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AN EFFECTIVE APPROACH FOR THE MANAGEMENT OF WASTE COFFEE GROUNDS

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ABSTRACT

In recent years the disposal of organic wastes from domestic, commercial, agricultural and industrial sources have caused concerns due to the environmental and economic problems associated with waste. The waste produced particularly in urban areas represents a huge cost for cities and a burden to the environment but, at the same time, represents an opportunity to take stock of valuable resources, which can be exploited. By boosting solutions to reduce waste and promoting its use as a resource the natural and living environment in urban areas can be enhanced. Cities are complex systems similar to living organisms that use energy, air, water and nutrients and need to dispose of waste in a sustainable way. By adopting an urban metabolism perspective cities can open the way for innovative and systematic approaches, which involve the analysis and use of resource-flows. Waste coffee grounds represent an under-utilised high nutrient material with potential to be exploited. Coffee is regarded as the highest consumed beverage in the developed world, and is the second most traded commodity in the world after oil. This paper will present research findings for an effective approach for the management of waste coffee grounds. This is achieved through examining an alternative approach of resource recovery and sustainable waste management practices for waste coffee grounds. It will also use a case study to examine the potential for waste coffee grounds to promote an ecological rethinking of nutrient flows.

1. Introduction

Since the Industrial Revolution, industrial production and urbanisation have constantly increased, using massive amounts of materials, water and energy. The mass consumption of resources contributes to serious problems, such as global warming, material depletion and the generation of enormous waste. It is widely accepted that the United Kingdom will have to deliver significant improvements to its waste infrastructure over the coming decades in order to successfully recycle, reprocess, treat and dispose of its waste. In the metabolism of the city, Lehmann (2012), defines sustainable urban metabolism as a vision of industrial organisation that applies the lessons of natural ecosystems to environmental management, where waste from one process becomes inputs and opportunities for another (Lehmann & Crocker, 2012). According to a new study published by the Department of Environment, Food and Rural Affairs (DEFRA), resource efficiency could generate an extra £3.58bn for UK businesses by 2020 (DEFRA 2015). Waste generation is a natural phenomenon and the amount of waste produced can be directly associated with changes in culture and the way of life. These changes bring with them a huge quantity of complex waste streams, which contains considerable amounts of nutrients, which have the potential to be recycled. Rethinking the way we deal with material flows and changing behaviour in regard to waste streams can contribute to significant improvements for curbing environmental degradation and global warming (Lehmann & Crocker, 2012). In his argument for "the economics of permanence," Schumacher (1973) implies a profound reorientation of science and technology is required. Emphasising a need for methods and equipment, which are cheap and accessible to virtually everyone, and also suitable for small-scale application. At present, not only is it virtually impossible to know the true environmental and ecological impact of the products we consume, but also the origins, the processes of manufacture and the cost of transportation. Kimbrell (2002) argues, that the distance between the consumer and production has created a tragic disconnection of the environmental consequences of production and consumption. Tompkins (2002) describes it as a cultural crisis rooted in the transformation from an essentially agrarian culture to one that's completely industrialised. It is clear that a holistic understanding and integrated approach to design and urban management are essential for the effective resolution of urban waste. In present circumstances it is advisable that waste products from one industry should be investigated with an intention to be used as raw materials for other industries.

The rapid expansion of global coffee consumption increased from 4.2 million tonnes in 1970 to 8.1 million tonnes in 2010, an increase of 91 per cent. With consumption growing by 12 per cent in Western European markets (ICO, 2011). In 2014, the coffee shop market outperformed the UK retail sector, with significant sales growth of 10.7%, equating to £7.2 billion in turnover. The coffee shop sector has been in growth for 16 consecutive years and is one of the most successful markets in the UK economy (Foottot, 2014). According to the Allegra World Coffee Portal definitive report, the UK coffee market is estimated at 18,832 outlets and predicted to exceed 27,000 by 2020 (Foottot, 2014). In the United Kingdom coffee consumption take various forms, including soluble and filter coffee. The preparation of the beverage and the location of consumption are largely influenced by national culture. However, coffee grounds (filter coffee) are a single use product and the total waste generated from the disposal of coffee is equal to all imports and sales. The environmental impacts of coffee are enormous, with large quantities of solid and liquid wastes being generated globally (Roussos et al., 1998; Hue et al., 2006; Liu et al., 2011). This is due to the dramatic change of cultivation methods. Coffee is cultivated in tropical and subtropical regions at high elevations and naturally grows under a shaded canopy of trees, which provide a valuable habitat for indigenous animals and insects, as well as preventing topsoil erosion and eradicates the need for chemical fertilisers. However, due to the increased market demands in recent years, this innocuous form of agriculture has been superseded by *sun-cultivation* techniques. Originating in the 1970's, sun-cultivated coffee is produced on plantations, where forestry is cleared so that coffee is grown in rows as a monoculture with no canopy. Coffee farmers were encouraged to replace their traditional and supposedly inefficient farming methods with the higher yielding techniques, which resulted in deforestation (Moore 2014). In a life cycle analysis of coffee, Salmone (2003) reported cultivation and consumption of coffee as the two largest contributors towards negative environmental impacts (Liu & Price 2011). The process of separating the commercial product (the beans) from the coffee cherries generates enormous volumes of waste material in the form of pulp, residual matter and parchment. Over a 6 month period in 1988, it was estimated that processing 547,000 tons of coffee in Central America generated as much as 1.1 million tons of pulp and polluted

110,000 cubic metres of water each day. This excess waste can also play havoc with soil and water sources as coffee pulp is often dumped into streams, severely degrading fragile ecosystems (Moore 2014). In the United Kingdom average annual imports during the period 1997 to 2010 totalled 3.4 million bags. Among the ten leading countries supplying coffee to the United Kingdom, re-exports from other importing countries, Germany (13.6%), Netherlands (7.6%), Spain (4.1%), Ireland (2.4%), France (2.3%) and Italy (2.1%), accounted for 32.2% of the total compared with 41.2% coming from exports by Vietnam (14%) Brazil (11.7%), Columbia (9.4%) and Indonesia (6.1%), (ICO, 2011). In the United Kingdom, the waste generated from total import of coffee grounds are either landfilled or processed at municipal facilities with other organic wastes. Coffee consumption in a city can take various forms; this study is interested in the out-of-home market and the location of consumption. It covered those food service establishments in Leeds where coffee is served. Of the 5,067 food businesses registered under the local authority of Leeds (Leeds City Council, 2015), 1892 are registered to serve coffee (Food & Health, 2014). The beverage maintains a social character in the city as consumption is widely distributed across bars (176 outlets), café (557), canteens (168), pubs (371), restaurants (387) and various leisure centres (248) see Figure 1. Costa Coffee holds a dominant share of the branded market in Leeds with a total of 17 outlets. Whitbread PLC evaluated waste generated by weight for their Costa chain stores and found that organic food & coffee grinds was the biggest contributor of waste produced followed by paper waste at 65.7% and 21.2% respectively (Costa, 2012). With the average Costa chain store producing approximately 20kgs of waste coffee grounds per day (Gourlay, 2014). This provides an enormous opportunity for waste diversion and resource recovery in the city of Leeds with the city generating approximately 38 tonnes of waste coffee grounds per day.

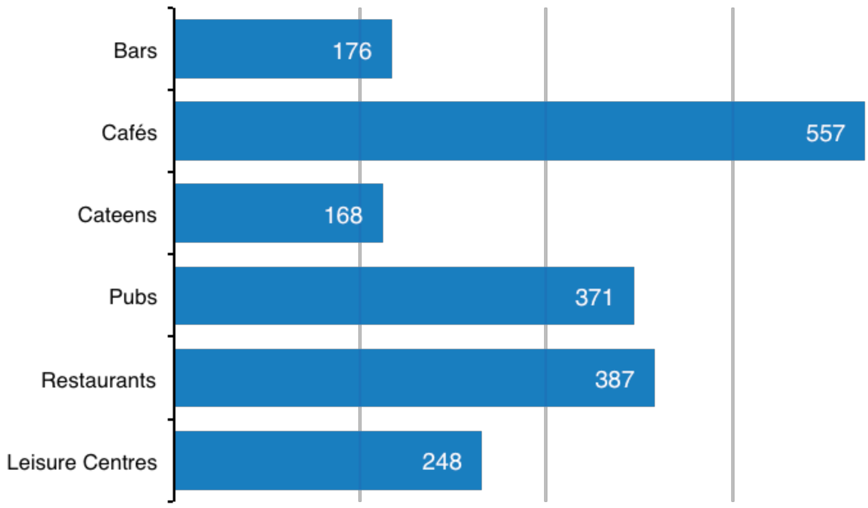


Figure 1. Distribution of coffee consumption in Leeds.

Waste coffee grounds represent an under-utilised high nutrient material with potential, as compost for horticultural use therefore recycling through vermicomposting can be a sustainable, low cost alternative to disposal. The available literature on vermicomposting waste coffee grounds is limited but some studies have evaluated its use as a horticultural amendment, as a mushroom growing medium, as compost feedstock, and as biofuel feedstock (Liu & Price, 2005; Barreto et al., 2008; Kondamudi et al., 2008). Composting technologies have been widely applied to transform raw organic feedstock into stabilised humus-like materials (Liu & Price, 2005; Tiquia et al., 1996). The biotransformation process is mediated by microbial biomass under idealised moisture, oxygen, pH, carbon (C) and nitrogen (N) conditions. Vermicomposting has been used to process a wide range of feedstocks, including coffee pulp, livestock manures, and food wastes (Liu & Price, 2005; Lopez, 2001). Earthworms can play a significant role in the management of waste coffee grounds. There are many species of earthworms with the potential for waste management, but the most commonly used are *E.fetida*, and *E.hortensis*. They are ubiquitous and many organic wastes are naturally colonised by the species. They can tolerate a wide range of temperatures and live in organic wastes with a good range of moisture contents (Edwards & Bohlen, 1996). The aims of the study are to evaluate the use of vermicomposting biotechnology as a viable option for the diversion of waste coffee grounds.

2. METHODS

2.1. VERMICOMPOSTING

Vermicomposting is a decomposition process involving interactions between earthworms and microorganisms. Although the microorganisms are responsible for the biochemical degradation of the organic matter, earthworms are the crucial drivers of the process. They fragment and condition the substrate, increasing surface area for microbiological activity and altering its biological activity. Earthworms act as mechanical blenders, and by comminuting the organic matter, they modify its biological, physical and chemical status, gradually reducing its C:N ratio, increasing the surface area exposed to microorganisms and making it much more favourable for microbial activity and further decomposition (Domínguez, 2004). Vermicomposting systems are designed to maintain conditions favourable to the most rapid decomposers, the mesophilic bacteria. The combination of earthworms and mesophilic bacteria are used to rapidly stabilise the organic chemical compounds, reducing the loss of valuable nutrients.

2.2. VERMICULTURE PROJECT

The Vermiculture Project was established as a bio-technological social enterprise to help coffee shops operating in the food service sector in Leeds transition towards zero waste. The aims are to provide landfill diversion and resource recovery services for coffee shops and to evaluate the potential for waste coffee grounds to be bio-transformed into a stabilised horticultural compost for use in organic food production. On the 22nd September 2014 the project started a landfill diversion and resource recovery service for two of Leeds Beckett Universitye recovery services for coffee shops and to d Headingley campuses. The waste coffee grounds are collected daily along with shredded paper and are being recycled using the vermicomposting experiment. The experimental project adapts four replications of the "Oregon Soil Corporation Reactor". The vermiculture compost system is a continuous-flow vermicomposting bin. The original concept for the continuous-flow system was devised by a team of researchers at Rothamsted Experimental Research Station, UK in the early 80's. The concept takes advantage of the fact that composting worms typically prefer to remain quite close to the surface of whatever material they happen to be living in, generally moving towards the most recently added organic wastes, leaving higher concentrations of their castings behind. The vermiculture compost bins measure 1220mm in length by 915mm wide by 915mm in height and are located in a shade tunnel at the Landscape Resource Centre & Experimental Gardens (LRC), Leeds Beckett University, Headingley Campus, Leeds. The experimental study is being conducted over a 12-month period.

2.3. BIN 1 & BIN 2

The bins were constructed using 18mm thick marine plywood and insulated with 25mm thick Celotex TB4000 insulation boards to provide additional insulation for composting during the winter period. They were loaded on site on the 3rd of October 2014 with a thin layer of newspaper. This is done to absorb any extra moisture and to restrain migrating earthworms from escaping into the harvest chamber. Bin 1 was loaded with 30kg of waste coffee grounds, pre-composted for 21 days and Bin 2 with 30kg of freshly collected waste coffee grounds (no pre-composting). The 21 days of pre-composting organic waste is done to avoid exposure of earthworms to high temperatures during the initial thermophilic stage of composting (Adi et al., 2009; Nair et al., 2006). It is also done to provide a readily available food source during inoculation because microorganisms constitute an important nutritional component to the earthworm's diet (Edwards & Bohlen, 1996). In both bins 3.4kg of shredded paper, 5 litres of water and 1kg of *E.fetida* was added, and on the 6th of March 2015 an additional 2kg *E.fetida* and 2kg *E.hortensis* was added to both systems.

2.4. BIN 3 & BIN 4

The bins were constructed using 18mm thick marine plywood and insulated with 65mm polypropylene insulation foam boards. They were loaded on site on the 6th of March 2015, with a thin layer of newspaper, 35kg of pre-composted waste coffee grounds (60 days), 1.7kg of shredded paper, 3 litres of water, and 2kg of *E. fetida* and 2kg of *E.hortensis.* The aims of the experiment are to evaluate the potential for waste coffee grounds, which are high in nitrogen (Adi et al., 2008; Dinsdale et al., 1996) to be decomposed through vermicomposting. Also to assess a vermicomposting system inoculated with a mixed colony of earthworm species, *E.fetida* and *E.hortensis* for transforming waste coffee grounds into a stabilised horticultural compost for use in food production. The experimental study evaluates two different ratios of waste coffee grounds (WCG) to shredded paper (SP), to determine the rate of waste processing for waste coffee grounds (kg/m^3 bed/week) for a processing system operating under UK conditions. The objectives are to analyse moisture content, temperature, and pH levels of the vermicompost, and measure chemical characterisation of the composting feedstock against cast produced by the earthworms to determine plant macro and micronutrients

3. Results and Discussions

3.1. Temperature

Temperature is the most important factor affecting microbial metabolism during composting. It is either a consequence or a determinant of the microbial activity. (Vallini et al., 2002) It is an important parameter in monitoring the composting process and determining compost quality. It is also strongly correlated with microbial activity and in relation to composting stages is used to determine the conditions suitable for the proliferation of different microbial groups, i.e. meso and thermophiles (Liu et al., 2011; Tiquia at al., 1996). The composting stages based on temperature, mesophilic, thermophilic, pre-composting, and ambient temperatures are clearly displayed for the four-replication vermicomposting experiment in Figure 2. Decomposition usually occurs in three stages characterised by the most active organisms. Psychrophilic bacteria begin the process at temperatures below 21°C, which was observed on day 7 by the colonisation of microbial activity to the underside of the newspaper bedding see Figure 3. A peak temperature of 12gure 3n three stages characterised by the most active organisms. Psychrophilic bacteria begin the process at temperatures below 21°C, which was observed on day 7 by the colonisation of microbial activity to the underside of thnompost temperature in Bins 1 (30°C), 2 (22°C), 3 (30°C) & 4 (33°C) on day 14. At temperatures over 38°C thermophilic bacteria take over and the presence of the bacteria was also evident from compost temperatures on day 18 in Bins 1 (45°C), 3 (48°C) & 4 (46°C) which signaled the thermophilic stage of decomposition. However, a peak temperature of 50°C was recorded on day 25 in Bin 1, after which temperatures gradually waned towards a range of 30°C on day 28. The ambient temperature during the composting period from 6 Mar 2015 to 7 April 2015 averaged 7.7°C, and ranged from 1 to 15°C. The different species of earthworms' response to temperature differentials during the study period was observed and it was found that *E.fetida* were more tolerant to differential temperatures compared to that of *E.hortensis.* The difference between the 21 & 60 days pre-composting of waste coffee grounds and temperature was marginal. However, in the no pre-composting bin low temperatures were recorded throughout the study period, only reaching a peak temperature of 35°C on day 25 and compositing through psychrophilic and mesophilic stages of decomposition only.

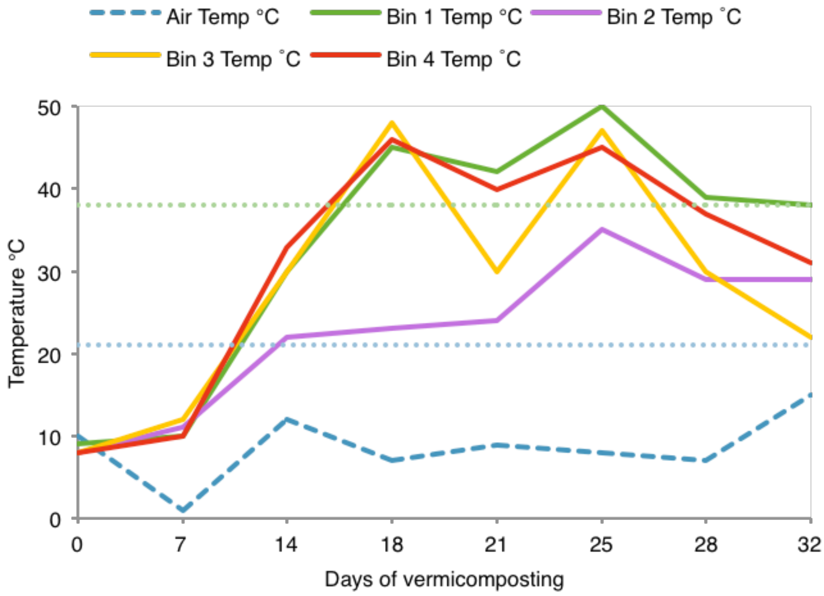


Figure 2. Changes in daily average temperature during the period 6 Mar. 2014 to 3 Apr. 2015.

Bin 1	Bin 2	Bin 3	Bin 4
30 kg of pre-composted waste coffee grounds (21 days)	30 kg of freshly collected waste coffee grounds (no pre-composting)	35 kg of pre-composted waste coffee grounds (60 days)	35 kg of pre-composted waste coffee grounds (60 days)
3.4 kg of shredded paper	3.4 kg of shredded paper	1.7 kg of shredded paper	1.7 kg of shredded paper
3 kg of *E.fetida* + 2 kg *E.hortensis*	3 kg of *E.fetida* + 2 kg *E.hortensis*	2 kg of *E.fetida* + 2 kg *E.hortensis*	2 kg of *E.fetida* + 2 kg *E.hortensis*
5 litres of water	5 litres of water	3 litres of water	3 litres of water
Thin layer of newsprint	Thin layer of newsprint	Thin layer of newsprint	Thin layer of newsprint

Table 1. Summary of inoculation contents for each vermicomposting bin.

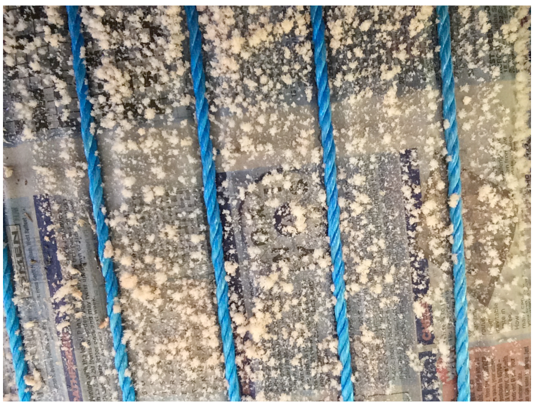
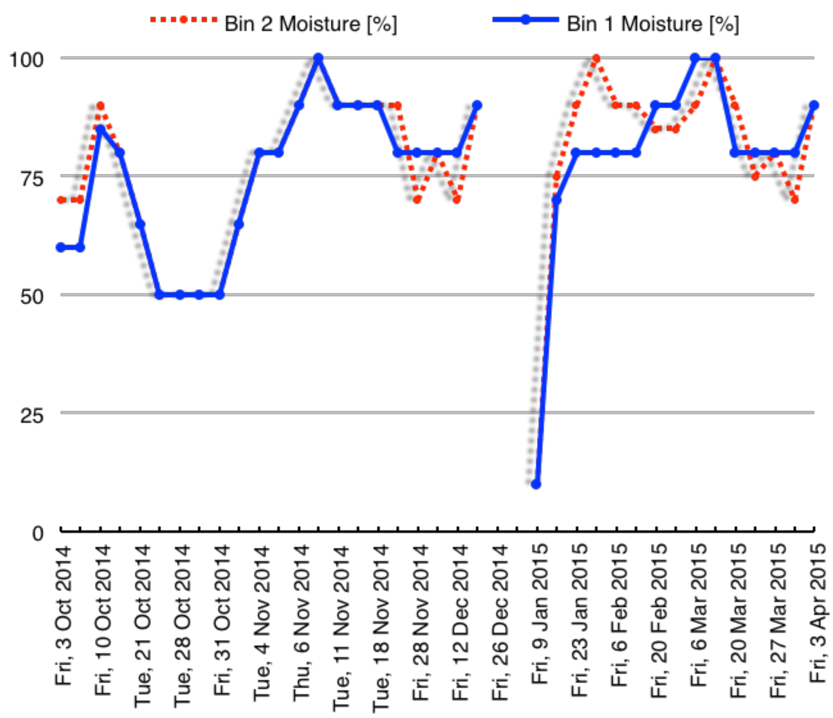


Figure 3. Microbial activity recorded on day 7 of vermicomposting experiment.

3.2. MOISTURE

Moisture is of crucial importance in maintaining microbial activity within a composting matrix because decomposition slows dramatically in mixtures fewer than 40% moisture (Domstguez 2004). There are strong relationships between the moisture contents in organic waste and the growth rate of earthworms (Dom04guez, 2004). In vermicomposting systems, the optimum range of moisture contents for most species has been reported to be between 50 and 90% (Dom00guez 2004; Edwards 1998). *E.fetida* can survive in moisture ranges between 50 and 90% (Dommsguez 2004; Sims and Gerard 1985; Edwards 1998) but grows more rapidly between 80 and 90% in animal wastes (Dom04guez 2004; Edwards 1998). Reinecke and Venter (1985) reported that the optimum moisture content for *E. fetida* was above 70% in cow manure. The average moisture content of compost in Bins 1 and 2 was recorded at 73% and 74% respectively during the composting period from 3 October 2014 to 3 April 2015. Both bins recorded the lowest moisture content of 10% on the 9 Jan 2015, see figure 5. Prior to this the system was left idle for a two-week period due to the holiday season (no records obtained during this period). It was observed that earthworms and microbial activity had dramatically slowed during this time. However, the choice of shredded paper provided a hospitable living environment for the earthworms. Earthworms usually consume their bedding as it breaks down, and it is important that it is a slow process, as it was observed that heating occurs in the food layers (waste coffee grounds) of the vermicomposting system and not in the bedding. The choice of shredded paper provided the earthworms with a high absorbency material, which absorbed and retained moisture, allowing the worms an environment to thrive. This was evident after the holiday season because worms were found in the high-absorbency material and survive the period of



reduced moisture.

Figure 5. Changes in moisture content of compost during the period 3 Oct. 2014 to 3 Apr. 2015.

3.3. PH

Most species of epigeic earthworms are relatively tolerant to pH, but when given a choice in the pH gradient, they moved towards the more acid material, with a pH preference of 5.0. However, earthworms will avoid acid material of pH less than 4.5, and prolonged exposure to such material could have lethal effects (Domt guez 2004; Edwards and Bohlen 1996). It is widely believed that waste coffee grounds are acidic but as the study clearly displayed consistent pH values around neutral (7.0) were recorded throughout the experiment. In general, the pH of worm beds tends to drop over time, however, the pH values recorded at the start of the experiment was recorded at 7.0 which has been consistently maintained. Microbes driving compost stabilisation operate best in the range of pHs between 6.5 and 8.0 (Vallini et al.,

2002) and as waste coffee grounds are neutral it represents a valuable feedstock which can sustain microbes for compost stabilisation.

3.4. C:N RATIO

The ratio of carbon to nitrogen (C: N ratio) in organic matter added to soil is of importance, because net mineralisation of the organic matter does not occur unless the C: N ratio is of the order of 20:1 or lower. Earthworms can have major influences on nutrient cycling processes in many ecosystems. By turning over large amounts of organic matter, they can increase the rates of mineralisation of organic matter, converting organic forms of nutrients into inorganic forms that can be taken up by plants (Edwards, 1996). In the managed compost operation special attention was paid to the ratio of carbon to nitrogen in the waste and moisture levels of the material as it broke down. The ratio of waste coffee grounds to shredded paper (WCG: SP) used was aimed at generating compost with a C: N ratio of 20:1 or lower. A weekly feeding program was adapted for the experiment using 19kg WCG: 5kg SP for Bins 1 & 2 and 19kg WCG: 2.5kg SP for Bins 3 & 4. On the 31st March 2015, 1kg of finished compost was harvested from Bins 1 & 2 and sent for chemical analysis. Analysis of the compost composition has not yet been completed but will be published at a later date.

CONCLUSION

In recent years, vermicomposting has emerged as a simple, easily adaptable and effective biotechnology for recycling a wide range of organic wastes for agricultural production. The technology is advantageous over thermophilic compost because it contains a considerable amount of organic acids, such as plant growth promoting hormones and humic acids. It also has high water holding capacity, low C:N ratio and low phytotoxocity (Pant & Wang, 2014). The initial results of this study indicate that waste coffee grounds have the potential to be vermicomposted as a primary feedstock. It found methods of inoculation for Bin 1 loaded with 21 days of pre-composted waste coffee grounds more effective than Bin 2 loaded with the non-pretreated waste. In relation to microbial activity and composting stages, the study found conditions in Bin 1 more favourable for decomposition. Bin 1 composted through all three stages of decomposition with an active population of psychrophilic, mesophilic, and thermophilic bacteria, while the conditions in Bin 2 were only favourable for psychrophilic and mesophilic bacteria. Bin 1 contained the most active population of microorganisms and was able to breakdown the waste coffee grounds at a much faster rate than Bin 2. Bin 1 processed 12.25kg of waste coffee grounds more than Bin 2 at a rate of 6kg/0.375m^3 bed/week. In the 30 weeks of landfill diversion and resource recovery the experiment successfully recycled and processed a total of 595kg of waste coffee grounds and 55kg of shredded paper, at a processing rate of 20kg/1.5m^3 bed/week producing zero waste.

To gain a true understanding of the potential that exists for vermicomposting, it is important to look at the 'Big Picture'. Currently, waste coffee grounds are mixed in with general waste and disposed of in a general collection bin. Businesses contract private waste management companies for the disposal of their waste and charges depend on size and frequency of their collection. These charges include the rental of collection bins and a duty of care charge. The true cost is only established when contracts are set up with the waste management company. However, WRAP estimates that waste costs businesses in the food and drink supply chain approximately £4 billion annually, with the sector producing 4.1 million tonnes of waste per year (WRAP, 2013). Businesses are being placed under increasing pressure to reduce their overall rate of waste to meet UK and EU limits on the amount of biodegradable municipal waste sent to landfills. Currently, there are 1892 food service establishments registered under the local authority of Leeds to serve coffee and there exists an opportunity within the city for the waste stream to be diverted, recovered and recycled using the biotechnology. Estimates reveal that approximately 266,000kg of waste coffee grounds can be recovered within the city weekly and made available as a primary feedstock for vermicomposting. If managed properly the waste stream can contribute to helping businesses meet targets on the amount of biodegradable municipal waste being sent to landfill. Vermicomposting can provide an opportunity for waste generators to divert their waste into local communities for beneficial uses, such as organically produced compost for organic food production. Currently only 4.2% of the UK farmland is organically managed, which is equivalent to 738,700 hectares. The study reveals that there is an existing opportunity for waste coffee grounds to be sustainably managed using vermicomposting on a commercial level at centralised sites. An estimated 266 tonnes of waste coffee grounds can be sustainably managed and processed at a rate of 266,000kg/19,950m^{3}bed/week using a worm population of approximately 53,200kg of *E.fetida* and *E.hortensis* to organically produced compost. The biotechnology can contribute to significant improvements to existing waste infrastructure and also be used as a resource to bridge the gap between waste and organic food production. Our findings also indicate an opportunity exists for further research into the use of waste coffee grounds as an alternative for renewable energy production (biofuel) as alternative to disposal.

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