivity potential, salinity content and total dissolved solids

All samples were centrifuged as in section 2.2.1.4.1 Conductivity, salinity and total dissolved solids (TDS) were all measured in triplicate using a Mettler Toledo Five Easy® Meter.

2.2.1.4.3 Analysis of samples for potassium content

All samples were centrifuged as in sections 2.2.1.4.1 and 2.2.1.4.2. The potassium content of all samples was measured using a HACH Lange DR 6000® spectrophotometer in accordance with the HACH Tetraphenylborate Method 8049 (HACH 2014). All necessary dilutions were made and samples were analysed in triplicate.

2.2.1.4.4 Analysis of samples for phosphorus content

All samples were centrifuged as above. The phosphorus content of all samples (reactive phosphorus – orthophosphate) was analysed using a HACH Lange DR 6000® spectrophotometer in accordance with the HACH Molybdovanadate Method 8114 (HACH, 2014). All necessary dilutions were made, and samples were analysed in triplicate.

2.2.1.5 Statistical analysis

For the samples analysed in section 2.2 a non-parametric Kruskal - Wallis test (IBM SPSS, Version 23, 2015) was conducted to determine if there were any significant differences among sample weights as time increased. This included a post-hoc test with Bonferroni correction to determine where the significance lay.

2.2.2 Results

2.2.2.1 Commercial Source One - Plagron®[1]

Both the weight of VC soaked to produce the VT samples as well as the number of days VC was soaked to produce the VT were investigated. As the results for all parameters were similar across all three tubs, an overall average value was taken to represent the commercial VC and statistically analysed. The null hypothesis was that there were no differences in any parameter across weight and time. A Kruskal-Wallis analysis determined where these significant differences stood in each parameter, therefore the null hypothesis was rejected.

When all weights and soakage times were statistically compared against each other in each parameter, there was a slight fluctuation in pH readings for all weights as time increased, likewise when comparing weight against weight. For conductivity, only

[1] See results tables in Appendix C for statistical results tables

weights affected conductivity levels, not time. Salinity levels fluctuated only slightly as time and weight increased. The majority of sample weights produced notable TDS results over the initial 24-hour period. For both potassium and orthophosphate, there were fluctuations in the VT samples over the 5-day period, again the smaller weights gave notable results.

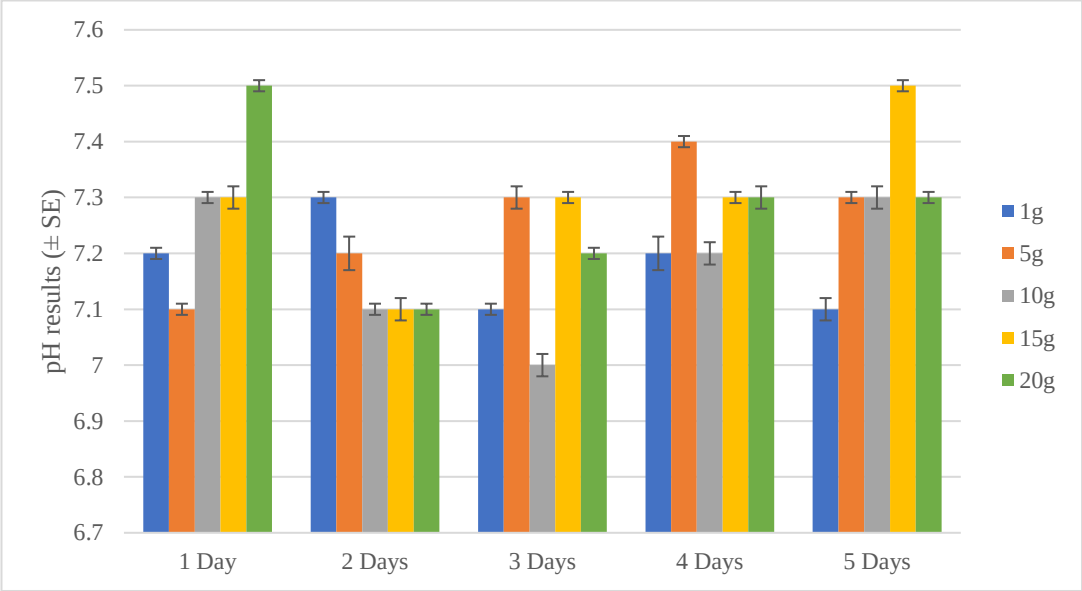


Figure 2.1: pH results (± SE) of VT samples from various amounts of VC and for various time durations

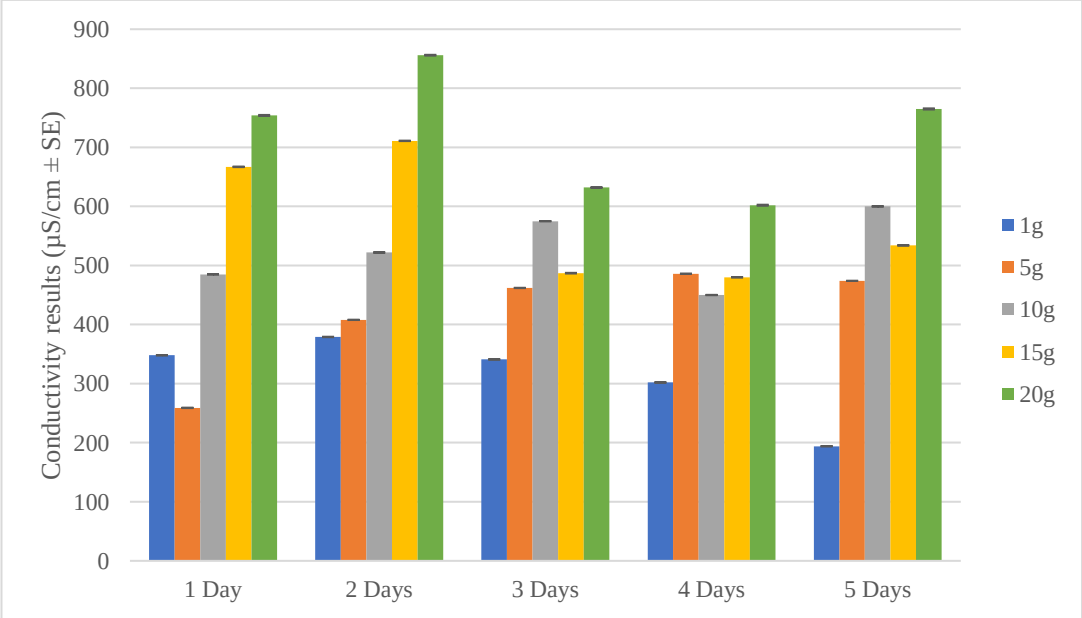


Figure 2.2: Conductivity results (µS/cm ± SE) of VT samples from various amounts of VC and for various time durations

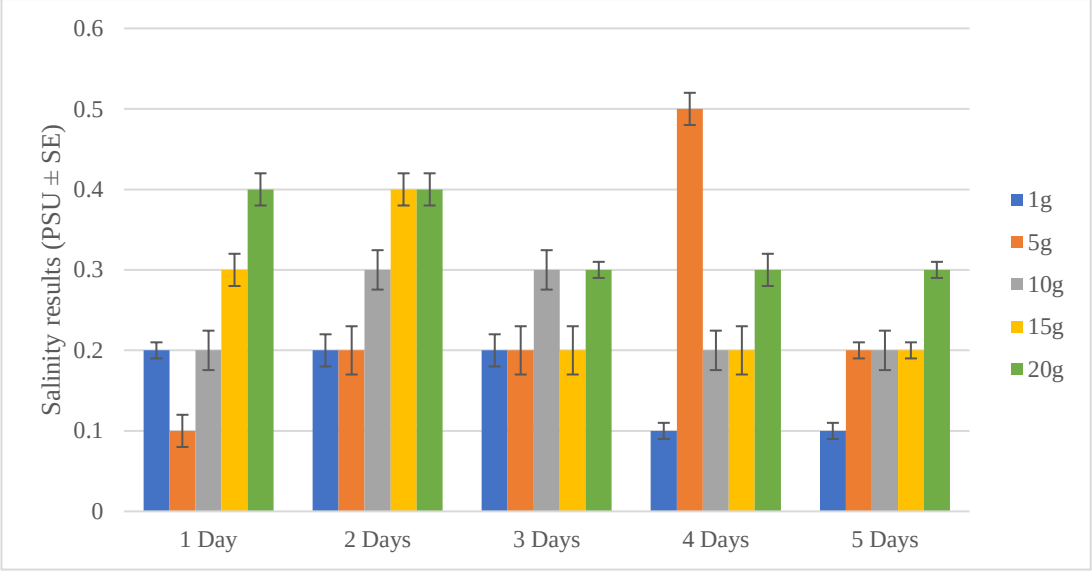


Figure 2.3: Salinity results (PSU ± SE) of VT samples from various amounts of VC and for various time durations

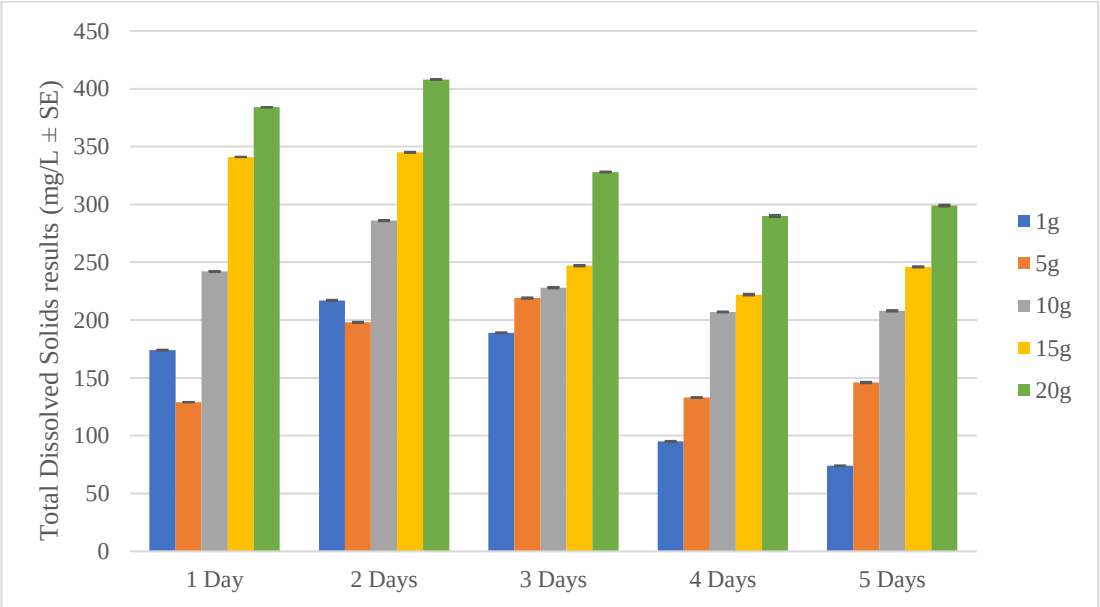
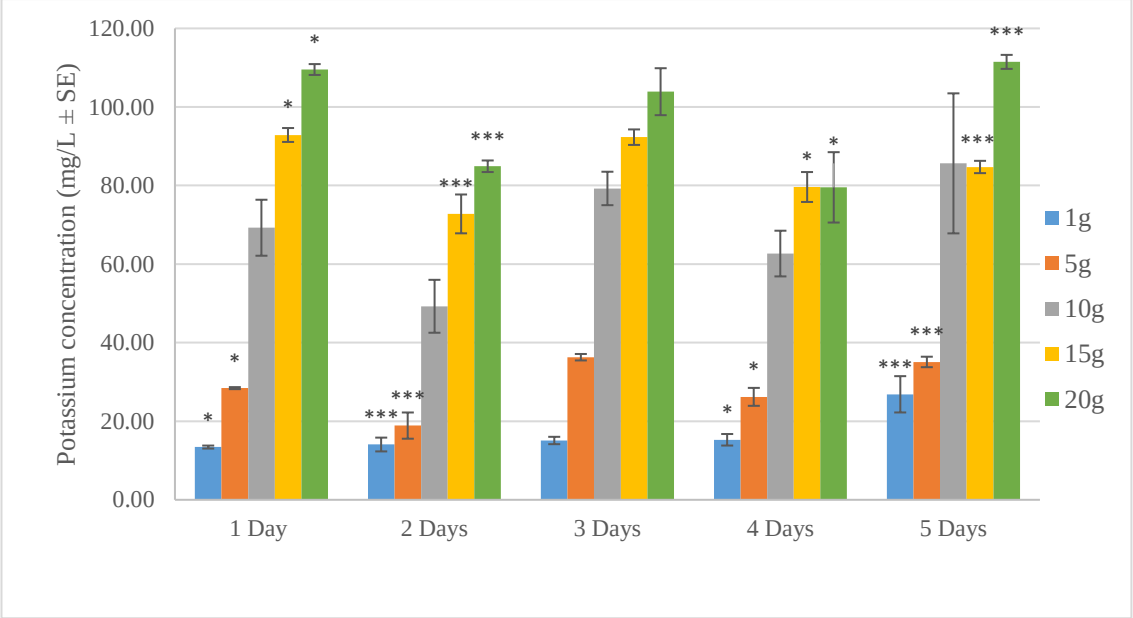
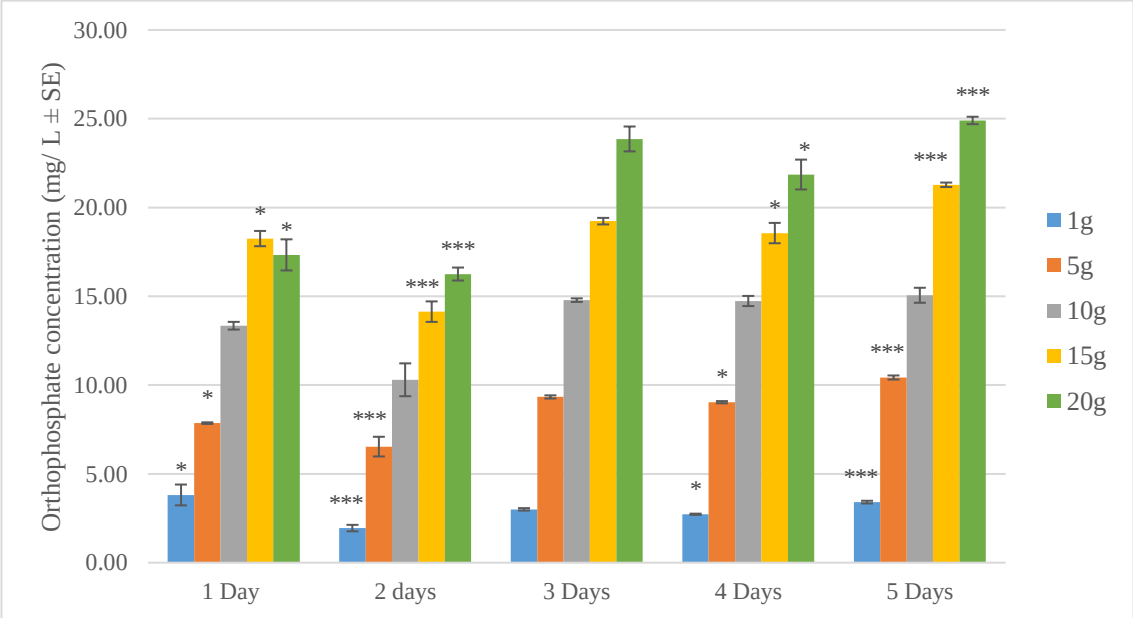


Figure 2.4: Total Dissolved Solids results (mg/L ± SE) of VT samples from various amounts of VC and for various time durations



*p < 0.05, ***p < 0.001

Figure 2.5: Potassium concentration of VT samples (mg/L ± SE) from various amounts of VC and for various time durations



*p < 0.05, ***p < 0.001

Figure 2.6: Orthophosphate concentration of VT samples (mg/L ± SE) from various amounts of VC and for various time durations

2.2.2.2 Commercial Source Two[2]

As time was not a variable included in this trial, only weights will be discussed. Generally, the pH increased in bags 2 and 5, with a decrease in bag 1. There were some fluctuations observed in bag 3 as weights increased. Conductivity increased with weight increase for bags 1, 2 and 5. Salinity was low overall with small increases observed in most bags as VC weight increased. There was an increase in TDS as sample weight increased for all four bags of VC. There were similar potassium concentrations present in all bags for each weight category, for example; similar results were observed for all 1 g samples weights in all bags of VC, likewise with 20 g samples. Both 15 and 20 g samples produced the greatest potassium content. Similar was seen in the orthophosphate results, with 15 and 20 g samples producing the greatest concentration also, for further detail see appendix B.

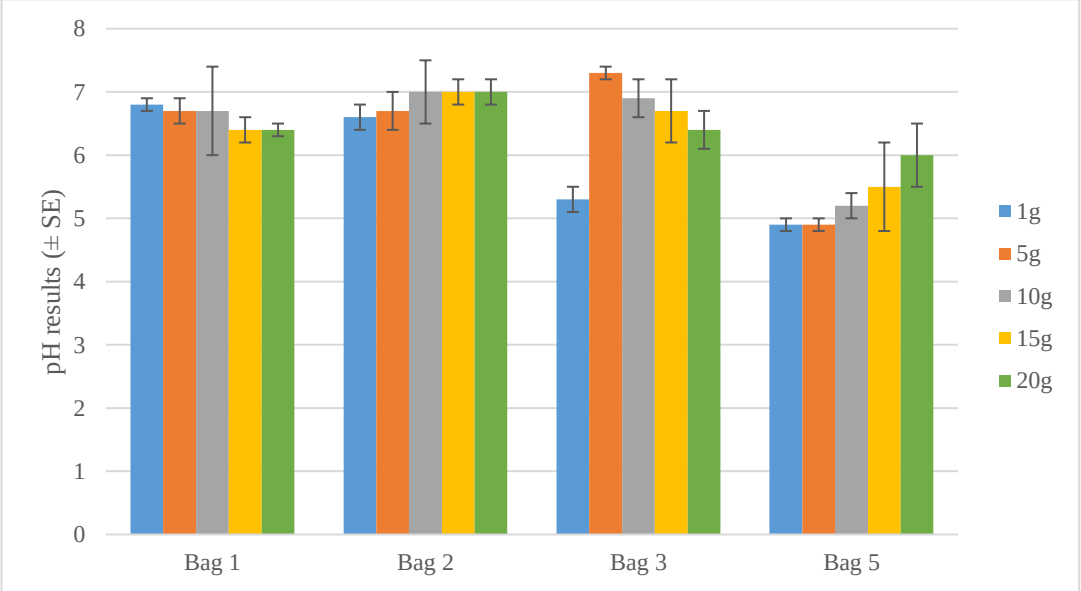


Figure 2.7: pH results for VT samples (± SE) from various amounts of VC

[2] See results tables in Appendix C for statistical results tables

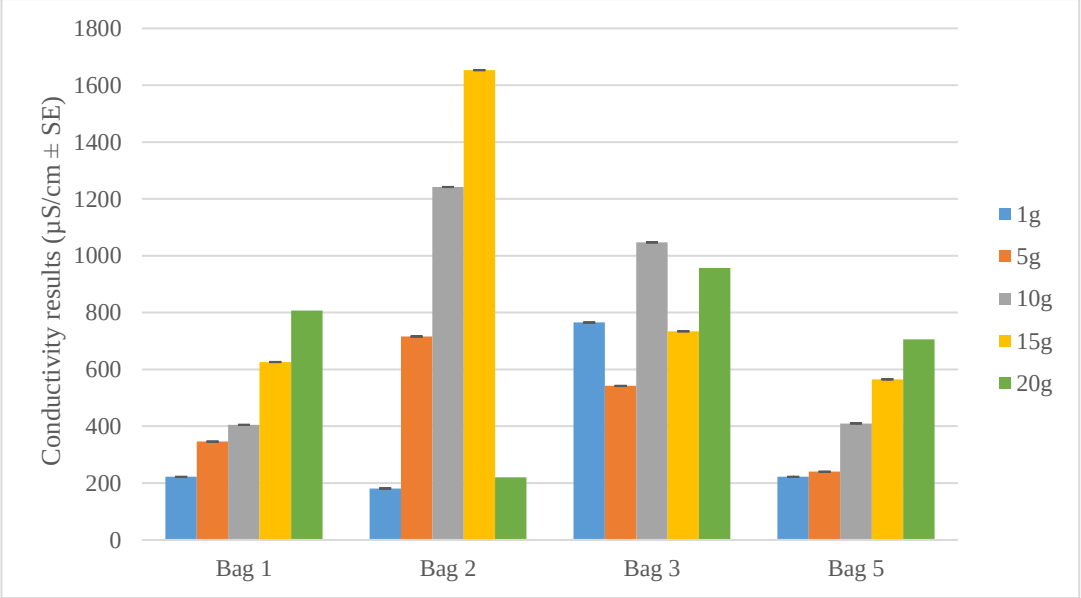


Figure 2.8: Conductivity results (µS/cm ± SE) from various amounts of VC

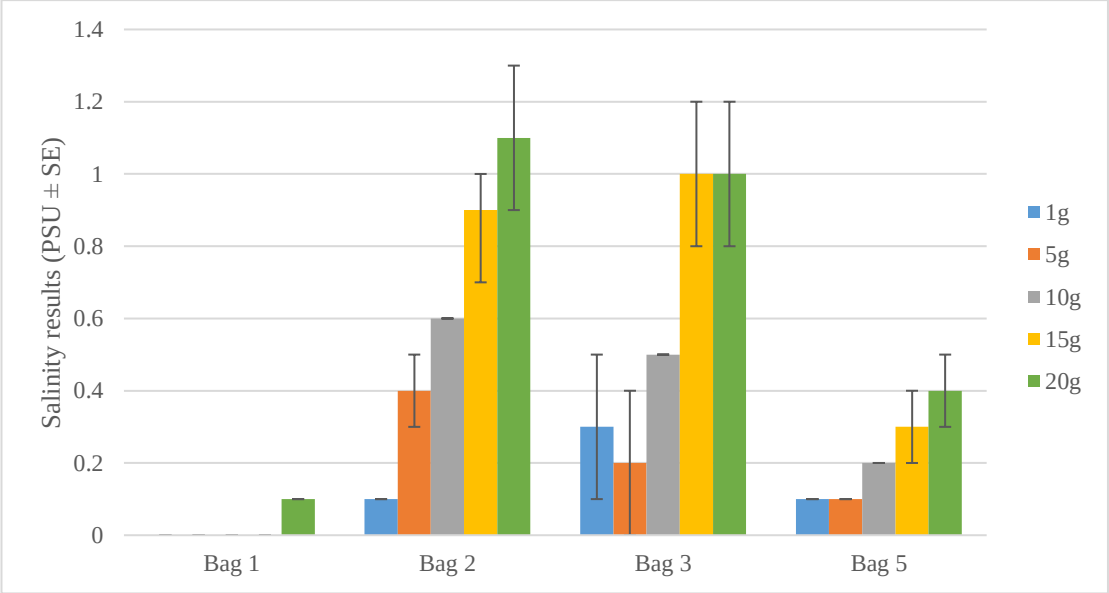


Figure 2.9: Salinity results (PSU ± SE) from various amounts of VC

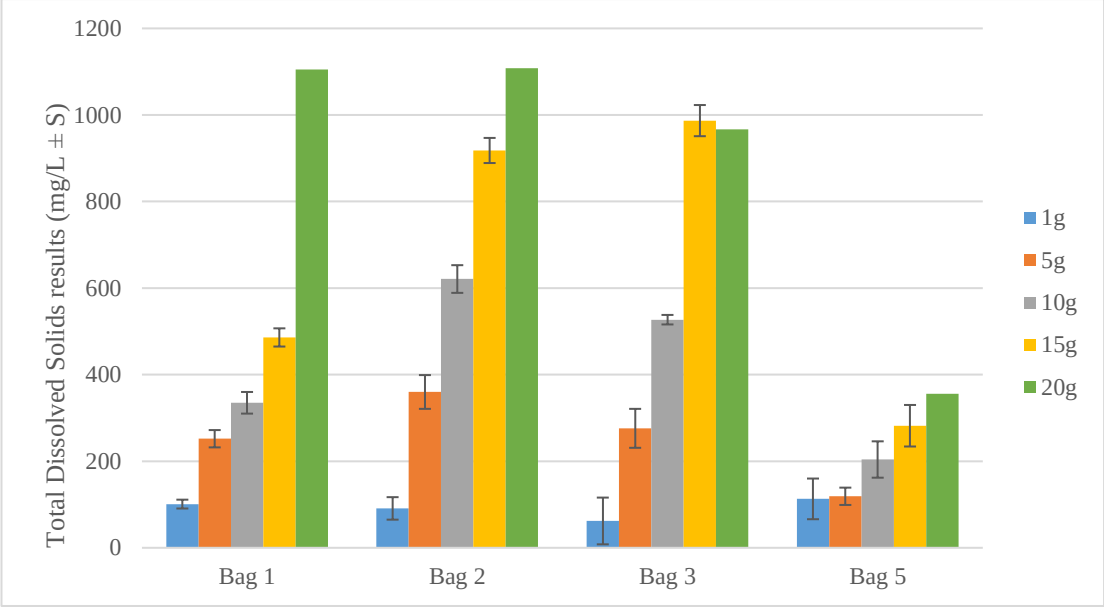
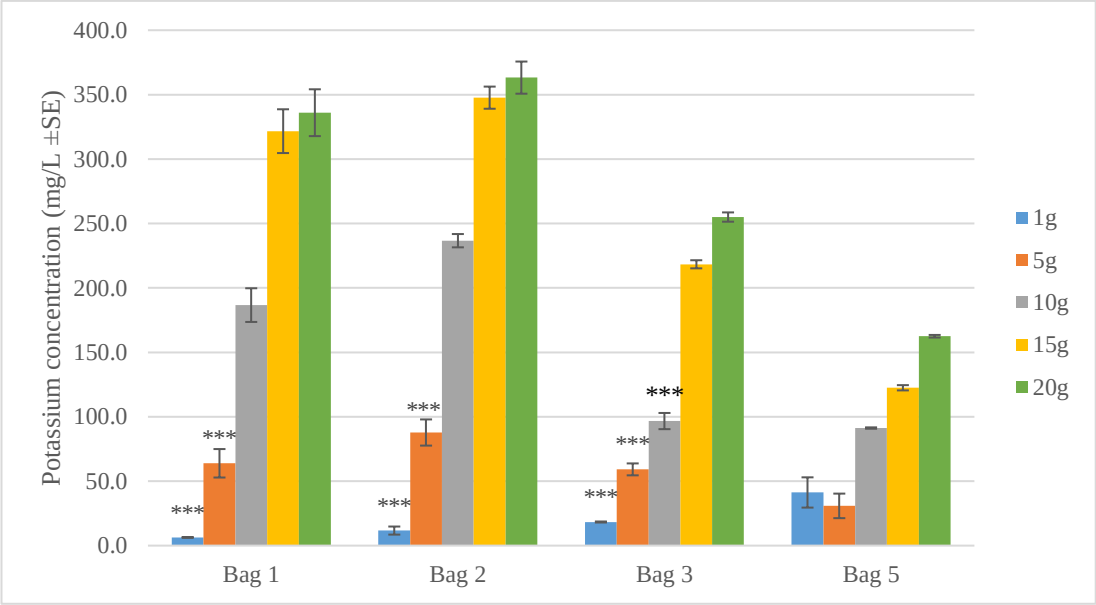
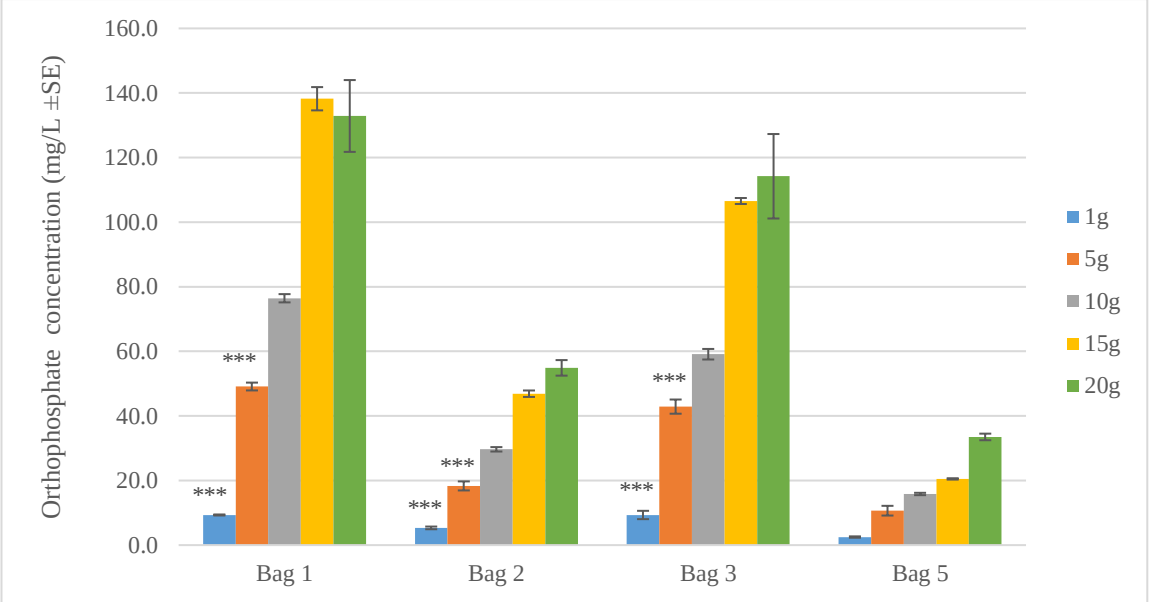


Figure 2.10: Total Dissolved Solids results (mg/L ± SE) from various amounts of VC



***p < 0.001

Figure 2.11: Potassium concentration (mg/L) of VT samples from various amounts of VC and for various time durations



***p < 0.001

Figure 2.12: Orthophosphate concentration (mg/L) from various amounts of VC and for various time durations

2.2.2.3 Topsoil (control)[3]

A Kruskal-Wallis test indicated that statistically, most physico-chemical parameters increased with sample weights increased, however, time had no significant effect. Salinity however, had some slight fluctuations with 10g decreased over the first two days, while 15g indicated the same salinity content in the same time period. There were fluctuations observed over time for potassium concentration, also there were notable differences for orthophosphates as weights increased over time. See Appendix B.

[3] See results tables in Appendix C for statistical results tables

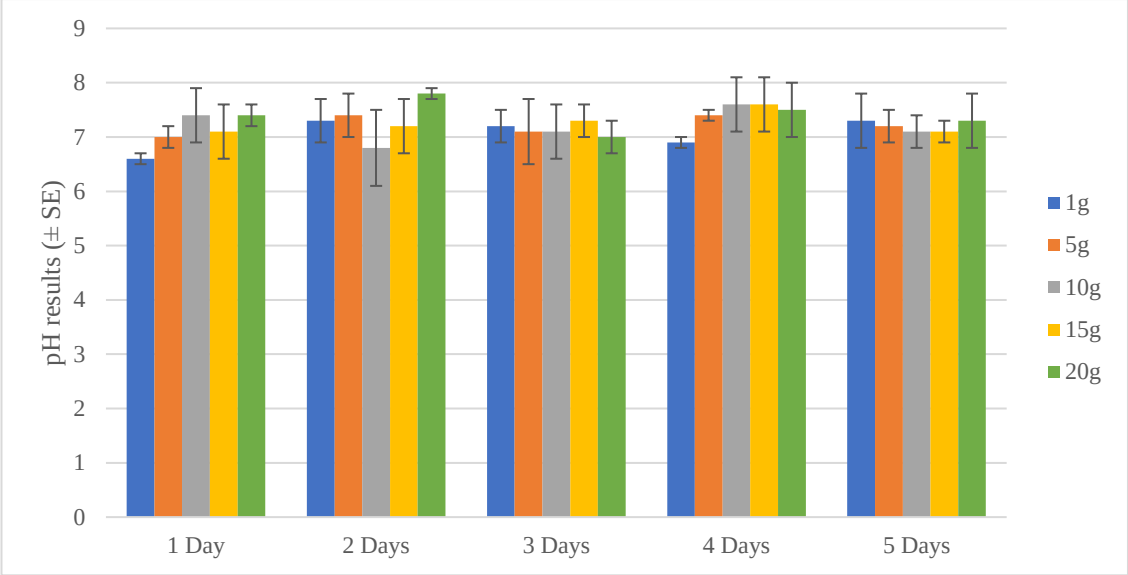


Figure 2.13: pH results (± SE) from various amounts of topsoil

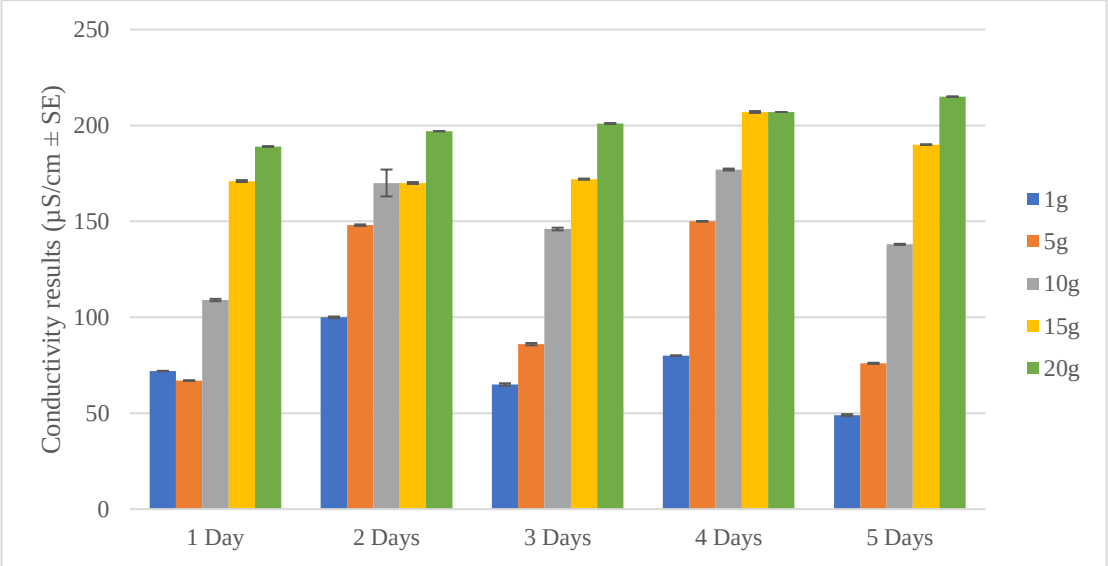


Figure 2.14: Conductivity results (µS/cm ± SE) from various amounts of topsoil

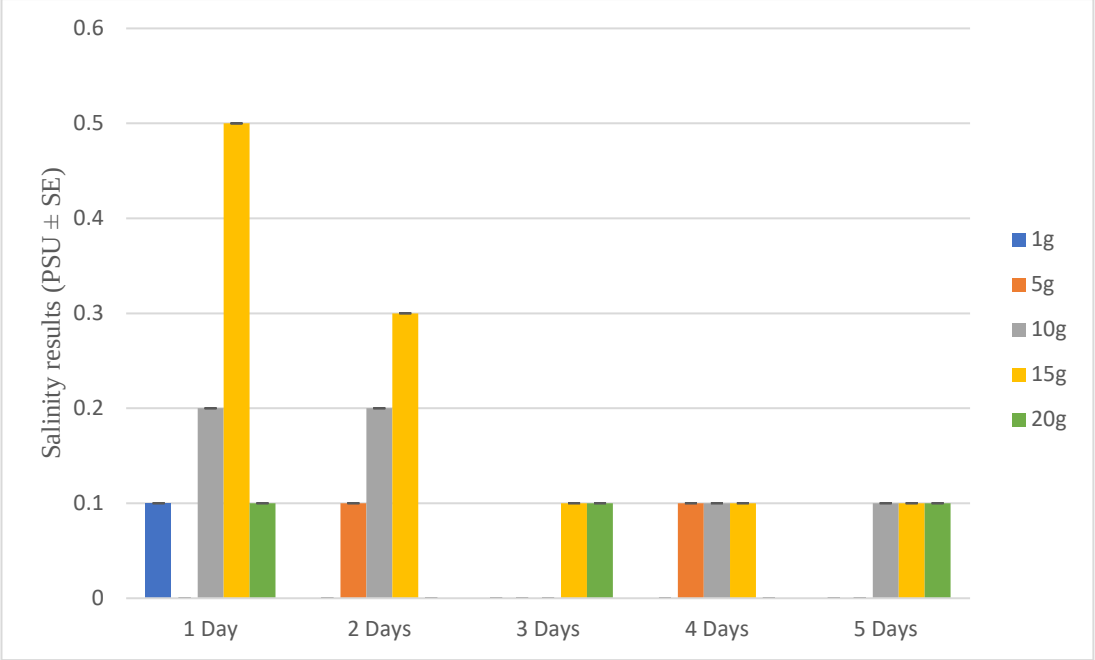


Figure 2.15: Salinity results (PSU ± SE) from various amounts of topsoil

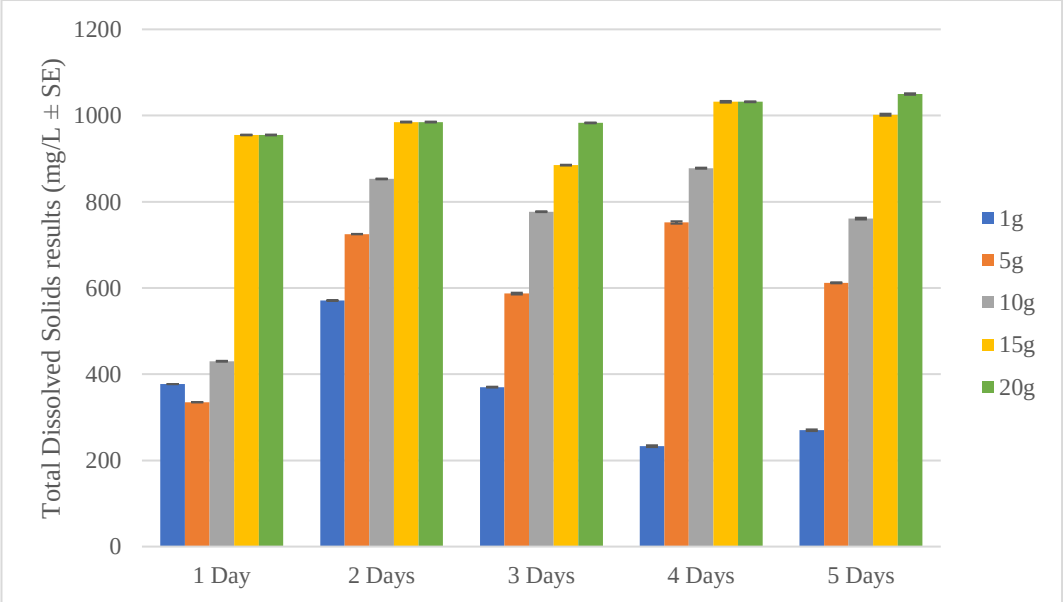
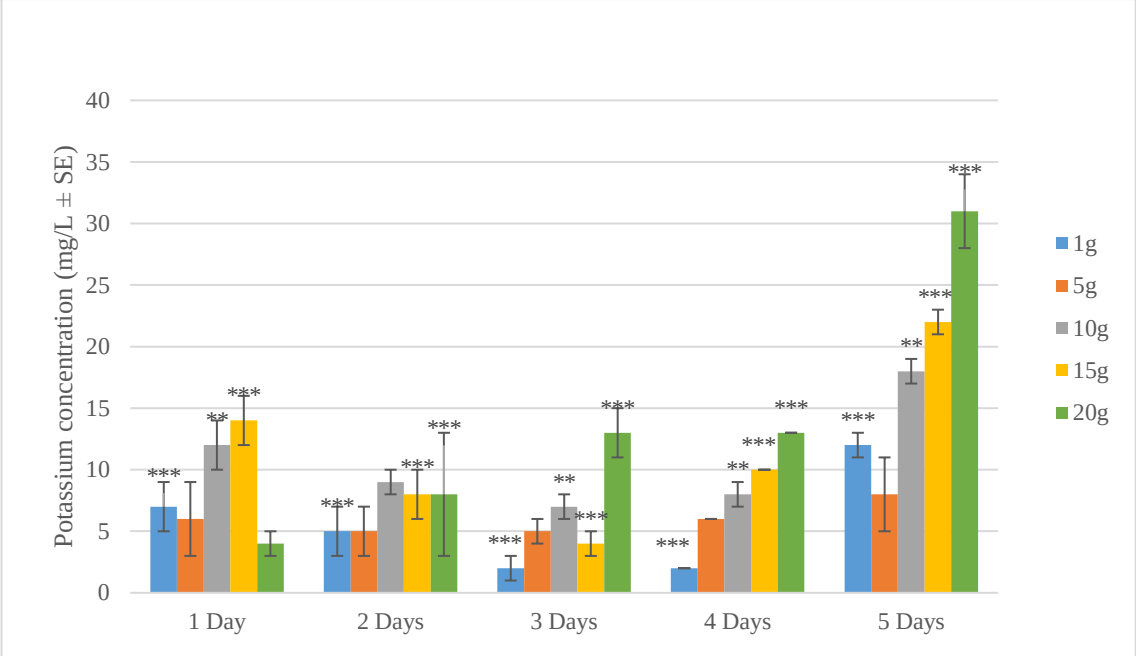
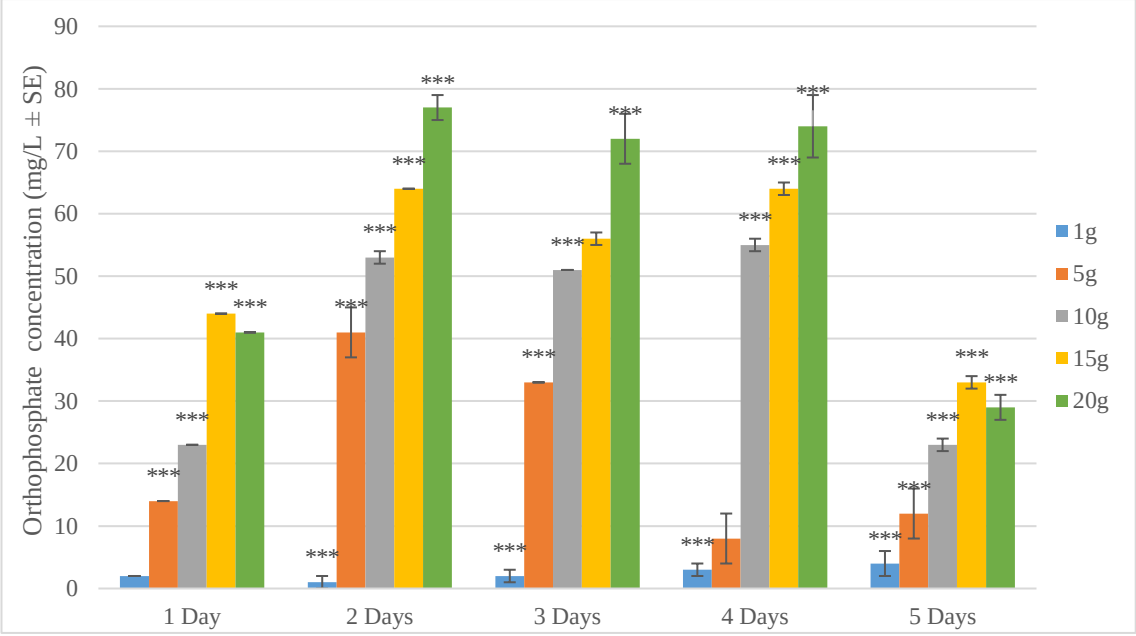


Figure 2.16: Total Dissolved Solids results (mg/L ± SE) from various amounts of topsoil



**p < 0.01, ***p < 0.005

Figure 2.17: Potassium concentration from various amounts of topsoil and for various time durations



***p < 0.005

Figure 2.18: Orthophosphate concentration from various amounts of topsoil and for various time durations

2.2.2.4 Comparison of commercial VC and topsoil (control)

Visually the liquid extract from the topsoil was slow filtering (on separation from the solid), contained sizable particles and had a dull grey colour. The VT however filtered quickly, contained very few particles and was golden yellow in colour.

For pH, conductivity and TDS, only topsoil (control) showed greater differences compared to VC for all three parameters as both weight and time increased. Plagron® was the only compost to have any larger differences in salinity and potassium levels as weight and time increased, while neither Plagron® nor topsoil had any notable differences in orthophosphate concentration over the same time period and weight, see appendix B.

2.2.3 Discussion

2.2.3.1 Plagron® and topsoil

The pH and salinity of VT produced from Plagron® VC differed slightly for the smaller weights over time. When a mean value is calculated for the highest weight of 20 g over five days for both Plagron® and topsoil, topsoil liquid samples (7.4 ± 0) had a slightly higher pH than VT (7.3 ± 0.1) which is comparable to that of work by Mahmoud and Ibrahim, (2012). While time had no notable effect for conductivity, 5 – 20 g were significant weights to produce notable conductivity results (Table 3). The majority of sample weights produced increased TDS levels in the initial 24 hours when compared to the control, topsoil. Possibly due to organic matter content in the initial time period. There were fluctuations in potassium levels in VT produced by Plagron®. However, this VT had a much higher concentration range (0 – 120 mg/L) in comparison to topsoil (0 – 40 mg/L). Similar findings were made by Mahmoud and Ibrahim, (2012). As regards orthophosphates, topsoil had a higher range, (0 – 80 mg/L) while Plagron® had a lower range (0 – 30 mg/L).

Overall in summary, based on these findings, smaller weights of compost produce better results across all parameters. As this protocol was designed for this experiment, these results are stand-alone in comparison to literature previously conducted. However, it was a successful procedure in the development of VT from commercially sourced VC.

2.2.3.2 Commercial source two VC

As this was a ‘blind trial’, the source of the waste composted and earthworm species unknown, the discussion of these results is limited. The pH generally increased as some weights increased in bags one to three, as did conductivity levels in bags one and two and

TDS. Salinity was low with only the second and third bags producing and significant results. Overall there was an increase in physico-chemical and nutrient levels as weights increased especially for bags two and three. Bag five did not produce any usable results at all.

2.3 Vermitechnology experiment on-site

2.3.1 Materials and Methods

A preliminary trial was first set up to determine the correct procedure and environmental conditions for the vermitechnology process, then a repetition trial (main experiment) was designed. A plastic bin labelled 'worm bin', consisting of a drainage tray with a tap and a 'food tray' lined with coir bedding was victualed with 120 *Eisenia fetida* earthworms. A second bin labelled 'control bin' was set up likewise, but no worms were introduced therein, as it represented normal composting conditions (control). The bins, bedding and *Eisenia fetida* worms were sourced from Original Organics (Ltd. (®)). Fruit and vegetable waste was added to the tray (see Appendix A) and the lid (with air holes) was secured to allow dark conditions preferrable by *E. fetida.* The bin was set aside for a week before the lid was removed. Food was being added gradually every four weeks to prevent food from building up and producing unsuitable environmental conditions for the earthworms. The bins were monitored for the whole duration of the experiment. A small volume of deionised water was added every week to ensure the appropriate moisture of the bedding. This water percolated down through the bins and was collected in a tray at the base of each bin. The contents of both bins were mixed every week to allow oxygen into the bedding and to aid percolation of any remaining water.

At set time points (days) liquid extract was collected from both bins. On collection date, the liquid in the collecting tray was stirred prior to collection. Approximately 200 ml of liquid was collected four times at 2-minute intervals in 250 ml beakers and stored in 50 ml falcon tubes at 4 °C until needed.

Based on the preliminary experiment, the suitable environmental conditions were then identified and a repetition experiment was carried out. Due to the cost of commercial plastic vermibins, a decision was made to manually construct the bins instead. Ten plastic bins were prepared with the help of The Men's Shed™ in Co. Carlow, five bins with earthworms ('vermibins') and five without ('control bins'). Ten 30 L buckets (with lids) were sourced at a local market and thoroughly cleaned to eliminate possible contaminants.

In each bin, a stainless-steel sieve with fine mesh was placed near the bottom of the bucket, secured with silicone adhesive. A small hole was drilled under this tray through the front of the bucket and a plastic tap with washers was fitted. The bucket was filled with moist coir bedding (Original Organics®). The lid was perforated with holes to allow air flow. Food waste was added to all bins (Appendix A) and four days later, approximately 120 *E. fetida* worms were added to the respective bins (time = zero days). Food waste and water were being added along with sample collection as outlined in the above procedure in for 65 days, with samples being collected every three weeks.

2.3.1.1 Statistical analysis

In section 2.3, a non-parametric Mann-Whitney U test compared worm and control bins over the nine-week period across all parameters. The resulting significance levels of these tests are indicated in the results section (section 2.3.2) as follows; * $p < 0.05$, ** $p < 0.01$ and ***$p < 0.005$.

2.3.2 Results

2.3.2.1 Preliminary Vermitechnology Trial

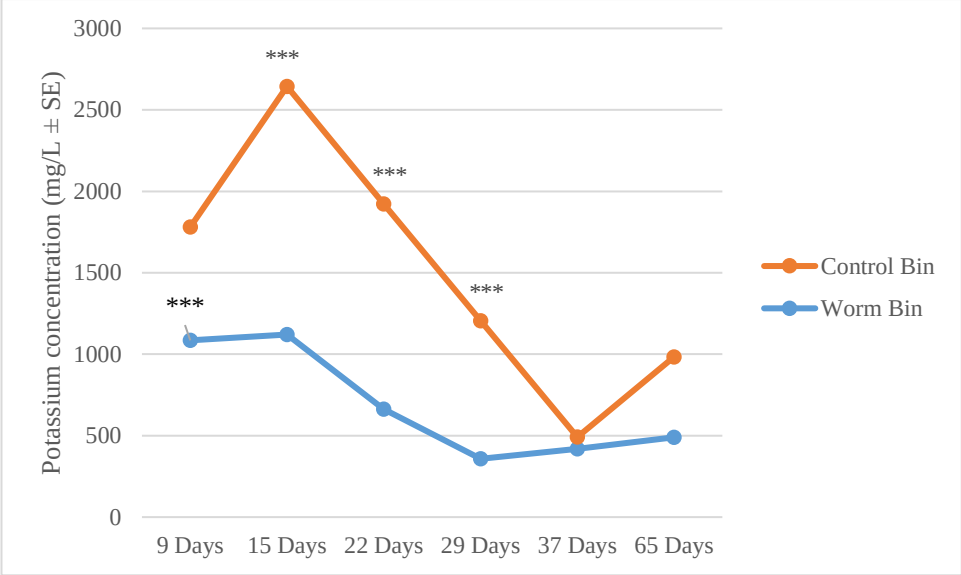
[Note: All samples from the worm bin mentioned here are classed as 'worm bin']

The pH of the worm bin increased up to fifteen days and then remained steady. Conductivity levels initially decreased then increased after food waste was added to bins. There was a decrease in the salinity levels of VT from the worm bin, while they fluctuated before decreasing in the control. There were fluctuations in TDS in the worm bin compared to the control, which increased after 22 days. Both potassium and orthophosphate levels were greater in the control than in the worm bin, with both decreasing slightly and then fluctuating in both bins over the sixty-five-day period.

Table 2.1: Preliminary results (± SD) for liquids collected from both worm and control bins over a 65-day period

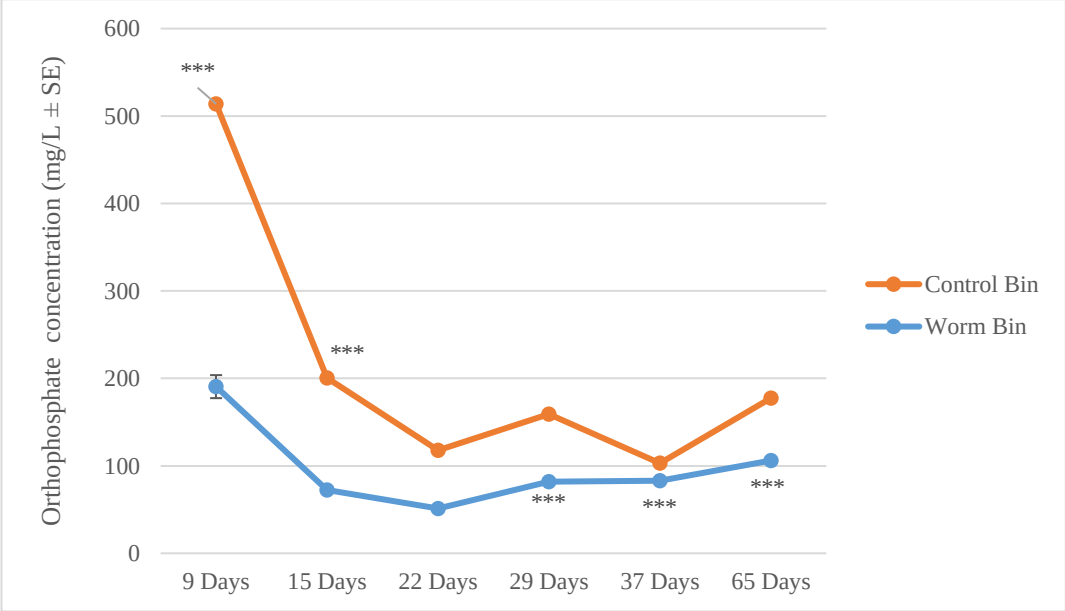
		Worm Bin		
	pH	Conductivity (µS/cm)	Salinity (PSU)	TDS (mg/L)
9 Days	6.4 ± 0***	1025 ± 2***	5.8 ± 0***	512 ± 1***
15 Days	7.0 ± 0	966 ± 1	5.6 ± 0	498 ± 1
22 Days	7.0 ± 0	560 ± 3	3.0 ± 0	727 ± 3
29 Days	7.0 ± 0	443 ± 1***	2.4 ± 0***	222 ± 1***
37 Days	7.0 ± 0	505 ± 3***	2.7 ± 0***	688 ± 3
65 Days	7.1 ± 0	266 ± 1	1.4 ± 0***	1333 ± 7
		Control Bin		
	pH	Conductivity (µS/cm)	Salinity (PSU)	TDS (mg/L)
9 Days	6.2 ± 0	661 ± 1	3.6 ± 0	331 ± 1
15 Days	7.4 ± 0***	1104 ± 1***	6.3 ± 0***	552 ± 1***
22 Days	7.8 ± 0***	1013 ± 3***	5. ± 0***	502 ± 7***
29 Days	7.1 ± 0	272 ± 1	1.4 ± 0	1368 ± 1
37 Days	7.2 ± 0***	210 ± 0	1.1 ± 0	1079 ± 34***
65 Days	8.4 ± 0***	260 ± 0	1.3 ± 0	1276 ± 2

***$p < 0.001$



***p < 0.001

Figure 2.19: Preliminary potassium levels (mg/L ±SE) in worm and control bins over a 65-day period



***p < 0.001

Figure 2.20: Orthophosphate levels (mg/L ±SE) in worm and control bins over a 65-day period

2.3.2.2 Repetition Vermitechnology Trial

Visual observations of the earthworms[4]:

- When the coir bedding started to dry out, the earthworms would gather on the side walls of the bin, just under the lid.
- They had a negative phototaxis reaction to light, as worms prefer a dark environment, when the lid was removed, they would burrow under the surface of the bedding. If any did not, it was a sign that they were not behaving normally and further observations were needed.
- The same applies for each time the bedding was mixed by hand.

Visual observations of worm and control bins[4]:

As expected, the food seemed to reduce quicker in the bin containing earthworms in comparison to the control bin. This was noted repeatedly in the time period between food waste addition and mixing of bedding.

Important note: In the repetition trial, the moisture level of the bedding remained high in comparison to the preliminary trial. This resulted in less water need being added to the bins in order to prevent unsuitable conditions for the earthworms. Also, a smaller volume of liquid was subsequently collected in each drainage tray but over a longer time period. Therefore, fewer samples were collected, the same volumes were collected but over fewer time points compared to the preliminary trial.

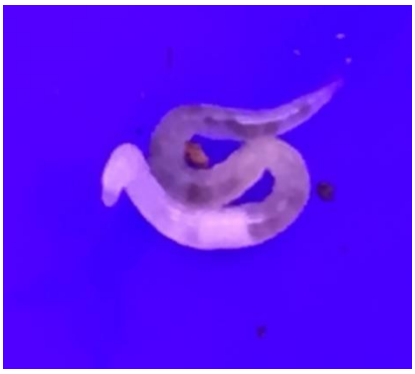


Figure 2.21: Juvenile earthworm (*Eisenia fetida*)

[4] These observations apply for both the preliminary and repetition trials

Figure 2.22: Adult earthworm (*Eisenia fetida*)

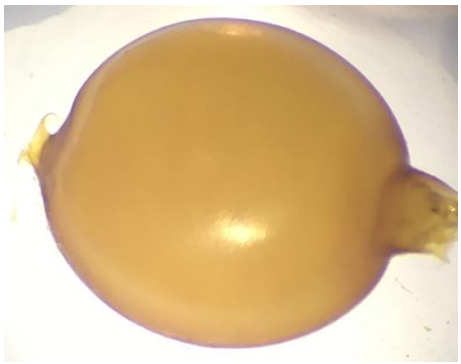


Figure 2.23: Earthworm egg (*Eisenia fetida*) viewed under a stereoscope

Figure 2.24: Adult earthworm (*Eisenia fetida*) and egg

2.3.2.2.1 Chemical analysis results

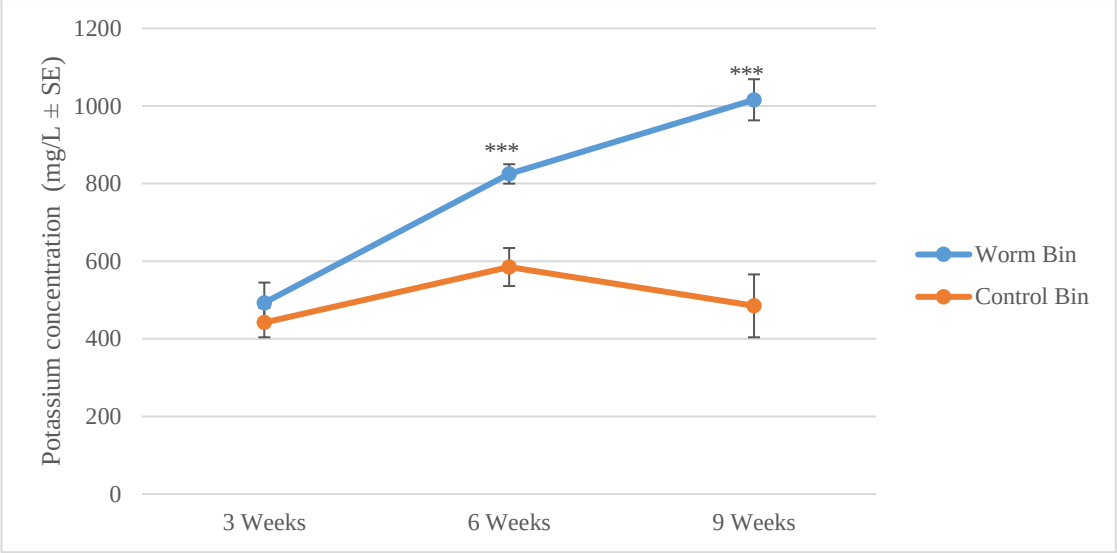
As the worm bin was compared to the control bin, a Mann-Whitney U test was conducted to investigate if there were any significantly different parameters over the given time period.

Regarding the pH values, only the control bin produced any notable pH results for six and nine weeks respectively. Overall the pH of VT decreased while the samples from the control bin increased. VT had higher conductivity and salinity levels which increased over time, while they decreased in the control bin. Orthophosphate concentration decreased over time in the worm bin, while in the control bin, increasing until week six, where after the levels decreased slightly. Neither of the bins had any noteworthy TDS results. Potassium levels in VT increased over time when compared to the control, where it peaked in concentration at six weeks.

Table 2.2: Results for liquids collected from both worm and control bins over a nine-week period (±SD)

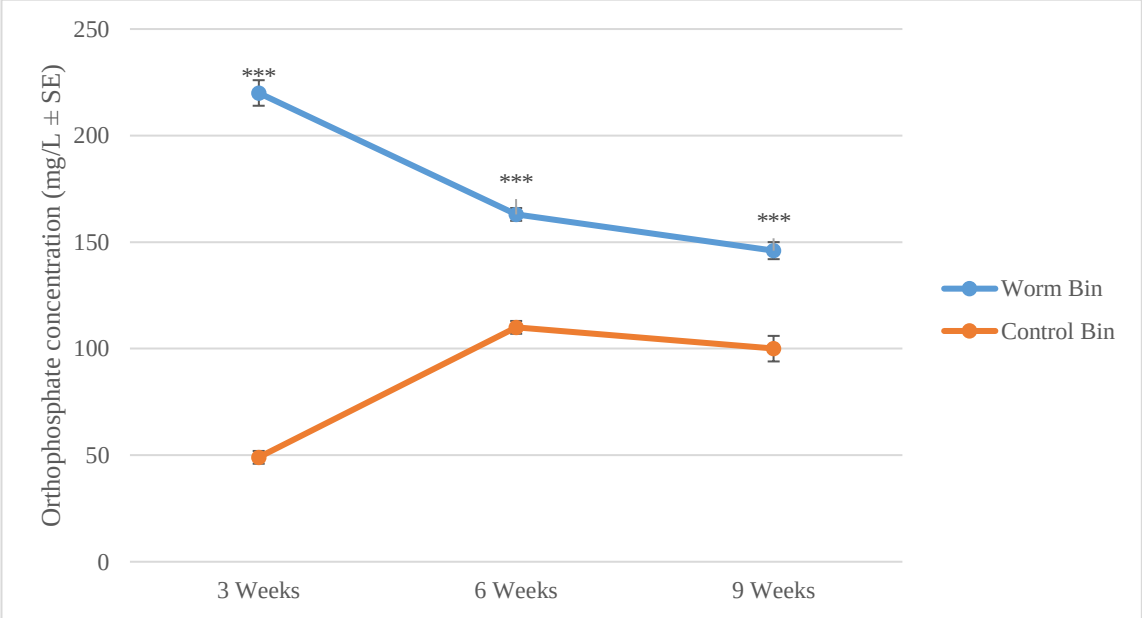
		Worm Bin		
	pH	Conductivity (µS/cm)	Salinity (PSU)	TDS (mg/L)
3 weeks	6.8 ± 0	655 ± 7***	3.5 ± 0***	322 ± 12
6 weeks	6.6 ± 0	703 ± 1***	3.7 ± 0***	314 ± 1***
9 weeks	6.6 ± 0	755 ± 2***	4.3 ± 0***	355 ± 1***
		Control Bin		
	pH	Conductivity (µS/cm)	Salinity (PSU)	TDS (mg/L)
3 weeks	6.9 ± 0	421 ± 31	2.3 ± 0	299 ± 18
6 weeks	6.8 ± 0*	532 ± 6	2.8 ± 0	360 ± 7
9 weeks	7.0 ± 0*	551 ± 4	3.3 ± 0	292 ± 1

*$p < 0.05$, ***$p < 0.001$



***p < 0.001

Figure 2.25: Potassium levels (mg/L ±SE) in worm and control bins over a nine-week period



***p < 0.001

Figure 2.26: Orthophosphate levels (mg/L ±SE) in worm and control bins over a nine-week period

2.3.3 Discussion

In the initial experiment, the pH levels increased slightly, but not as much as the control. In the repetition experiment, there was a decrease in the pH levels of VT (6.8 ± 0 to 6.6 ± 0 in nine weeks) when compared to the control (6.9 ± 0 to 7.0 ± 0 in the same time period). Similar findings were made by Rajpal *et al.,* (2011) and Majlessi *et al.,* (2012), the latter suggesting as cause for this decrease "*the alkalization of food waste because of the release of ammonia from the degradation and mineralisation of organic compounds"*. On the other hand, Rajpal *et al.,* (2011) noted an increase in conductivity over time, which was also observed in the present experiment, EC increased from 655µS/cm ± 7, to 755µS/cm ± 2, with a higher EC range than the control, similar to that reported by Nath *et al.,* (2009). VT had a higher salinity content than the control, a final reading of 4.3 *PSU* ± 0 in comparison to 3.3 *PSU* ± 0 after nine weeks (Table 2.2). Potassium levels increased over time in the worm bin, resulting in notable potassium levels in the VT, unlike the control (Figure 2.25). This was also noted by Pramanik *et al.,* (2007). Kaviraj and Sharma (2003) treated municipal solid waste using *E. fetida* and noted an increase in potassium and EC levels in the resulting VT samples over time. Similar results were found in our study when VT was compared to the control. They noted a gradual increase in EC over time, as did Wong *et al*., (1997), and noted as possible explanation the loss of organic matter over time resulting in the release of available forms of salts, for example, phosphate and potassium. Mahmoud and Ibrahim (2012), noted a higher potassium concentration in VC compared to the soil while Benitez *et al.,* (1999) noted potassium in VT samples. VT had a greater orthophosphate concentration than the control even though it decreased slightly over the nine-week period (Figure 2.26). This was similar to the results of Nath *et al.,* (2009) and comparable to those of Mishra *et al.,* (2014), who reported an increase in phosphorus in VT. As orthophosphate is a plant available form of phosphorus, the similarity can be reported.

Overall, VT had significant physico-chemical and nutrient contents. This illustrates that the presence of earthworms has a positive effect and that it took a short time for them to break down the food and pass it through the system to gather in sufficient concentrations in the VT. These findings were similar to the work reported by Adhikary (2012). Visually, the food was broken down quicker by earthworms than that of a natural composting process, along with the production of a by-product. In conclusion, it can be stated that

vermitechnology was successful in the reducing food waste and hence could be a possible alternative waste treatment.

Chapter Three

Investigation on the use of vermitea as a plant growth promoter

3.1 Introduction

In recent years, sustainability in agriculture has become important due to issues such as soil degradation and pollution (Fathima and Sekar, 2014). Synthetic fertilisers are one of the most popular means of promoting plant growth through the addition of 'man-made' agrochemicals to provide important nutrients such as nitrogen (N), potassium (K), phosphorus (P) and other microelements that plants need for growth and development. Currently, 6% of Irish farms are tillage farms (Wall *et al.,* 2017) which produce wheat, barley and oat, the three main cereal crops grown annually in Ireland. Both winter and spring varieties are grown; spring varieties require warmer temperatures and are sown in early spring, while winter varieties are hardier, so seeds are sown in winter, can remain dormant during the cold winter months and then sprout and develop once temperatures increase. In 2016, farmers in Ireland produced 836,000 tonnes of spring barley and 73,000 tonnes of spring oat, with an average yield of 7.3 – 7.9 tonnes per hectare for each crop, while wheat gave over 8 tonnes/ha (Central Statistics Office, 2017a). Fertilisation is one of the main costs of crop production in Ireland and worldwide. A pre-plant soil test will determine the type and the quantity of fertiliser needed. There are two types used: straight fertilisers (containing only one element, e.g. potash) and compound fertilisers, containing more than one element, e.g. N, P and K (Alexander, 2017).

An example of a leading commercial horticultural fertiliser is Miracle Gro® (from now on referred to as MG), which is available in both granular and liquid forms. Due to the high cost of fertilisers rand their environmental impact, their use is becoming more unsustainable, which is why it is necessary to research for alternative soil fertility enhancers, through organic systems, such as vermitechnology, reducing the cost of crop production and limiting the environmental effects, while retaining the nutritional benefits to ensure cost-effective production of these crops in the future. Vermitea (or 'vermiwash') is a form of leachate of vermicompost that contains minerals and vitamins which can enhance plant growth and improve growth performance (Ali *et al.,* 2014) and therefore is used as a biological fertiliser (Fathima and Sekar, 2014).

Vermicompost has also been proved beneficial, as it may contain good quantities of nutrients and vitamins (Prabha and Priya, 2014). As vermitea is the liquid extract of

vermicompost, its nutrient content would be similar to that of the vermicompost it derived from. The application of vermicompost to plants result in the promotion of root formation, especially in horticultural plants, along with promoting both height and biomass (Singh *et al.,* 2008). A recent study indicated that vermicompost is environmentally friendly and a good fertiliser substitute in conventional and organic agriculture (Makkar *at al.* 2017). Vermicompost may contain nutrients at high concentrations which plants can then readily take up from the soil to enhance their growth and productivity (Raghavendra and Bano, 2001).

Several studies have investigated the potential of vermicompost as an alternative form of fertiliser (Ali *et al.* 2014; Makkar *et al.* 2017; and Singh *et al*. 2008). However further work is required in this area, especially with respect to seed germination and early seedling development of plants, whereupon this chapter focuses.

3.2 Materials and Methods

The aim of this experiment was to investigate the potential of vermitea as a plant growth promoter with respect to seed germination of a variety of arable, horticultural crops in addition to a pasture crop, over a four-day period. This time point was chosen based on pilot plant trials which showed that four days were enough to determine if germination would ever occur.

3.2.1 Plant Species

The arable crops consisted of two varieties chosen from the Irish crop recommended list (Department of Agriculture, Food and the Marine (DAFM), 2016). The selected plant species were: spring barley (*Hordeum vulgare*) (variety: KWS Irina) and spring oat (*Avena sativa*) (variety: Husky), both sourced commercially from a local supplier (Connolly's Red Mills, Kilkenny). Horticultural crops consisted of; carrot *(Daucus carota),* cauliflower (*Brassica oleracea*), turnip (*Brassica rapa*), pea (*Pisum sativum*), and tomato (*Solanum lycopersicum*). All seeds were sourced from a local garden centre. Finally, the pasture crop used was red clover (*Trifolium pratense*).

3.2.2 Seed germination tests

This procedure was used for all crops mentioned in section 3.2.1. Vermitea was collected from worm bins on site, 7-10 days after food waste was added for vermicomposting. For the control, chemical treatments, Miracle Gro® (MG) was used. A randomised block experiment was used (Little and Hills, 1978).

Table 3.1. Fertiliser treatments for seed germination trials

Treatment No.	Treatment (T)	Final concentration
T1	Control (deionised water)	-
T2	20 % Miracle Gro®	0.6 %
T3	100 % Miracle Gro®	3 %
T4	20 % Vermitea	-
T5	100 % Vermitea	-

The trial design consisted of five treatments (50 ml) as outlined in Table 3.1 using 50 ml falcon tubes (supplied by VWR®). For MG treatments, a 3 % stock solution was prepared as per manufacturer's instructions. The 20 % MG and 100 % MG treatments were prepared from this stock solution. For both VT treatments, VT was collected straight from

the five respective worm bins and all samples were mixed thoroughly into one stock solution. From this stock solution, both VT treatment solutions were prepared by dilution. Four barley seeds were placed in a 90 mm non-vented Petri dish (supplied by, Sparks®) lined with a sheet of 90 mm Whatman® Grade 1 filter paper pre-treated with 4 ml of each respective treatment, using a plastic syringe for each application. There were ten replications made for each treatment. All plates were stacked using a random block design (Little and Hills, 1978), secured with masking tape and stored in the dark at 23°C for four days. At 24-hour intervals, the plates were randomly positioned in the dark to ensure fair conditions and any resulting growth which occurred was recorded. On the final day, both root and shoot growth, along with percentage of seed germination were recorded to determine the plant promotion potential of the various treatments.

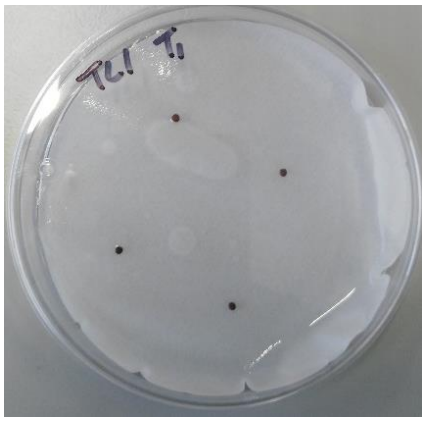


Figure 3.1. Petri-dish containing pre-treated filter paper and four seeds

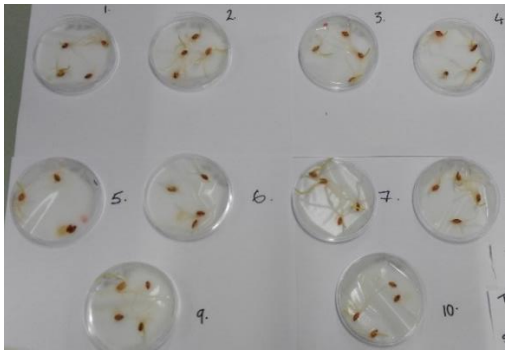


Figure 3.2. Ten replicated Petri-dishes on the final day (day four) of the trial, positive for germination

3.2.3 Early seed development tests

To investigate the plant promotion potential of vermitea on the early seedling development of arable crops, a two-week trial was designed in a greenhouse to replicate field conditions, using the crops mentioned in section 3.2.1.

Plastic pots of 7 cm diameter were filled with compost (Woodies DIY garden centre) and all seeds (4 seeds per pot) were germinated in the soil for 48 hours prior to treatment application in a greenhouse at 23° C ± 1° C, with system-controlled lighting. The trial was arranged using a randomised block design (Little and Hills, 1978). Each treatment consisted of forty replications for arable crops and ten replications for each of the remaining crops. All treatments were applied twice, each application consisting of a 200 ml solution (Table 3.1). Initially, the first treatment was applied 48 hours after the seeds were sown and the second 7 days later. All plants were watered when required and were harvested after two weeks. The roots were then washed to remove excess soil and dried with a lab grade paper towel. The total number of plants germinated was calculated and root and shoot height were measured and recorded.

Figure 3.3. Early seedling development trials (Barley)

3.2.4 Statistical analysis

A χ^2 test of homogeneity (IBM SPSS, Version 23, 2015) was conducted in all seed germination trials to determine which treatments affected the respective germination rates of all crops studied. Each of the five groups representing a treatment applied in the experiment as outlined in Table 3.1.

A Kruskal, Wallis test (1952; IBM SPSS, Version 23, 2015) was conducted to evaluate if any statistically significant differences were present among all treatments applied in terms of root and shoot height of all crops studied. If the null hypothesis was rejected ($p < 0.05$), subsequently, pairwise comparisons were performed using Dunn's (1964) procedure and a Bonferroni correction for multiple comparisons.

3.3 Results

3.3.1 The effect of vermitea against a commercial fertiliser on arable crops

3.3.1.1 Effect on seed germination

With respect to germination of barley seeds, the control treatment was the best treatment, in that neither of the other fertiliser treatments aided in germination sufficiently. In oat, 100% VT affected germination significantly, as seen in Table 3.2. Both MG treatments resulted in low percentage germination of seeds.

Table 3.2: Germination percentage of spring barley and oat observed under various fertiliser treatments

	Barley	**Oat**
Water (control)	34% ***	44% ***
20% MG	5%	28%
100% MG	3%	21%
20% VT	28%	46% ***
100% VT	23%	64%

*** $p < 0.001$

3.3.1.1.1 Root and shoot growth in seed germination

For barley and oat in this experiment, 20 % MG and 100 % MG had a significant adverse effect on both root and shoot height, $p < 0.001$. For barley, both for root length and shoot heights, no treatment produced better results than the control, as seen in Table 3.3. Therefore, in this instance, water is seen to be the best treatment for barley. VT 100 % produced similar results to the control for root length of oat, while it resulted in better shoot height for oat (Table 3.3).

Table 3.3. Root length and shoot height (cm) (± SD) of arable crop seedlings under various fertiliser treatments

	Root	
Treatment	Barley	Oat
Water (control)	1.5 ± 1.8	2.2 ± 1.7
20% MG	0.0 ± 0.1***	0.0 ± 0.1***
100% MG	0.0 ± 0.0	0.0 ± 0.0
20% VT	1.1 ± 1.6	1.8 ± 1.5
100% VT	1.3 ± 1.8	2.3 ± 1.4
	Shoot	
Water (control)	0.7 ± 1.1	1.1 ± 1.2
20% MG	0.1 ± 0.4***	0.2 ± 0.4***
100% MG	0.0 ± 0.1	0.1 ± 0.2
20% VT	0.6 ± 0.8	1.1 ± 1.1
100% VT	0.6 ± 1.1	1.4 ± 1.0

*** $p < 0.001$

3.3.1.2 Effect on early seed development

There were no statistical differences present among all treatments for root length of barley and oat ($p > 0.05$). With respect to barley, 20 % VT produced the greatest root length compared to the control, with 100 % MG for shoot height (Table 3.9). Both VT treatments produced the greatest root growth for oat. While the control treatment had a significant effect on the shoot height of oat, 100 % VT produced slightly better shoot height (Table 3.9).

Table 3.4: Root and shoot height (± SD) of spring barley and oat seedlings

	Root	
Treatment	Barley	Oat
Water (control)	14.0 ± 5.0	11.4 ± 3.5
20% MG	14.4 ± 5.2	15.1 ± 3.5
100% MG	14.1 ± 4.0	15.1 ± 3.6
20% VT	15.9 ± 5.4	15.8 ± 3.4
100% VT	15.5 ± 5.0	15.8 ± 3.3

	Shoot	
Water (control)	40.3 ± 7.0	21.2 ± 2.9***
20% MG	41.1 ± 7.6	20.7 ± 4.0
100% MG	41.7 ± 5.6	21.2 ± 3.3
20% VT	40.9 ± 7.6	19.8 ± 3.9
100% VT	41.2 ± 8.2	21.6 ± 3.6

*** $p < 0.001$

3.3.2 The effect of vermitea against a commercial fertiliser on horticultural crops

3.3.2.1 Effect on seed germination

The results for carrot, cauliflower, turnip and pea were all similar with 20 % VT producing the greatest percentage germination. Tomato was an exception as 20 % MG resulted in the best germination rate. One hundred percent MG had a significant effect on seed germination, which caused a significant diminution of germination.

Table 3.5: Percentage germination of horticultural crops as affected by the various fertiliser treatments

	Carrot	Cauliflower	Turnip	Tomato	Pea
Control (Water)	75%	89%	88%	89%	86%
20% MG	66%	91%	85%	93%	75%
100% MG	3%***	50%***	55%***	26%***	76%***
20% VT	78%	96%	98%	91%	88%
100% VT	71%	89%	86%	88%	81%

*** $p < 0.001$

3.3.2.1.1 Root and shoot growth in seed germination

With respect to root length of cauliflower, turnip and tomato, 100 % MG had a significant adverse effect, while both MG treatments had the same effect on both the root and shoot development of carrot (Table 3.4). No fertiliser treatment had as good an effect on root length as the control, therefore water is the best treatment in this case, while 20 % VT was the best for cauliflower and tomato (Table 3.4). With respect to shoot height if carrot, both VT treatments produced the same result as the control, while VT resulted in the greatest shoot height of cauliflower, turnip and tomato (Table 3.4).

For the radical length of pea, 100 % MG had a significant effect in the radicle length of pea, with 20 % VT resulted in the greatest radicle growth (Table 3.5).

Table 3.6: Root and shoot height (cm ± SD) of horticultural crop seedlings as affected by the various fertiliser treatments

		Root		
Treatment	Carrot	Cauliflower	Turnip	Tomato
Water (control)	0.9 ± 0.6	1.8 ± 1.0	4.8 ± 2.4	3.1 ± 1.1
20% MG	0.1 ± 0***	1.1 ± 0.6***	0.8 ± 0.4***	0.5 ± 0.2***
100% MG	0.0 ± 0.0	0.2 ± 0.3	0.2 ± 0.2	0.1 ± 0.1
20% VT	0.8 ± 0.6	2.5 ± 1.3	4.3 ± 2.4	3.5 ± 1.4
100% VT	0.8 ± 0.6	2.2 ± 1.0	2.3 ± 1.2	2.7 ± 1.0
		Shoot		
	Carrot	Cauliflower	Turnip	Tomato
Water (control)	0.1 ± 0.1	1.1 ± 1.1	2.0 ± 1.0	1.6 ± 0.8
20% MG	0.0 ± 0.0	1.5 ± 0.8	2.7 ± 1.2	0.7 ± 0.3
100% MG	0.0 ± 0.0	0.2 ± 0.2	0.3 ± 0.1	0.1 ± 0.1
20% VT	0.1 ± 0.2***	1.6 ± 0.7***	3.2 ± 1.6***	2.0 ± 1.1***
100% VT	0.1 ± 0.1***	1.8 ± 0.9***	3.7 ± 1.8***	1.8 ± 0.9***

*** $p < 0.001$

Table 3.7: Radicle length (± SD) of pea seedlings

	Pea Radicle
Water (control)	2.4 ± 1.7*
20% MG	1.6 ± 1.2***
100% MG	0.8 ± 0.5
20% VT	4.8 ± 6.1
100% VT	2.8 ± 1.7

*p <0.05, *** p < 0.001

3.3.3.2 Effect on early seed development

There were no significant differences observed among the treatments, in both root and shoot height of the crops analysed ($p > 0.05$). No treatment produced better root growth of all crops than the control, except for pea where 20 % MG produced the same root length as the control (Table 3.10). Similar results were observed for shoot height, with

the only exception was 100 % MG producing the best shoot growth for turnip (Table 3.10).

Table 3.8: Root and shoot height (cm ± SD) of horticultural crop seedlings under various fertiliser treatments

		Root		
Treatment	Carrot	Cauliflower	Turnip	Pea
Water (control)	5.3 ± 2.4	8.0 ± 3.2	8.8 ± 3.6	15.0 ± 3.7
20% MG	3.9 ± 2.0	6.0 ± 3.6	7.1 ± 2.4	15.0 ± 5.8
100% MG	4.1 ± 2.5	6.8 ± 1.1	7.9 ± 3.6	14.4 ± 7.4
20% VT	3.9 ± 2.2	6.7 ± 2.8	8.5 ± 4.8	14.8 ± 4.6
100% VT	4.4 ± 2.5	7.8 ± 4.1	7.0 ± 3.0	12.7 ± 5.6
		Shoot		
	Carrot	Cauliflower	Turnip	Pea
Water (control)	4.8 ± 1.8	12.6 ± 1.0	18.3 ± 4.0	17.6 ± 3.3
20% MG	4.5 ± 1.6	12.0 ± 4.1	17.6 ± 3.9	15.8 ± 2.5
100% MG	4.0 ± 2.0	12.1 ± 2.1	20.9 ± 2.4	15.7 ± 3.5
20% VT	4.0 ± 1.8	11.9 ± 2.9	20.0 ± 4.0	14.6 ± 2.0
100% VT	4.7 ± 1.6	11.0 ± 1.9	20.0 ± 3.8	15.6 ± 3.6

3.3.3 The effect of vermitea against a commercial fertiliser on a pasture crop

3.3.3.1 Effect on seed germination

On examination of the χ^2 test for clover, 100% MG adversely affected germination ($p < 0.001$) and 100 % VT produced the greatest percentage germination (Table 3.7).

Table 3.9: Percentage germination of clover under various fertiliser treatments

Clover	
Control (Water)	73%
20% MG	63%
100% MG	1%***
20% VT	75%
100% VT	81%

*** $p < 0.001$

3.3.3.1.1 Root and shoot growth in seed germination

The root length of clover was significantly lower with MG, when statistically compared to water and VT ($p < 0.001$). One hundred percent MG had a statistically significant effect also for shoot height when compared to VT and water ($p < 0.001$) as it produced the shortest growth. Both VT treatments had similar results to the control, with 20 % VT producing the greatest root length, while 100 % VT resulted in the greatest shoot height of clover (Table 3.8).

Table 3.10: Root and shoot height (cm ± SD) of clover under various fertiliser treatments

	Clover	
Treatment	Root	Shoot
Water (control)	1.9 ± 1.3	1.3 ± 0.9
20% MG	0.3 ± 0.3***	0.7 ± 0.8
100% MG	0.0 ± 0.0***	0.0 ± 0.0***
20% VT	2.0 ± 1.3	1.4 ± 1.0
100% VT	1.7 ± 0.9	1.8 ± 1.1

*** $p < 0.001$

3.3.3.2 Effect on early seed development

There were no significant root and shoot heights observed among the treatments in clover ($p > 0.05$). Both chemical treatments produced the best growth with 100 % MG for root and 20% MG for shoot respectively (Table 3.10).

Table 3.11: Root and shoot height (cm ± SD) of clover seedlings under various fertiliser treatments

	Clover	
Treatment	**Root**	**Shoot**
Water (control)	6.6 ± 5.1	7.3 ± 2.0
20% MG	8.7 ± 2.3	7.6 ± 1.1
100% MG	9.0 ± 5.6	6.5 ± 2.4
20% VT	7.4± 2.6	7.4 ± 1.6
100% VT	7.7 ± 4.0	6.9 ± 2.1

3.4 Discussion

Some work has been conducted on the use of vermicompost on plants such as work on tomato plants by Abduli *et al.* (2011) and Singh *et al*., (2010). Other work reported on the use of vermitea, by spraying the plants with vermitea, *e.g.* Hatti *et al.*, (2010) who used vermitea from *Perionyx excavatus* on mung bean (*Vigna radiata*). The present research examined the effect of vermitea on the initial plant growth stages when added to the soil instead of being sprayed directly on the plants as has been described previously. Thus, this work is novel in that respect and therefore, only some aspects are comparable previously conducted research.

Both seed germination experiments and early seedling development trials were conducted to investigate the potential role of VT as a plant growth promoter on arable, horticultural and pasture crops (all experiments were carried out in duplicate, and the mean results reported). VT was compared to a well-known and frequently used commercial chemical fertiliser, Miracle Gro®. A control treatment was used to represent no fertiliser addition at all. The seed germination experiments looked at the initial growth stages of each selected plant over a 4-day period. Looking solely at the fertiliser added (or lack of), the seeds were germinated on just filter paper, to try to eliminate any environmental factors, where possible. The early seedling development experiments were designed to mimic the first two weeks of seed germination and growth as done commercially or domestically. Seed germination and growth in soil was performed under conditions similar to those applied commercially and in domestic gardens. The same treatments were applied twice (once per week) directly to the soil, while for the seed germination trials, the filter paper was pre-treated prior to placement of seeds. Overall, when the results of all experiments were compiled, a composite picture of the germination action and seedling development in soil emerged. These experiments were an imitation of the actual growth practices in Ireland, and shed light as to how VT may affect both germination and growth of all plants under study.

3.4.1 Arable crops

Regarding the arable crops studied, both spring barley and spring oat were used for the purposes of germination and early seed development tests (ESD). Statistically, none of the chemical treatments resulted in abundant seed germination, or early seed development tests, irrespective of the crop type, compared to water and VT. Thirty four percent of barley seeds germinated in water, this was the highest percentage rate observed, while 64

% of oat seeds germinated in 100 % VT. Similar results were seen for the root and shoot growth in barley, with water producing the best results of 1.5 cm ± 1.8 and 0.7 cm ± 1.1 for root and shoot respectively. Oat also benefited the greatest from 100 % VT treatment, with 2.3 cm ± 1.4 for root length and 1.4 cm ± 1.0 for shoot height.

In ESD trials, very few barley seeds germinated successfully in the repetition trial, therefore this trial could not be continued. Initial results suggested that both 20 % VT and 100 % MG may aid the root and shoot development. Root and shoot results were the same as those observed in germination tests, with 100 % VT resulting in the best treatment, 15.8 cm ± 3.4 for root length and 21.6 cm ± 3.6 for shoot height.

Thus, in conclusion, overall water was seen to be the best treatment for growth in barley, however a combination of VT and MG could be used also to aid in the initial root and shoot development, while VT could be used to aid in the growth of oat.

3.4.2 Horticultural Crops

Overall for the seed germination tests (SG) of horticultural crops, VT produced high quantities of germinated seeds of the majority of crops, after four days in warm, dark conditions, at the lowest concentration of 20 %, which is, in general, comparable to findings reported by Fathima and Sekar, (2014). Their study also found that VT at lower concentrations was *"effective in bringing about seed germination and seedling growth"* on *Hibbiscus* and common bean (*Phaseolus vulgaris)* in petri dishes. The only exception in our study was tomato seeds, with 93 % germination due to 20 % MG.

As it was quite difficult to see any growth in the soil after only 4 days, due to the growth development of the seeds still occurring under the soil surface, final results were taken after two weeks at the end of the experiment. Therefore, the plant growth and plant health are discussed in general rather than in specific time points in the development stage.

In the SG experiment, 20 % MG significantly affected root growth of all crops, producing the least growth in comparison to the other treatments. Water resulted in the best root length of carrot 0.9 cm ± 0.6 and turnip 4.8 cm ± 2.4, while 20 % VT was the best treatment for root development of cauliflower, 2.5 cm ± 1.3, tomato, 3.5 cm ± 1.4 and for radicle length of pea 4.8 cm ± 6.1. Three treatments resulted the greatest shoot height of carrot; 20 % VT 0.1 cm ± 0.1, 100 % VT 0.1 cm ± 0.2 and control treatment, 0.1 cm ± 0.1, while 100 % VT produced the best shoot growth of cauliflower, 1.8 cm ± 0.9 and

turnip, 3.7 cm ± 1.8 respectively. Again, as with percentage germination, 20 % VT produced the best shoot height of tomato seeds, 2.0 cm ± 1.1.

In respect to ESD tests, when the treatments were applied to the same varieties of plants in the soil, there were no significant differences seen among all treatments for either root or shoot development. Regarding root development, water benefitted all crops in comparison to the other treatments, with the exception of turnip, where 20 % MG also produced the greatest root length, 15 cm ± 5.8 (control; 15 cm ± 3.7). Similar was observed in shoot growth of all crops, in this instance, 100 % MG produced the greatest shoot height of turnip, 20.9 cm ± 2.4.

When both SG and ESD experiments are compared, it can be noted that in some cases, there was not one particular treatment which produced these results but a combination. In addition, SG trials were done on filter paper as the growth medium without a light source (to replicate the seed development in the soil) when planted, while the ESD trials were done in soil (with the same environmental temperatures). The nutrients in the soil could have possibly been a factor in the growth of the plants, which may have affected the experiment results slightly. This finding is similar to that of Singh *et al.,* (2011), who reported that the use of both fertilisers and vermicompost could benefit the growth and development of French bean (*Phaseolus vulgaris).* This comparison can be applied to the results of the above experiment as the nutrients present in vermicompost should also be present in vermitea, given that vermitea is derived from this type of compost. Peas are legume members of the family known as Fabaceae, showing a great ability to fix nitrogen from the air and being a good source of protein (Alexander, 2017). Peas have a different root and shoot system compared to the other plants tested. At the first stage of germination, a growth called a radicle emerges which develops further offshoots roots. The growth above ground is known as the stem or shoot.

Thus, in conclusion, VT could be added to aid in the growth of cauliflower and pea, while a combination of water and VT added to aid carrot and turnip and possibly a combination of 20 % MG and VT for tomato.

3.4.3 Pasture crop

For SG of clover seeds, statistically 100% MG caused the greatest percentage of dead seeds (1 %), while 100 % VT produced the greatest germination percentage, 81 %. Twenty percent VT produced the best root growth, 2.0 cm ± 1.3 and 100 % VT for the greatest shoot growth, 1.8 cm ± 1.1.

In ESD experiment, there were no statistically significant root or shoot for VT or control, with MG observed to be the best treatment for root and shoot development. One hundred percent MG resulted in the greatest root length, 9 cm ± 5.6 and 20 % MG for shoot height, 7.6 cm ± 1.1. Therefore, seedling development experiments indicate that the chemical fertiliser was the treatment which aided in plant growth. This is understandable as chemical fertilisers are formulated to have high quantities of nutrients and also to provide these nutrients over a short time period. However, in arable crops, spring barley and oats, both chemical fertiliser and VT can add to the health and development of plants as was also seen by Saha *et al.,* (2005), who found that both sources were seen effective in the development of Aloe vera.

In conclusion VT aids in the germination of clover seeds in the initial growth stages, while MG then contributes to growth in the following growth stages in soil.

3.5 Conclusions

- MG at a high concentration killed seeds in Petri dishes, with the exception of tomato, but adverse effects were mitigated in a soil-based experiment.
- Oat benefits hugely from VT treatment; however further testing could be conducted to examine this in more detail.
- Overall, VT aids in the germination of most species of seeds, while MG aids tomato germination and water for barley germination. Therefore, water can be used without the aid of VT or chemical treatments for crops in soil.

3.6 Recommendations

- Increase in the number of applications of VT to the soil over a longer period of time to allow the build-up of nutrients and increase availability to plants.
- For some plants, VT could be added as a single treatment in addition to water throughout the initial growth stages.

Chapter Four

4.1 General Discussion

Waste is an ongoing issue in Ireland. Current treatment methods, such as landfill, are unsustainable, therefore research is needed to develop alternative waste treatment methods. Vermitechnology has been previously studied as a possible method to reduce waste, sewage, sludge and some food waste. Suthar (2008) studied vermitechnology on vegetable waste, while (Mishra *et al.*, 2014) used earthworms to treat municipal solid wastes.

While conducting a literature research on previous vermitechnology work, it was noticed that quite a lot of work has been done with vermicompost and its uses for plant development. For instance, Suthar (2008) investigated the physico-chemical properties of vermicompost, while Pramanik (2012) studied the chemical and biochemical properties of soils amended with vermicompost. Arancon *et al.*, (2004) studied the effect of vermicompost from food waste on greenhouse peppers, Roberts *et al.*, (2007) and Suthar (2005), the yield response of wheat using vermicompost. Vermicompost has also been tested on tomato plants by Atiyeh *et al.* (1999) and Gutiérrez-Miceli *et al.* (2007), while Peyvast *et al.*, (2008) studied the effect of vermicompost on spinach yield. However, less research has been carried out on vermitea, a by-product of this system, with Zambare *et al*., (2008) and Arthur *et al.*, (2012) conducting some research into this area.

This project investigated the use of vermitechnology as a novel treatment for food waste along with the positive effects of vermitea, on plant health and development. Experiments were designed to examine the use of earthworms to degrade food waste in purpose-built bins. Also, a number of experiments were conducted to determine the effect of vermitea on the germination and early seedling development (root and shoot growth) of various species of plants. This research was divided into two main sections.

The first section looked at vermitechnology and the chemical analysis of vermitea. Bins including earthworms and control bins were built to study the vermitechnology, or ‘vermicomposting’, process of breaking down a variety of food, fruit and vegetable wastes. Along with analysing vermitea collected from the above system, vermicompost deriving commercially from two sources and was soaked to produce vermitea. The hypothesis was to investigate whether tea produced from these vermicomposts had similar physio-chemical and nutritional results as the vermitea derived straight from a

working system. If so, whether there is an optimum weight of vermicompost needed to soak over a certain timeframe to produce these similar results. This safe, cost-effective protocol was designed and developed for this project and was successful in producing VT from VC quickly and efficiently in a lab environment.

The second section focussed on the application of vermitea on a variety of agricultural, horticultural and pasture crops. Experiments were developed to compare vermitea to a commercial chemical fertiliser Miracle Gro® with a control treatment of water to represent no fertiliser addition. Both seed germination along with root and shoot growth was measured to determine if vermitea (an organic solution) could produce similar plant development results to those generated by a leading chemical fertiliser.

The main findings were:

1. Earthworms reduce food waste quicker than that of a plain composting system.
2. Smaller amounts of VC (1g and 5g especially) can be soaked over 1-5 days to produce vermitea which has good amounts of orthophosphate and potassium, along with notable levels of pH, electrical conductivity, salinity and total dissolved solids. The results showed that the VC weight and not the soakage time length was a significant factor.
3. Vermitea from the in-house vermitechnology system had significantly different physico-chemical and nutrient parameters in comparison to liquid samples from the control, which was a normal composting system without earthworms.
4. Oat benefits hugely from VT treatment; however further testing could be conducted to examine this in more detail.
5. Overall, VT aids in the germination of most species of seeds, while MG aids tomato germination and water for barley germination.

The work in chapter two investigated the use of vermitechnology as a treatment for food waste. In a paper review of vermicomposting, Adhikary (2012) described it as a "*process faster than composting; because the material passes through the earthworm gut"*. The results of our work were similar in that, visually, reduction of the food waste volume by earthworms was achieved quicker than that observed in the control, non-earthworm, common composting system. The similarities between these works suggest that a vermitechnology system, irrespective of what waste it is using, it breaks it down faster when earthworms are used compared to a natural composting system. Research conducted

by Adhikary (2012) also noted that earthworms can reduce volumes of organic waste by up to 60 % and produce vermicast (vermitea) equal to approximately 50 % of the waste volume consumed per day.

As previously mentioned, numerous research has been conducted internationally on vermicompost (for example: Pramanik, 2012; Suthar 2008; Roberts *et al.,* 2007 and Suthar 2005). It was noted that while vermicompost is a good additive to soil, worm castings (vermitea) have a higher nutrient content and can have five times more nutrients than average soil mixtures (Adhikary 2012). In the work discussed in this current thesis, similar results were found in one experiment examining the process of soaking vermicompost in water to produce vermitea. For example, when 20 g of compost samples were soaked for five days, the resulting liquid samples were analysed for potassium content.

Results revealed that samples from vermicompost produced approx. three times greater potassium concentration (110 mg/L) than samples from topsoil (32 mg/L). When this was compared to vermitea produced from a vermitechnology system on-site, those samples contained approx. up to fifteen times more potassium (450 mg/L) than the topsoil samples tested. Further work discussed by Adhikary (2012) noted that phosphorus is converted to the plant available form (orthophosphate) when passed through the gut of an earthworm. In our experiment, it was noted that after nine weeks, vermitea samples from vermibins had an orthophosphate concentration of approximately 150 mg/L, while control samples produced less at 100 mg/L. This illustrates that the higher concentration of orthophosphate in vermitea compared to the control was due to the presence of earthworms. There was a notable difference in the physico-chemical parameters between vermitea and the control in the same vermitechnology experiment. There was a decrease in the pH of vermitea samples (6.8 ± 0 to 6.6 ± 0) compared to samples from control bins (6.9 ± 0 to 7.0 ± 0) over time. Similar results were reported by Majlessi *et al.,* (2012) and Rajpal *et al.,* (2011). There was an increase in electrical conductivity in the same VT samples during the same period, EC increased from 655µS/cm ± 7, to 755µS/cm ± 2, which was comparable to results reported by Rajpal *et al.,* (2011). In addition, in our study, an increased salinity, (3.3 *PSU* ± 0 up to 4.3 *PSU* ± 0 after nine weeks) and total concentration of dissolved solids (322 mg/L ± 12 to 355 mg/L ± 1) in vermitea was noted in over study but since there was a slight increase for electrical conductivity and salinity in control samples, these were not statistically significant in comparison to vermitea.

The determination of the effects of vermitea in comparison to the chemical fertiliser used as a control was the main focus of chapter three. Previous work has been done by other researchers on the use of vermicompost for plant development (Makkar *et al.,* 2017; Ali *et al.,* 2014; Prabha and Priya, 2014; Singh *et al*., 2008) however less on the use of vermitea. In this study, the first experiment compared both chemical and vermitea treatments on seed germination of barley and oat, along with carrot, cauliflower, turnip, tomato, pea and clover.

Plant development parameters consisted of; germination percentage, root length and shoot height. All seeds were placed in petri dishes using filter paper and placed in the dark for four days. Early seedling development trials were also conducted.

In the seed germination experiment, water produced the best germination of barley, 34% while VT produced the best oat germination, 64%. While MG had a significant effect on germination of horticultural crops (the lowest rate of all treatments, 20 % VT produced the best percentage germination (Table 3.4). Similar was seen in germination of clover seeds, with 100 % VT producing the highest germination rate, 81 %.

The second experiment of early seedling development of a variety of crops showed interesting results. Vermicompost has been applied to several plant species such as tomato (Singh *et al.,* 2010; Abduli *et al.,* 2011). Another study sprayed vermitea derived from the worm *Perionyx excavatus* on the mungo bean plant (Hatti *et al.,* 2010). This chapter studied the effect of vermitea when added to the soil in the initial plant growth stages, instead of spraying it directly on plants as has been done previously.

In this experiment, the treatments had no statistically different effects on plant growth. One possible explanation could be that when vermitea was added to the soil, this organic solution may have been absorbed. As it had low physico-chemical and nutrient contents, any immediate effect was lost in the soil over the two-week period. This resulted in results similar to the control treatment, (water) in some trials. The opposite effect was observed for the chemical fertiliser, which produced effects immediately, as it is formulated to have high nutrient levels and the chemicals can build up in the soil quicker than an organic solution. This could explain how the chemical treatments produced better results, as chemical fertilisers are formulated specifically for soil amendments and thus add to the nutrients already present in the soil. Therefore, a combination of both may be used more effectively. This was seen in our study for barley, carrot, tomato and turnip. This

comparison of a chemical fertiliser and vermicompost has also been studied by Singh *et al*., (2010) on the yield of tomato. This research concluded that a combination of both VC and fertiliser produced better yield and quality of tomato in field trials. Future work could examine more varied concentrations of VT in comparison to chemical fertilisers. In addition, time could be another parameter worth investigating, with trials consisting of the same plant species and treatments over various longer time periods.

Overall on completion of this work, it can be concluded that vermitechnology is a novel treatment that is successful treating and reducing food waste. It is a clean and low-cost process which that can be easily applied at home, while being environmentally friendly. Further research can be conducted on this process to include more types of food wastes over longer time periods along with analysis of the vermicompost produced from this system. Vermitea, a by-product of vermicompost has also notable nutrient contents and physico-chemical levels, but further work is needed to determine any further plant growth promoting properties, both in seed germination and especially in seedling development.

This work has highlighted how useful this technology can be in reducing food waste which is currently sent to landfill, while producing a nutritional organic fertiliser, which could be used to aid in the germination of many crops, thus hopefully in the future in reducing the quantities of chemical fertilisers used in this country, especially in horticultural crops.

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Appendix A

A1 Food waste input to bins - preliminary vermitechnology trial

Time (days)	Bin	Weight of food waste (g)	Type of food waste
1	Worm Bin	200	FW,PP, MB
	Control Bin	201	FW,PP, MB
24	Worm Bin	72	FW
	Control Bin	73	FW
54	Worm Bin	179	FW, PP
	Control Bin	178	FW, PP

FW = Fruit Waste, PP = Potato Peals, MB = Mouldy Bread

A2 Food waste input to bins - repeat vermitechnology trial

Time (days)	Bin (each bin had five reps)	Weight of food waste (g)	Type of food waste
1	Worm Bin 1	31	FW, VW
	Worm Bin 2	31	FW, VW
	Worm Bin 3	31	FW, VW
	Worm Bin 4	31	FW, VW
	Worm Bin 5	31	FW, VW
	Control Bin 1	30	FW, VW
	Control Bin 2	30	FW, VW
	Control Bin 3	29	FW, VW
	Control Bin 4	28	FW, VW
	Control Bin 5	30	FW, VW
12	Worm Bin 1	51	FW,PP, MB
	Worm Bin 2	49	FW,PP, MB
	Worm Bin 3	51	FW,PP, MB
	Worm Bin 4	50	FW,PP, MB

	Worm Bin 5	49	FW,PP, MB
	Control Bin 1	51	FW,PP, MB
	Control Bin 2	47	FW,PP, MB
	Control Bin 3	46	FW,PP, MB
	Control Bin 4	41	FW,PP, MB
	Control Bin 5	44	FW,PP, MB
36	Worm Bin 1	49	PP, MB
	Worm Bin 2	46	PP, MB
	Worm Bin 3	46	PP, MB
	Worm Bin 4	45	PP, MB
	Worm Bin 5	48	PP, MB
	Control Bin 1	48	PP, MB
	Control Bin 2	46	PP, MB
	Control Bin 3	47	PP, MB
	Control Bin 4	48	PP, MB
	Control Bin 5	46	PP, MB

FW = Fruit Waste, VW = Vegetable Waste, PP = Potato Peals, MB = Mouldy Bread

Appendix B

B1: Kruskal - Wallis results for VT samples from, commercial VC source one

		Kruskal Wallis results incl. post hoc test	**Days with notable results**
pH	1g - 20g	H (4) = 28.6, p < 0.001	All 5 days
Conductivity	1g – 20g	p > 0.05	NS
Salinity	1g – 20g	H (4) = 120.4, p < 0.005	1, 2, 3, 5D
TDS	1g – 20g	H (4) = 35.1, p < 0.005	1, 2, 4, 5D
Potassium	1g – 20g	H (4) = 11.8, p < 0.05	All 5 days
Orthophosphate	1g – 20g	H (4) = 17.5, p < 0.005	All 5 days

NS – No Significant differences

B2 Kruskal - Wallis results for VT samples from, commercial VC source two

Bag One	**Notable weights**	**Kruskal Wallis results incl. post hoc test**	**Days with notable results**
pH	1g, 5g	H (4) = 10.3, p < 0.05	Only 5D tested
Conductivity	1g, 5g, 10g	H (4) = 42.3, p < 0.005	Only 5D tested
Salinity	5g	H (4) = 42.4, p < 0.005	Only 5D tested
TDS	1g, 5g, 10g	H (4) = 42.3, p < 0.005	Only 5D tested
Potassium	1g, 5g	H (4) = 40.6, p < 0.005	Only 5D tested
Orthophosphate	1g, 5g	H (4) = 40.4, p < 0.005	Only 5D tested

Bag Two		Kruskal Wallis	Days with notable results
pH	1g, 5g	H (4) = 35.1, p < 0.005	Only 5D tested
Conductivity	1g, 20g	H (4) = 37.3, p < 0.005	Only 5D tested
Salinity	1g, 5g, 10g	H (4) = 42.4, p < 0.005	Only 5D tested
TDS	1g, 5g, 10g	H (4) = 42.4, p < 0.005	Only 5D tested
Potassium	1g, 5g	H (4) = 40.5, p < 0.005	Only 5D tested
Orthophosphate	1g, 5g	H (4) = 41.1, p < 0.005	Only 5D tested

Bag Three		Kruskal Wallis	Days with notable results
pH	1g, 5g, 20g	H (4) = 37.6, p < 0.005	Only 5D tested
Conductivity	-	p > 0.05	NS
Salinity	1g, 5g	H (4) = 30.9, p < 0.005	Only 5D tested
TDS	1g, 5g, 10g	H (4) = 40.6, p < 0.005	Only 5D tested
Potassium	1g, 5g, 10g	H (4) = 41.8, p < 0.005	Only 5D tested
Orthophosphate	1g, 5g	H (4) = 40.4, p < 0.005	Only 5D tested

Bag Five		Kruskal Wallis	Days with notable results
pH	-	p > 0.05	NS
Conductivity	-	p > 0.05	NS
Salinity	-	p > 0.05	NS
TDS	-	p > 0.05	NS
Potassium	-	p > 0.05	NS
Orthophosphate	-	p > 0.05	NS

NS – No Significant differences

B3: Kruskal - Wallis results for topsoil liquid samples

		Kruskal Wallis results incl. post hoc test	**Days with notable results**
pH	1g	H (4) = 33.7, p < 0.005	All 5 days
	5g	H (4) = 19.9, p < 0.01	1, 2, 3, 5D
	10g	H (4) = 35.3, p < 0.005	1, 2, 3, 4D
	15g	H (4) = 35.8, p < 0.005	All 5 days
	20g	H (4) = 32.6, p < 0.005	All 5 days

Conductivity		Kruskal Wallis results incl. post hoc test	Days with notable results
	1g	H (4) = 37.2, p < 0.005	All 5 days
	5g	H (4) = 30.9, p < 0.005	All 5 days
	10g	H (4) = 23.3, p < 0.005	All 5 days

	15g	H (4) = 21.5, p < 0.005	1, 2, 3, 5D
	20g	H (4) = 28.4, p < 0.005	1, 2, 4, 5D
Salinity		Kruskal Wallis results incl. post hoc test	Days with notable results
	1g	H (4) = 38.7, p < 0.005	All 5 days
	5g	H (4) = 42.0, p < 0.005	All 5 days
	10g	H (4) = 32.3, p < 0.005	All 5 days
	15g	H (4) = 26.9, p < 0.005	1, 2, 3, 5D
	20g	H (4) = 32.7, p < 0.005	All 5 days
TDS		Kruskal Wallis results incl. post hoc test	Days with notable results
	1g	H (4) = 33.8, p < 0.005	All 5 days
	5g	H (4) = 41.0, p < 0.005	All 5 days
	10g	H (4) = 30.2, p < 0.005	All 5 days
	15g	H (4) = 30.0, p < 0.005	1, 2, 3, 4D
	20g	H (4) = 27.0, p < 0.005	1, 2, 3, 4D
		Kruskal Wallis results incl. post hoc test	Days with notable results
Potassium	1g	H (4) = 30.6, p < 0.005	All 5 days
	5g	p > 0.05	NS
	10g	H (4) = 17.6, p < 0.01	1, 3, 4, 5D
	15g	H (4) = 37.3, p < 0.005	All 5 days
	20g	H (4) = 24.7, p < 0.005	2, 3, 4, 5D
Orthophosphate		Kruskal Wallis results incl. post hoc test	Days with notable results
	1g	H (4) = 27.8, p < 0.005	2, 3, 4, 5 D
	5g	H (4) = 38.6, p < 0.005	1, 2, 3, 5D
	10g	H (4) = 35.5, p < 0.005	All 5 days
	15g	H (4) = 33.5, p < 0.005	1, 2, 4, 5 D
	20g	H (4) = 34.6, p < 0.005	All 5 days

NS – No Significant differences

B4 Mann - Whitney U Test results, comparison of Plagron and topsoil (control) – pH, illustrating which sample source had notable results

Weight	**1D**	**2D**	**3D**	**4D**	**5D**
1g	Plagron*** r = 14	Plagron** r = 53	Topsoil* r = 12	Plagron** r = 14	NS
5g	NS	Topsoil* r = 52	NS	NS	NS
10g	NS	NS	NS	Topsoil** r=13	Plagron** r = 13
15g	Plagron** r =13	Plagron* r = 52	NS	Topsoil** r=13	Plagron** *r = 14
20g	Plagron* r =13	Topsoil* r = 52	NS	Topsoil*** r=14	NS

*p < 0.05, **p < 0.001, ***p < 0.005 NS = No significant difference present

B5 Mann - Whitney U Test results, comparison of Plagron and topsoil (control) – Conductivity, illustrating which sample source had notable results

Weight	**1D**	**2D**	**3D**	**4D**	**5D**
1g	Topsoil*** r = 14	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14
5g	Topsoil*** r = 14	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14
10g	Topsoil*** r = 14	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14
15g	Topsoil*** r = 14	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14
20g	Topsoil*** r = 14	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14

*p < 0.05, **p < 0.001, ***p < 0.005 NS = No significant difference present

B6 Mann - Whitney U Test results, comparison of Plagron and topsoil (control) – Salinity, illustrating which sample source had notable results

Weight	1D	2D	3D	4D	5D
1g	NS	Plagron*** r = 65	Plagron*** r = 14	Plagron*** r = 14	Plagron*** r = 14
5g	Plagron*** r = 14	Plagron*** r = 68	Plagron*** r = 14	Plagron*** r = 14	Plagron*** r = 14
10g	NS	Plagron*** r = 56	Plagron*** r = 14	NS	NS
15g	NS	NS	Plagron*** r = 14	Topsoil*** r = 14	NS
20g	Plagron*** r = 14	Plagron * r = 52	Plagron*** r = 14	Topsoil*** r = 14	NS

*p < 0.05, **p < 0.001, ***p < 0.005 NS = No significant difference present

B7 Mann - Whitney U Test results, comparison of Plagron and topsoil (control) – TDS, illustrating which sample source had notable results

Weight	1D	2D	3D	4D	5D
1g	Topsoil*** r = 14	Topsoil*** r = 63	Topsoil*** r = 14	Topsoil*** r = 14	Plagron*** r = 14
5g	Topsoil*** r = 15	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14
10g	Topsoil*** r = 16	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14
15g	Topsoil*** r = 17	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14
20g	Topsoil*** r = 18	Topsoil*** r = 68	Topsoil*** r = 14	Topsoil*** r = 14	Topsoil*** r = 14

*p < 0.05, **p < 0.001, ***p < 0.005 NS = No significant difference present

B8 Mann - Whitney U Test results, comparison of Plagron and topsoil (control) – Potassium, illustrating which sample source had notable results

Weight	1D	2D	3D	4D	5D
1g	Plagron** r = 13	Plagron*** r = 64	Plagron*** r = 14	Plagron*** r = 14	Plagron** r = 13
5g	Plagron** r = 13	Plagron*** r = 67	Plagron*** r = 14	Plagron*** r = 14	Plagron*** r = 14
10g	Plagron** r = 13	Plagron*** r = 68	Plagron*** r = 14	Plagron*** r = 14	Plagron*** r = 14
15g	Plagron** r = 13	Plagron*** r = 68	Plagron*** r = 14	Plagron*** r = 14	Plagron*** r = 14
20g	Plagron** r = 13	Plagron*** r = 68	Plagron*** r = 14	Plagron*** r = 14	Plagron*** r = 14

*p < 0.05, **p < 0.001, ***p < 0.005 NS = No significant difference present

B9 Mann - Whitney U Test results, comparison of Plagron and topsoil (control) – Orthophosphate, illustrating which sample source had notable results

Weight	1D	2D	3D	4D	5D
1g	NS	Plagron**	Plagron***	NS	NS
5g	Topsoil***	Topsoil***	Topsoil***	Topsoil***	NS
10g	Topsoil***	Topsoil***	Topsoil***	Topsoil***	NS
15g	Topsoil***	Topsoil***	Topsoil***	Topsoil***	NS
20g	Topsoil***	Topsoil***	Topsoil***	Topsoil***	NS

*p < 0.05, **p < 0.001, ***p < 0.005 NS = No significant difference present

B10 Kruskal - Wallis results for VT samples collected from vermitechnology trial on-site

Worm Bin	**Kruskal Wallis**	**Significant weeks**
pH	H (2) = 7.41, $p < 0.05$	9 weeks
Conductivity	H (2) = 10.5, $p < 0.01$	3 weeks
Salinity	H (2) =21.7, $p < 0.05$	3, 6 weeks
TDS	H (2) = 12.3, $p < 0.01$	3 weeks
Potassium	H (2) = 65.1, $p < 0.01$	3, 6 weeks
Orthophosphate	H (2) = 43.8, $p < 0.005$	6, 9 weeks
Control Bin		
pH	H (2) = 6.5, $p < 0.05$	None to report
Conductivity	H (2) = 30.1, $p < 0.005$	3 weeks
Salinity	H (2) =45.5, $p < 0.01$	3, 6 weeks
TDS	H (2) = 16.3, $p < 0.01$	6 weeks
Potassium	$p > 0.05$	NS
Orthophosphate	H (2) = 52.1, $p < 0.005$	3 weeks

NS = No significance differences

B11 Mann - Whitney U Test results, comparison of worm and control bins

pH	**Bin**	**Significance value**
3 weeks	NS	$p > 0.05$
6 weeks	CB	$p < 0.05$
9 weeks	CB	$p < 0.005$
Conductivity		
3 weeks	WB	$p < 0.005$
6 weeks	WB	$p < 0.005$
9 weeks	WB	$p < 0.005$
Salinity		
3 weeks	WB	$p < 0.005$
6 weeks	WB	$p < 0.005$
9 weeks	WB	$p < 0.005$
TDS		

3 weeks	NS	$p > 0.05$
6 weeks	WB	$p < 0.005$
9 weeks	WB	$p < 0.005$
Potassium		
3 weeks	NS	$p > 0.05$
6 weeks	WB	$p < 0.005$
9 weeks	WB	$p < 0.005$
Orthophosphate		
3 weeks	WB	$p < 0.005$
6 weeks	WB	$p < 0.005$
9 weeks	WB	$p < 0.005$

NS – No Significant differences, WB – Worm Bin, CB – Control Bin

Appendix C

Commercial source one

C1 pH results (± SD) of VT samples from various amounts of VC and for various time durations

	1 Day	2 Days	3 Days	4 Days	5 Days
1g	7.2 ± 0.1	7.3 ± 0.1*	7.1 ± 0.1**	7.2 ± 0.2*	7.1 ± 0.1**
5g	7.1 ± 0.1	7.2 ± 0.2	7.3 ± 0.1	7.4 ± 0.2	7.3 ± 0.1
10g	7.3 ± 0.1	7.1 ± 0.1*	7.0 ± 0.1**	7.2 ± 0.1*	7.3 ± 0.1**
15g	7.3 ± 0.2	7.1 ± 0.1	7.3 ± 0.1	7.3 ± 0.1	7.5 ± 0.2
20g	7.5 ± 0.1	7.1 ± 0.1	7.2 ± 0.1	7.3 ± 0.1	7.3 ± 0.1

*p < 0.05, **p < 0.01

C2 Conductivity results (µS/cm ± SD) of VT samples from various amounts of VC and for various time durations

	1 Day	2 Days	3 Days	4 Days	5 Days
1g	348 ± 92	379 ± 63	341 ± 39	302 ± 65	194 ± 52
5g	259 ± 39***	408 ± 62***	462 ± 79***	486 ± 20***	474 ± 66***
10g	485 ± 45***	522 ± 33***	575 ± 29***	450 ± 67***	600 ± 68***
15g	667 ± 60***	711 ± 74***	487 ± 6***	480 ± 28***	534 ± 90***
20g	754 ± 46***	856 ± 50***	632 ± 13***	602 ± 18***	765 ± 15***

***p < 0.001

C3 Salinity results (PSU ± SD) of VT samples from various amounts of VC and for various time durations

	1 Day	2 Days	3 Days	4 Days	5 Days
1g	0.2 ± 0.0***	0.2 ± 0.0**	0.2 ± 0.0**	0.1 ± 0.0	0.1 ± 0.0***
5g	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.5 ± 1.1	0.2 ± 0.0
10g	0.2 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
15g	0.3 ± 0.0***	0.4 ± 0.0**	0.2 ± 0.0**	0.2 ± 0.0	0.2 ± 0.0***
20g	0.4 ± 0.0	0.4 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0

**p < 0.01, ***p < 0.001

C4 Total Dissolved Solids results (mg/L ± SD) of VT samples from various amounts of VC and for various time durations

	1 Day	**2 Days**	**3 Days**	**4 Days**	**5 Days**
1g	174 ± 46*	217 ± 73***	189 ± 25	95 ± 34*	74 ± 3***
5g	129 ± 20*	198 ± 38***	219 ± 45	133 ± 3*	146 ± 4***
10g	242 ± 22	286 ± 22	228 ± 56	207 ± 8	208 ± 19
15g	341 ± 26*	345 ± 39***	247 ± 7.0	222 ± 17*	246 ± 8***
20g	384 ± 47*	408 ± 24***	328 ± 18	290 ± 6*	299 ± 15***

*p < 0.05, ***p < 0.001

Commercial source two

C5: pH results for VT samples (± SD) from various amounts of VC

	Bag 1	**Bag 2**	**Bag 3**	**Bag 5**
1g	6.8 ± 0.4*	6.6 ± 0.1*	5.3 ± 1.6***	4.9 ± 0.1
5g	6.7 ± 0.3*	6.7 ± 0.1*	7.3 ± 0.1	4.9 ± 0.1
10g	6.7 ± 0.3	7.0 ± 0.1	6.9 ± 0.0	5.2 ± 0.4
15g	6.4 ± 0.3	7.0 ± 0.0	6.7 ± 0.1***	5.5 ± 0.1
20g	6.4 ± 0.1	7.0 ± 0.0	6.4 ± 0.5***	6.0 ± 0.2

*p < 0.05, ***p < 0.001

C6: Conductivity results (µS/cm ± SD) from various amounts of VC

	Bag 1	**Bag 2**	**Bag 3**	**Bag 5**
1g	222 ± 2.6***	181 ± 0.5***	765 ± 462	222 ± 24.9
5g	346 ± 3.2***	716 ± 2.2	542 ± 108.6	240 ± 1.4
10g	405 ± 2.8***	1242 ± 1.4	1047 ± 292.2	410 ± 4.4
15g	626 ± 3.2	1653 ± 518.1	734 ± 747.9	565 ± 6.4
20g	807 ± 4.1	220 ± 0.9***	957 ± 447.5	706 ± 35.2

***p < 0.001

C7: Salinity results (PSU ± SD) from various amounts of VC

	Bag 1	**Bag 2**	**Bag 3**	**Bag 5**
1g	0 ± 0.0	0.1 ± 0.0***	0.3 ± 0.3***	0.1 ± 0.0
5g	0 ± 0.0	0.4 ± 0.0***	0.2 ± 0.1***	0.1 ± 0.0
10g	0 ± 0.0	0.6 ± 0.0***	0.5 ± 0.1	0.2 ± 0.0
15g	0 ± 0.0	0.9 ± 0.0	1.0 ± 0.1	0.3 ± 0.0
20g	0.1 0.0	1.1 ± 0.0	1.0 ± 0.5	0.4 ± 0.0

***p < 0.001

C8: Total Dissolved Solids results (mg/L ± SD) from various amounts of VC

	Bag 1	**Bag 2**	**Bag 3**	**Bag 5**
1g	101 ± 0.5***	91 ± 0.1***	62 ± 14.4***	113 ± 9.0
5g	252 ± 2.8***	360 ± 0.9***	276 ± 64.9***	119 ± 2.1
10g	335 ± 2.1***	621 ± 1.3***	527 ± 144.4***	204 ± 5.2
15g	486 ± 2.9	918 ± 1.0	987 ± 5.9	282 ± 2.8
20g	1105 ± 1554.5	1108 ± 1.8	967 ± 471.3	356 ± 17.8

***p < 0.001

Topsoil

C9: pH results (± SD) from various amounts of topsoil and for various time durations

	1 Day	**2 Days**	**3 Days**	**4 Days**	**5 Days**
1g	6.6 ± 0***	7.3 ± 0***	7.2 ± 0***	6.9 ± 0***	7.3 ± 0***
5g	7.0 ± 0**	7.4 ± 0**	7.1 ± 0**	7.4 ± 0	7.2 ± 0**
10g	7.4 ± 0***	6.8 ± 0***	7.1 ± 0***	7.6 ± 0***	7.1 ± 0
15g	7.1 ± 0***	7.2 ± 0***	7.3 ± 0***	7.6 ± 0***	7.1 ± 0***
20g	7.4 ± 0***	7.8 ± 0***	7.0 ± 0***	7.5 ± 0***	7.3 ± 0***

**p < 0.01, ***p < 0.005

C10: Conductivity results (µS/cm ± SD) from various amounts of topsoil

	1 Day	2 Days	3 Days	4 Days	5 Days
1g	72 ± 2***	100 ± 5***	65 ± 4***	80 ± 8***	49 ± 4***
5g	67 ± 1***	148 ± 36***	86 ± 4***	150 ± 2***	76 ± 4***
10g	109 ± 28***	170 ± 4***	146 ± 5***	177 ± 13***	138 ± 3***
15g	171 ± 5***	170 ± 6***	172 ± 4***	207 ± 7	190 ± 4***
20g	189 ± 5***	197 ± 5***	201 ± 7	207 ± 9***	215 ± 4***

***p < 0.005

C11: Salinity results (PSU ± SD) from various amounts of topsoil

	1 Day	2 Days	3 Days	4 Days	5 Days
1g	0.1 ± 0***	0 ± 0***	0 ± 0***	0 ± 0***	0 ± 0***
5g	0 ± 0***	0.1 ± 0***	0 ± 0***	0.1 ± 0***	0 ± 0***
10g	0.2 ± 0***	0.2 ± 0***	0 ± 0***	0.1 ± 0***	0.1 ± 0***
15g	0.5 ± 0***	0.3 ± 0***	0.1 ± 0***	0.1 ± 0***	0.1 ± 0
20g	0.1 ± 0***	0 ± 0***	0.1 ± 0***	0 ± 0***	0.1 ± 0

***p < 0.005

C12: Total Dissolved Solids results (mg/L ± SD) from various amounts of topsoil

	1 Day	2 Days	3 Days	4 Days	5 Days
1g	377 ± 9***	571 ± 27***	370 ± 12***	233 ± 13***	270 ± 9***
5g	335 ± 5***	725 ± 14***	587 ± 7***	752 ± 11***	612 ± 7***
10g	430 ± 8***	853 ± 7***	777 ± 9***	878 ± 62***	761 ± 7***
15g	955 ± 16***	985 ± 29***	885 ± 9***	1032 ± 41	1002 ± 1***
20g	955 ± 10***	985 ± 26***	983 ± 6***	1032 ± 48***	1050 ± 13***

***p < 0.005

Project Risk Assessment

ACTIVITY: Analysis of the vermicomposting process and its implications for plant growth promotion under Irish conditions.

LOCATION: *EnviroCore (K304)*

ASSESSMENT UNDERTAKEN BY: Mary Fitzpatrick (Postgraduate Student)

ASSESSMENT DATE: 2016

ASSESSMENT REVIEW DATE: Updated 2017

ACADEMIC/PROJECT SUPERVISOR: Dr. Thomais Kakouli-Duarte, Dr. Andrew Lloyd

EQUIPMENT ACTIVITY	HAZARD	L	S	RISK CLASS	FURTHER CONTROLS REQUIRED	PERSONS RESPONSIBLE	TARGET COMPLETION DATE
Greenhouse	1. Slips, trips and falls 2. Dehydration 3. Cuts	2 2 1	2 1 1	3 low 2 low 2 low	1. Note first-aid station (incl eyewash) location Ensure there are no obstacles/objects in walkways/pathways which could cause injury		

Vermitea Preparation	4. Glassware – injury (cuts etc.)	1	1	1 low	2. Highlight the hazards associated with this in a safe operating procedure		
Vermitea Collection	5. Lifting bins – possible injury to back, strained muscles due to weight of bins			2 low	3. Check bins before lifting. If heavy, collect samples from bin on ground		
House gas	6. Gas leak 7. Explosion 8. Inhalation of gas	1 1 1	2 4 2	4 medium 9 high 2 low	4. EOP required		
HACH UV Spectrophotometer	9. UV Light – Temporary blindness 10. Electric shock 11. Glassware – injury (cuts etc.) 12. Burns (heating mantle)	1 1 1 2	3 2 1 1	3 low 5 med	5. Place warning sign on area 6. SOP 7. Note first-aid station (incl eyewash) location		
-20 °C Freezer (walk-in)	13. Slips or falls	2	1	3 low	8. Housekeeping		

Chemicals	14. Corrosive acids burn 15. Toxic acids eye, skin, inhale 16. Irritant	2 2	3 2	8 medium 8 medium	9. Ensure Material Safety Data Sheets are available. 10. Chemicals should be fully labeled in a clear, concise way 11. Appropriate PPE must be worn when handling the chemicals 12. Emergency spill kits should be used 13. Note first-aid station (incl eyewash) location		
Fridge	17. Microbial contamination	2	1	1 low	14. House keeping		
Fume hood	18. Respiratory hazard depending on fumes being given off.	2	2	6 medium	15. Ensure fume cupboard is in working order before work 16. Ensure sash is at the correct protective height		
Autoclave	19. Burns 20. Cuts – glassware breakage	2 1	2 1	6 medium 3 low	17. SOP 18. PPE must be worn 19. Note contact details of First Aid personnel on campus		

***RISK CLASS** (After existing controls and before further controls):-

High (H) [7 to 10] (Probability of fatality, serious injury or significant loss, possibility of minor injury to a number of people.)
Medium (M) [4 to 7] (Unlikely possibility of fatality, serious injury or significant material loss, possibility of minor injury to a small number of people.)
Low (L) [1 to 4] (Injury or material loss unlikely though conceivable.)

Likelihood of an accident occurring (L):

1. Unlikely
2. Likely
3. Very likely

Severity of accident (S):

1. First-aid required
2. Medical attention required
3. Long term illness
4. Fatality

Signature of Assessor: *Mary Fitzpatrick* **Date:** March 2017

Signature of Supervisor: _____ Date: _____