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EXPLORING TECHNICAL AND ECONOMIC ASPECTS OF VERMICOMPOSTING AS A MICROENTERPRISE IN RURAL COMMUNITIES OF LEBANON

by
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AN ABSTRACT OF THE THESIS OF

Sara Moledor for Master of Science in Environmental Sciences
Major: Ecosystem Management

Title: Exploring Technical and Economic Aspects of Vermicomposting as a Microenterprise in Rural Communities of Lebanon

This study aims to develop an efficient small-scale vermicomposting system suitable to the Lebanese context. It then considers how such a system can improve agricultural productivity sustainably while at the same time benefiting disfavored rural communities through decentralized, home-scale production.

With the aim of optimizing the vermicomposting process, a simple and affordable model was developed using plastic crates, a locally-produced textile, and native earthworms. An on-campus collection trial tested the grounds for future organic waste collection systems. An extensive plant growth experiment confirmed that locally produced vermicast can maintain or enhance plant growth when replacing up to 25% of typical potting media. In order to test the established vermicompost model within a microenterprise context, an enterprise simulation was carried out in a rural community of Lebanon. This study tested the ease and logistics of the system, as well as revealed some of the social dynamics surrounding the handling of earthworms and organic waste. Lastly, a social cost-benefit analysis indicates that the production and use of one ton of vermicast will yield an estimated $871 – 1,352 across three sectors - landfill operations, the private vermicompost microenterprise, and agriculture.

This study demonstrates that vermicomposting is affordable, can be carried out through a microenterprise approach and has a promising market (agricultural sector, horticultural industry, home consumption), all of which will trigger very positive socioeconomic impacts. This sustainable activity can be considered, therefore, as a possible circular-economy solution to Lebanon's linear production-to-consumption-to-waste market economy.

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INTRODUCTION

Ideally, fruits and vegetables fall to the ground, decompose, and supply the soil with the minerals and nutrients needed to replace those taken up by the plant roots. Similarly, animal manure is left wherever animals graze and wander, likewise serving to rejuvenate the soil. In today's agricultural system, however, these organic matter cycles are interrupted – fruits and vegetables are transported elsewhere for consumption and decomposition and there is a growing tendency for farm animals to be kept separately from agriculture, in concentrated feedlots. What was once a circular system has become linear, with soil degradation on one end and an over-accumulation of organic plant and animal waste - in such quantities as to compromise human and environmental health - on the other end (Gardiner & Miller, 2004; Kumar et al, 2009; Schröder et al, 2009). Traditional composting is a means of managing this problem by turning waste into a nutrient-rich material to return to the soil, thereby returning some semblance of a circular food system. Vermicomposting is a *value-added* means of management that can take the form of a microbusiness, thereby offering an incentive to small-scale entrepreneurs and relief to farmers who have become dependent on costly chemical fertilizers and pesticides (Shivakumar et al, 2009; Purkayastha, 2012; VermiCo, 2013).

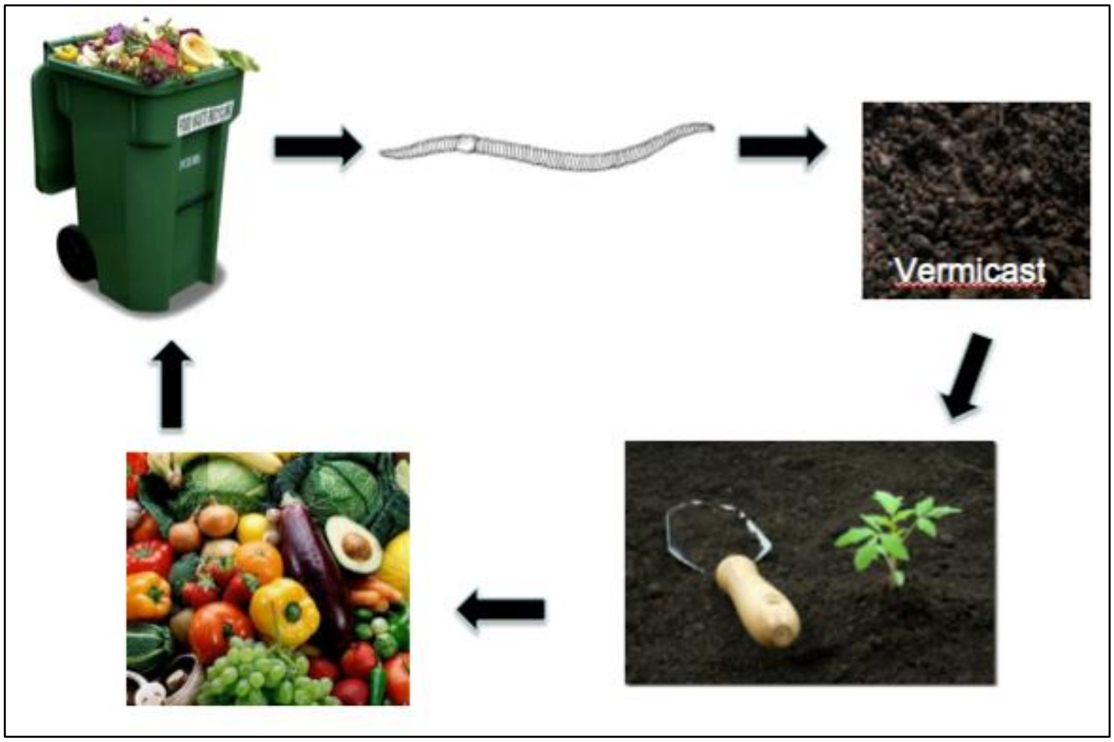


Figure 1: Circular Use of Resources

Almost all scientific studies and development projects related to vermicomposting have revealed very promising results. The hypothesis underpinning this project is that vermicomposting will meet with the same success in Lebanon: this biotechnology, introduced in the form of microenterprises, will have a beneficial impact on a range of sectors including, but not limited to solid waste management (Clarke, 2000; Singh et al, 2011; Tognetti, et al, 2007), community development (Shivakumar et al, 2009; Purkayastha, 2012) (Roseland & Soots, 2007), and agriculture (Munnoli et al, 2010; Singh et al, 2008; Atiyeh et al, 2000; Edwards et al, 2010; Aroncon et al, 2005). Research indicates that the vermicompost market has already taken root in Europe and North America (Doherty & McKissick, 2000; Sherman, 1997; Munroe, 2005). The successful and far-reaching programs of India, however, have provided inspiration for this project wherein vermicompost initiatives contribute to environmental protection, local economic development, and enhanced social wellbeing of the participating communities (Purkayastha, 2012; Shivakumar et al, 2009; VermiCo, 2013).

The lack of knowledge and experience in vermicomposting methods, the stigmatization of handling waste and worms, and a lack of initial investment are predicted to be the major obstacles for the realization of widespread vermicompost systems.

The overarching objective of this project is to explore how vermicompost could contribute to Lebanon's environmental, social, and economic security. This will be accomplished by investigating the many facets of vermicompost production and consumption within the Lebanese context. We will focus on the technical needs required for vermicomposting, how a vermicompost program can be shaped for socioeconomic and environmental betterment, and how it could impact the country's economy. Ultimately, this project aims to develop a simple and affordable vermicomposting system that will suit the lifestyle and climate of rural inhabitants. The vermicompost microenterprise is the key ingredient to jumpstart Lebanon's circular vermicompost economy.

CHAPTER 2

LITERATURE REVIEW

2.1 The Science of Vermicomposting

2.1.1 Earthworm Biology

2.1.1.1 Earthworms in the Ecosystem

Before exploring the subject of vermicomposting, it is important to understand the ecology of the earthworm. Earthworms, together with microbes, play an integral role in the soil-air-water-plant ecosystem and are a particular boon to agricultural systems. Earthworms deposit their nutrient-rich casts throughout the soil while their burrowing serves to till and aerate the soil and prevent compaction. Furthermore, their burrows facilitate the percolation of surface water, thereby enhancing moisture content of the soil (Munnoli et al, 2010).

2.1.1.2 Physical Description & Speciation

Earthworms are long and cylindrical in shape and vary greatly in size. Some species measure less than 20 mm in length, while others have been reported at 4 – 7 meters (Munnoli et al, 2010). They have an opening at each end of their soft bodies, one the mouth and the other, the anus. The earthworm's body surface is kept moist by the regular secretion of body fluids from minute pores in their skin. Lacking formal sensory organs, earthworms are nonetheless equipped with special cells, spanning the length of their bodies, which provide sensory functions (Gajalakshmi & Abbasi, 2004).

More than 4,200 species of earthworms exist throughout the world. These invertebrates belong to the *Annelida* phylum and *Oligochaeta* class. They can be further divided into ecological categories: Epigeic species are litter dwellers, endogeic species dwell in the upper soil layers rich in organic matter, while anecic species are deep burrowers (Munnoli et al, 2010).

Table 1 Characteristics of earthworms of different ecological categories.

Characteristics	**Epigeic**	**Endogeic**	**Anecic**
Habitat	Litter dwellers	Naturally found in upper organic rich soil layers	Deep burrowing
Food	Litter and humus feeder	Litter and organic rich soil feeder	Litter and soil feeder
Burrow formation	Do not construct burrows and remains active in litter layers	Construct horizontal burrows lined by mucus and excretory products	Construct vertical burrow
Microbial communities in burrows	–	Well documented in literature	Positive evidences are available
Cocoon production rate	Highest	Moderate–high	Low
Life cycle	Short	Intermediate	Long
Efficiency in waste Recycling	Well established	Well established in some species	Efficiency data is not available
Species adopted in waste management	*Eisenia fetida* *Bimastos parvus* *Dendrobaena rubida* *Eisenia hortensis*	*Eudrilus eugeniae*	*Pheretima elongata* *Megascolex megascolex* *Perionyx excavatus* *Lumbricus terristris* *Amnthus diffringens* *Lampito mauritii* *Perionyx sanisbaricus* *Lumbricus rubellus*

Table 1: Characteristics of Earthworms of Different Ecological Categories (from Munnoli et al, 2010)

2.1.1.3 Feeding & Diet

Earthworms have no teeth, so they first coat their food with an enzymatic secretion making it easier to shred and ingest. Their diet is primarily composed of decaying organic matter, and consequently, the microorganisms that facilitate this decay, found throughout the soil (Gajalakshmi & Abbasi, 2004; Munnoli et al, 2010). Most studies indicate that earthworms can eat their full weight in organic matter per day (Riggle & Holmes, 1994; Sinha et al, 2010).

The earthworms' gut is full of enzymes that aid in digestion while a host of bacterial colonies are responsible for the biochemical changes in the organic matter that passes through. Earthworms produce manure, or casts, in high quantities and these casts represent considerable modifications in biochemical properties in relation to the ingested material (Munnoli et al, 2010). The casts are composed of microorganisms, inorganic minerals, enzymes, and organic matter (Gajalakshmi & Abbasi, 2004).

2.1.1.4 Reproduction

The development of the clitellum, a band that appears near the anterior end of the worm, indicates sexual maturity. Earthworms are hermaphroditic (they posses both male and female reproductive systems) and require mating between two worms for fertilization to take place (Gajalakshmi & Abbasi, 2004). They produce 1-3 cocoons per week (Sinha et al, 2002), each carrying 1-4 young (Singh et al, 2011). It takes 60-70 days for earthworms to double in number. Their lifespan ranges between less than a year to seven years, depending on the species and the environment (Sinha et al, 2010; Sinha et al, 2002).

2.1.2 What is Vermicomposting?

Vermicomposting is just one method of using earthworms to meet human needs (see appendix 1 for a list of current earthworm technologies). It is a biotechnology harnessing and maximizing the earthworm's natural digestive cycle to produce valuable worm manure, an organic fertilizer. Vermicomposting can be described as an aerobic process through which organic material is bio-oxidized and stabilized via synergistic interactions between earthworms and microorganisms. While the microorganisms are mainly responsible for the biochemical degradation of organic matter, the role of the earthworm is crucial – they aid in fragmenting and conditioning the substrate, increase its surface area to suit microorganism growth, which in turn, enhances decomposition. The product of this decomposition process is worm manure, also referred to as vermicasts (Munnoli et al, 2010; Singh et al, 2011).

Vermicomposting is composed of three phases – the first phase involves the acclimatization of the worms to their new substrate. In the second, all readily degradable matter is broken down, followed by a curing phase in which more recalcitrant matter is degraded (Jack & Thies, 2006).

2.1.3 The Vermicomposting Process

2.1.3.1 Earthworm Collection

Simple digging is one method to collect earthworms. Another is commonly referred to as "grunting" and involves driving a stake into the ground and drawing the flat side of an iron rod across it. This sends low-density vibrations into the ground. Within an hour, thousands of earthworms will come to the surface, allowing for easy collection. The most commonly recognized explanation for such behavior is that proposed by Darwin, himself – the vibrations imitate the vibrations produced by burrowing moles, thus inciting the earthworms to rise to the surface and escape their predator (Catania, 2008).

2.1.3.2 Vermicomposting at a Glance

Sinha et al (2002) outline the basic methodology for household vermicomposting, though it should be noted that many different approaches exist. Containers may be made of wood, cement, plastic, or terra cotta, but all should incorporate holes at the bottom for water discharge and aeration purposes. The size of the containers should be based on the amount of anticipated waste generation. Three to four centimeters of moist coconut coir waste or sawdust fill the bottom of the container. Next, 5-6 cm of partially degraded manure (cattle or poultry) can be placed as 'bait' in order to facilitate the worms' transition to organic waste. A moist cloth can then be placed over the container to provide an ideal environment for the worms- darkness, protection from predators, retained moisture, temperature stability, and aeration. Once the waste has been degraded into loose, black castings, the worms move to the lower levels of the container and the upper layer may be removed and, ideally, dried in the shade (Sinha et al., 2002).

2.1.3 3 Maintaining an Ideal Environment

A review by Munnoli et al. (2010) summarizes the literature on proper earthworm environments. Some studies indicate that earthworms prefer soil environments with a neutral pH while others suggest that they inhabit soils with a wide pH range (5-9). Water moisture is another property that must be monitored and maintained. Most studies recommend moisture content between 60 and 70%, though one study suggests 28 – 42%. The vermicompost model must be able to simultaneously hold in ambient moisture and prevent water logging. Temperature plays a critical role in earthworm activity, metabolism, growth, reproduction, etc, but varies according to the species (Munnoli et al, 2010).

2.1.3.4 Differences in Substrates

The range of organic waste that can be fed to worms is vast. Besides kitchen and municipal wastes, the focus of this study, Sinha et al (2002) study garden waste, agricultural waste, dairy farm waste, sugar mill residues, slaughterhouse waste, distillery and hatchery wastes. Murthy & Naidu (2012) explore the potential of vermicomposting as a means of disposing of the by-products of the coffee industry. However, highly acidic substrates are toxic to earthworms, so foodstuffs such as citrus and onions should be kept to a minimum (Nair et al, 2006).

2.1.3.5 Hastening Activities

Sinha et al (2002) report that cooked foods degrade faster than raw foods because the cooking process breaks down the primary material into a substrate that is more easily degraded by the worms. Similarly, the degradation process can be sped up by shredding the organic waste (Tognetti et al, 2007). Additionally, the aforementioned addition of 'bait' such as cattle dung will accelerate the initial transition period necessary for worms to accept new kitchen waste feed while a mix of worm species will increase the degradation rate (Sinha et al, 2002). A 1.6 kg-worm/m^2 stocking rate, combined with a 1.25 kg-feed/kg-worm/day feeding rate has been found to yield the fastest bioconversion of the waste into vermicast (Ndegwa et al, 2000). One experiment discovered that uncovered vermicompost containers experienced a severely decreased degradation rate while the process accelerates when covered. This confirms that worms function best in a dark environment (Sinha et al, 2002).

2.1.3.6 Methods to Enhance Quality

Quality criteria are composed of various parameters including reduced pathogen levels, maturity and stability indexes, trace metal concentrations, organic matter, and total and available nutrients (Tognetti et al, 2007). Vermicast of the highest quality was obtained with a stocking density of 1.60 kg-worms/m^2 and a feeding rate of 0.75 kg-feed/kg-worm/day (Ndegwa et al, 2000). Moreover, evidence indicates that vermicast that undergoes an initial thermophilic composting phase over the course of 15 to 30 days results in higher quality in terms of reduced pathogen content (Tognetti et al, 2005; Nair et al, 2006). Tognetti et al, (2007) confirmed through a series of experiments, that a shredded substrate leads to a more mature and stable vermicast, while the processes of shredding *and* adding wood shavings produced the highest organic matter values.

2.1.3.7 Seasonal Variation

Bioconversion rates are highest in warm, humid climates (Sinha et al., 2002). Vermicomposting activities will, of course, be less constrained by seasonal temperature fluctuations if conducted indoors.

2.1.3.8 Earthworm Species Used in Vermicomposting

It is important to select an earthworm species suitable for the vermicomposting system. Favorable criteria include a high affinity to the substrate, decomposition efficiency, high fecundity, a high rate of casting output, and stress-resistance (Gajalakshi & Abbasi, 2004; Munnoli et al, 2010). Several worm species stand out as the most efficient biodegraders. These include the temperate species *Eisenia foetida* (also known as 'Red Wiggler'), *Lumbricus rubellus,* and *Dendrobaena veneta* and the tropical species *Eudrilus euginae* and *Perionyx excavatus*. (Sinha et al, 2002) (Tripathi & Bhardwaj, 2004; Gajalakshi & Abbasi, 2004). Interestingly, Sinha et al (2002) found that degradation was fastest in the presence of a mix of species.

2.1.4 Benefits for the Soil

Adding vermicast to the soil offers a myriad of physical, chemical, and biological benefits, which will vary depending on the original feedstock (Tognetti et al, 2005; Tognetti et al, 2007). The next section discusses these benefits separately, though it must be acknowledged that many are intertwined.

2.1.4.1 Soil Aggregation

Soil aggregation is a component of soil structure. Aggregates are mineral granules joined together that resist soil erosion and compaction and provide a habitat for microflora and -fauna. Soil rich in aggregates is well aerated and drained and therefore plays an important role in soil fertility. Vermicast enhances aggregation while worms contribute to this property by secreting a gelatinous substance that stabilizes these soil aggregates (Munnoli et al, 2010).

2.1.4.2 Porosity & Bulk Density

Earthworm activity involves extensive burrowing, which keeps the soil loose and porous in nature. Vermicast has also been shown to increase total cracks in the soil but decrease large cracks. This increases overall soil porosity and reduces soil bulk density. For example, one study found that soil treated with a combination of vermicast and chemical fertilizers reduced the bulk density to 1.40 Mg/m^3 as compared to 1.57 Mg/m^3 when the soil was treated with chemical fertilizers alone (Chaudhary et al, 2004). These are all properties indicative of enhanced soil structure important for aeration, water infiltration and drainage, and resistance to erosion, all of which support the development of plant roots (Munnoli et al, 2010).

2.1.4.3 Water Holding Capacity

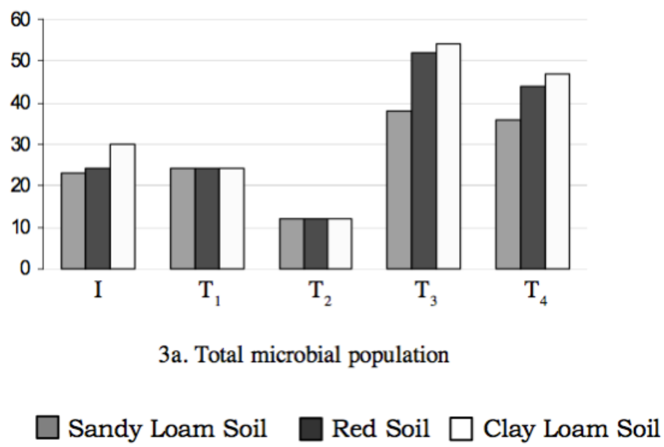
The above improvements are linked to subsequent improvements in water holding capacity. Vermicasts have a high surface area, providing strong absorbability (Atiyeh et al, 2000) and are therefore capable of storing water in higher quantities. They have been shown to increase total water holding capacity of the soil anywhere from 3% (Manivannan et al, 2009) to 10% (Adhikary, 2012) per ton per hectare applied. The moisture content of soil is, in conclusion, important for plant nourishment and for the establishment of beneficial microorganisms.

2.1.4.4 Organic Matter and Microbial Populations

Decomposition occurs in the presence of decomposer organisms that provide the necessary enzymes to break the bonds of a substance. Soil organic matter is organic waste (food, animal manure, etc) in varying stages of decomposition. Humus is organic matter that is resistant to further decomposition. Although humus and organic matter provide only a small amount of nitrogen, this constitutes the soil's nitrogen reservoir. They also provide oxygen, hydrogen, and phosphorous among other important nutrients. Microbes rely on these nutrients, especially carbon and nitrogen, for growth and reproduction (Gardiner & Miller, 2004). A low C:N ratio indicates abundant quantities of these two nutrients, and is therefore a means of anticipating efficient decomposition.

Because earthworm castings have a high surface area and are covered in a layer of mucus from the worm's intestinal track, they are able to adsorb particularly high quantities of carbon and nitrogen compounds. Therefore, castings stimulate a flush of microbial activity in the soil, more so than traditional composts (Jack & Thies, 2006). By producing growth promoting substances, fixing atmospheric N, solubilizing insoluble P and decomposing waste which releases plant nutrients, the abundance of microorganisms in vermicasts elevate the overall fertility of the soil (Munnoli et al, 2010; Gardiner & Miller, 2004).

In Figure 2 below, notice the difference in microbial populations between T_2 (soil treated with NPK) and T_3 (soil treated with vermicompost).



I: Initial Soils before sowing blackgram
T_1: Control, after harvesting blackgram
T_2: 100% recommended dose of NPK
T_3: 100% recommended dose of vermicompost
T_4: 50% vermicompost + 50% NPK

Figure 2: Total Microbial Population in Three Soil Types (from Parthasarathi et al, 2008)

Interestingly, the microbial species that tend to flourish in the presence of earthworms have been found to be more metabolically efficient (Lazcano et al, 2008; Jack & Thies, 2006). Compared to traditional compost, which is limited to thermophilic-tolerant species, vermicompost maintains widely diverse microbial communities. These can include bacteria, fungi, protozoa, nematodes, and microarthropods (Jack & Thies, 2006).

Humus and organic matter also play an important structural role in that they provide the cementing substances needed to form aggregates, which protects the soil from excessive erosion, enhances aeration, water movement, water holding capacity, and serves as a buffer against rapid changes in toxicity, acidity, and temperature of the soil (Gardiner & Miller, 2004).

2.1.4.5 Soil Nutrients

Vermicast is a slow-release fertilizer, releasing nutrients over an extended period of time (Jack & Thies, 2006). This is important because it means that fewer nutrients are lost to leaching after rainfall or heavy irrigation (Gardiner & Miller, 2004). Nitrogen, phosphorous, and potassium are referred to as macronutrients because plants require them in large quantities and are often the limiting factors of plant growth (Gardiner & Miller, 2004). Nitrogen and phosphorous are made available by the breakdown of organic matter. Potassium, on the other hand, is released during the early stages of decomposition of fresh plant residues. More important than actually supplying nutrients, organic matter promotes the activity of bacteria that render nutrients into more plant-available forms. Nitrogen-fixing bacteria, such as Azospirillum spp., fixes atmospheric nitrogen into ammonium and nitrate, nitrogen forms that are more readily available for plant uptake. Similarly, bacteria convert insoluble forms of phosphorous into plant-available phosphate (Jack & Thies, 2006). Interestingly, worm castings contain five times the quantity of plant-available nutrients found in average potting soil. There is even evidence that the conversion of phosphorous occurs inside the earthworm gut (Adhikary, 2012). Castings were also shown to contain two to three times more available potassium than ambient soil (Gajalakshmi & Abbasi, 2004).

In sum, the great value of vermicompost lies in the provision of nutrients and stimulation of microbial populations, but also by virtue of being able to hold on to them. The large particulate surface area of vermicompost provides many microsites for microbial activity and strong retention of nutrients that might otherwise be lost to leaching (Gardiner & Miller, 2004; Singh et al, 2008).

2.1.4.6 pH

The high pH of decomposing organic matter and compost can be decreased through the vermicomposting process (Gajalakshmi & Abbasi, 2004; Lazcano et al, 2008; Lleó et al, 2012). Singh et al (2005) tested the effects of vermicomposting on substrates of different initial pH levels. The pattern indicates that even acidic substrates with a pH of 4.3 will eventually level out around neutral. Possible causes are the mineralization of nitrogen and phosphorous, the release of CO_2 and organic acids during microbial metabolism, or the production of fulvic and humic acids (Lazcano et al, 2008).

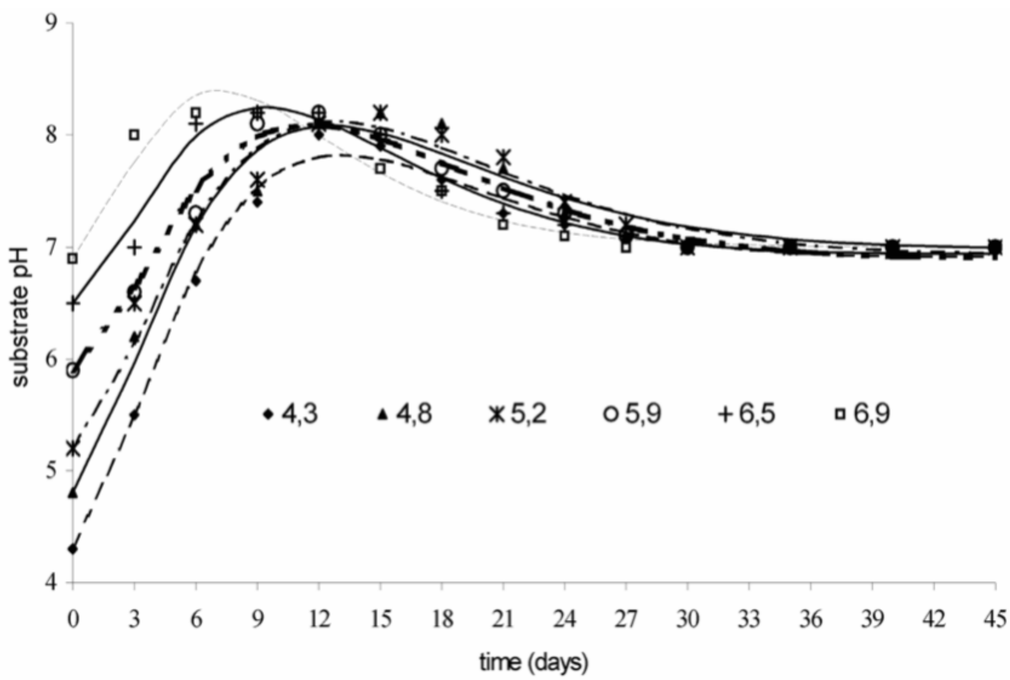


Figure 3: Variation of substrate pH with different initial substrate pH (from Singh et al, 2005)

Vermicompost, itself, has a pH near neutral (Singh et al, 2011), which makes it suitable as a soil amendment according to compost quality standards (between 6.5 and 8; Lleó et al, 2012). Chaudhary et al (2004) claim that, when added to the soil, vermicast will bring the pH toward neutrality. However, a slightly lower pH in the range of 6-7 provides optimal nutrient availability for plants (Manivannan et al, 2009) and vermicompost has been shown to bring alkaline soils down into this range (Manivannan et al, 2009; Parthasarathi et al, 2008).

2.1.4.6 Electrical Conductivity (EC)

Electrical Conductivity, indicative of salinity, is measured in siemens per meter (S/m). Salts in the soil force plants to exert more energy to absorb soil water (Gardiner & Miller, 2004) and high concentrations can cause salinity stress (Jack & Thies, 2006) or phytotoxicity to plants (Lazcano et al, 2008). Thus, EC is an important indicator of the safety and suitability of a soil amendment.

During decomposition of organic matter, the EC usually increases in response to the release of soluble salts. Vermicomposting brings the EC down, most likely due to the production of soluble metabolites and the precipitation of dissolved salts. For example, raw cattle manure was found to have an EC of approximately 1.25 dS/m, which rose to 2.13 dS/m when composted, but decreased to 0.78 dS/m when vermicomposted (Lazcano et al, 2008). Soils treated with vermicompost have lower EC (Manivannan et al, 2009; Parthasarathi et al, 2008).

A review of earthworm action by Sinha et al (2010) elucidates the benefits of earthworms in saline soils. The species *Eisenia foetida* can not only tolerate, but improve soils with a salt content nearly half that of seawater. Farmers in Maharashtra, India were growing their sugarcane on saline soils irrigated with saline ground water. A year after applying live earthworms to the soil, there was a marked improvement in soil chemistry with 37% more nitrogen, 66% more phosphates, and 10% more potash. Chloride content decreased by 46%.

2.1.5 Benefits for Plants

2.1.5.1 Plant Growth

It is clear that vermicompost enhances the quality of the soil, but how does it affect plant growth? Many studies have found that vermicast mixtures have increased various plant growth parameters including seed germination, plant spread, plant height, leaf number, leaf area, dry matter, root length and overall plant productivity (Singh et al, 2008; Peyvast et al, 2008; Munnoli et al, 2010). Moreover, a variety of plants have been tested, including cereals and legumes, vegetables, ornamentals and field crops (Peyvast et al, 2008). The following table shows the effects of vermicompost, applied in different quantities, on several growth parameters of strawberries.

Treatment	Days taken to 1st flowering	No. of fruits/ plant	Individual berry weight (g)	Total fruit yield (g/plant)
Inorganic nutrients	93.1a	25.5a	11.7a	298.5a
VC @ 2.5 t ha^{-1}	90.2b	25.6a	12.5b	320.0b
VC @ 5.0 t ha^{-1}	88.1c	26.7b	13.0bc	347.1c
VC @ 7.5 t ha^{-1}	87.4d	27.7c	13.4c	371.2c
VC @ 10.0 t ha^{-1}	86.8e	27.5c	14.2d	396.2 d

Means within the column with the same letter are not significantly different by Duncan multiple range test at $P \leqslant 0.05$.

Table 2: Effect of Vermicompost on Strawberry Plants (from Singh et al, 2008)

Fruit quality was also improved, as judged by firmness, higher Total Soluble Solids (TSS), ascorbic acid content, lower acidity, attractive color (Singh et al, 2008), protein and sugar content (Parthasarathi et al, 2008) and vitamin C content (Meerabai et al, 2007). Vermicast has also been shown to improve the keeping quality in fruits, vegetables, and flowers (NABARD, 2007). In a study comparing the response of bitter gourd to eight different organic fertilizers and recommended NPK doses, it was found that vermicompost resulted in the best keeping quality over time (Meerabai et al, 2007).

Research indicates that despite the high nutrient content of vermicast, this property is not responsible for enhanced plant growth. With all nutrients held equal, plant growth was still significantly greater with vermicast (Jack & Thies, 2006). One study suggests that plant growth is triggered indirectly by the biological properties of vermicast. A significant body of evidence has demonstrated that microorganisms (fungi, bacteria, yeasts, acinomycetes and algae) are capable of producing plant growth regulators (PGR) in appreciable quantities. Humic acids are another product of microbial activity and may also be responsible for stimulating growth in plants. They are thought to bind these plant growth hormones in the soil, making them more available for plant uptake (Jack & Thies, 2006). A greenhouse experiment extracted small concentrations of humic acids and added them into container media. This consistently resulted in plant growth independent of nutrient supply. Humic materials are naturally present in animal manure, but are far more abundant in vermicompost (Arancon et al, 2004, a).

2.1.5.2 Plant Protection against Diseases, Disorders, and Pests

The plant disease-suppression properties of vermicast have been widely documented. Adding vermicast to growth media has been shown to significantly suppress the following diseases: damping off (Pythium, Rhizoctonia), wilts (Verticillium), Fusarium, root rot (Phytophthera), club root (Plasmodiophora), white rot (Sclerotium), sugar beet cyst nematode (*Heterodera schachtii*), bacterial canker (*Clavibacter michiganensis*), brown plant hopper (*Nilapavata lugens*), sheath blight, grey mould, albinism, fruit malformation, aphids, mealy bugs, cabbage while caterpillars, cucumber beetles and tobacco hornworms (Jack & Thies, 2006; Singh et al 2008; Aroncon et al 2005; Edwards et al, 2010). Another study measured the decrease in albinism, injury, malformation and *Botrytis* rot symptoms in strawberries and concluded that vermicompost can improve the marketable fruit yield by up to 58.6% (Singh et al, 2008).

The mechanisms by which vermicast conveys disease suppression are not entirely understood. Jack & Thies (2006) report that suppression is most likely biological in nature since heat-sterilized vermicast was not found to be disease-repressive. However, Arancon et al (2005) suggest that vermicast provides certain nutrients that increase the plant's natural resistance to pests or makes the plants less palatable for the pests. A study by Edwards et al (2010) identified water-soluble phenols as the most likely mechanism protecting plants from pest attacks.

	Banana	Grapes	Apple	Pepper	Strawberry	Turmeric	Tomato	Okra	Maize	Eggplant	Medicinal	Sorghum	Marigold	Coriander	Barley	Wheat	Sugarcane	Onion	Papaya	Amaranth	Spinach	Rice	Soybean	Bitter Gourd	Raspberry	Cabbage	Cucumber	Black Lentil	String Bean	Cherry
Y	√	√	√	√	√	√	√	√		√			√			√	√	√	√	√	√	√	√	√			√	√	√	√
G				√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√	√		√			√	√	
Q	√	√	√		√	√	√	√	√															√		√			√	

Table 3: Positive responses to vermicompost in terms of yield (Y), growth (G), and quality (Q) of various crops

Compiled from: (Munnoli et al, 2010; Singh et al, 2008; Meerabai, et al, 2007; Atiyeh et al, 2000; Arancon et al, 2005; Edwards et al, 2010; Parthasarathi et al, 2008; Manivannan et al, 2009; Sinha et al, 2010).

Table 3 is a compilation of data from various studies, but is not exhaustive. Yield parameters include the number of fruits per plant, the number of fruits per hectare, and/or the individual fruit weight, as well as a greater marketable yield through less pest and disease damage (Singh et al, 2008). Growth parameters include leaf number, leaf area, flower number, number of runners, plant spread, shoot biomass, shoot and root length, germination, and faster growth (Munnoli et al, 2010; Singh et al, 2008). Quality parameters are reducing, non-reducing, and total sugars, total soluble solids (TSS), ascorbic acid, vitamin C, proteins, firmness, color, acidity, sweetness, and taste (Munnoli et al, 2010; Meerabai et al, 2007).

In conclusion, a substantial body of evidence suggests that vermicomposting could be promoted as a low-cost, sustainable way to inoculate agricultural or potting soils with beneficial bacteria that can biologically enhance plant growth and resilience (Jack & Thies, 2006).

2.1.6 Application Methods and Rates

Vermicompost can be incorporated into the top 10 centimeters of the soil (Singh et al, 2008) or spread and left on top of the soil as a mulch cover. This way, it protects the soil from erosion, prevents rapid moisture loss, and helps moderate soil temperature (Gardiner & Miller, 2004). Another study, however, found that the yield of cherry trees was much greater when the vermicompost, itself, was covered with mulch (Sinha et al, 2009).

Much of the literature recommends vermicast in doses of 2 - 5 tons/hectare (Manivannan et al, 2009; Parthasarathi et al, 2008; Munnoli et al, 2010) although 7.5 tons/hectare has also been suggested for optimal growth and health parameters (Singh et al, 2008). The following table shows recommended doses according to crop.

Crop	**Rate/Th^{-1}**
Cereals	5
Pulses	5
Oil seeds	12.5
Spices	10
Vegetables	12.5
Fruits	7.5
Cash crops	15-17.5
Plantations	7.5
*Horticulture crops	100-200 g/tree
*Kitchen garden and pots	50 g/pot

Table 4: Application rate (tons/ha) per crop (from Munnoli et al, 2010)

Very little information is available regarding the frequency of vermicompost application. One study found that cherry yields were boosted over the course of three years after just one application (Sinha et al, 2010). Another study found that yearly applications of 2 tons/ha resulted in *continually higher* wheat yields over the four-year study period (Sinha et al, 2009). These findings are significant since they suggest that vermicompost applications can be decreased as time progresses, whereas chemical fertilizer and pesticide quantities must be continually increased over time in order to maintain a constant yield.

As a container media, 10 to 20% vermicompost is the recommended dosage (Atiyeh et al, 2000; Jack & Thies, 2006). Arancon et al (2004, b) found, however, that plant growth decreased significantly above 60%, so quantities above this are not advised.

Nearly all studies test the effects of vermicompost either as an application to agricultural fields or as a percentage of a potting soil media for potted plants, but a third application method exists for plants that have already been planted. Vermicompost tea is a liquid made by adding hot water to worm castings and applied via irrigation (Doherty & McKissick, 2000). Similarly, the liquid that collects beneath a vermibed, referred to as vermiwash can be applied as a spray, in which case it will act as an insecticide or as a liquid fertilizer (Munnoli et al, 2010).

2.1.7 Vermicompost Versus Compost

While vermicomposting is a relatively new concept, traditional composting is a well-known and established practice (Jack & Thies, 2006; Lazcano et al, 2008). Jack & Thies (2006) define compost as the "stabilized product of the decomposition of plant and animal residues at high temperatures (40-70˚C) by the activity of thermophilic (heat-loving) microorganisms." Vermicomposting, on the other hand, is the biooxidized and stabilized product of earthworm and mesophilic (10-40˚C) microorganism activity.

Figure 4 below illustrates the differences between the two processes in terms of temperature and time.

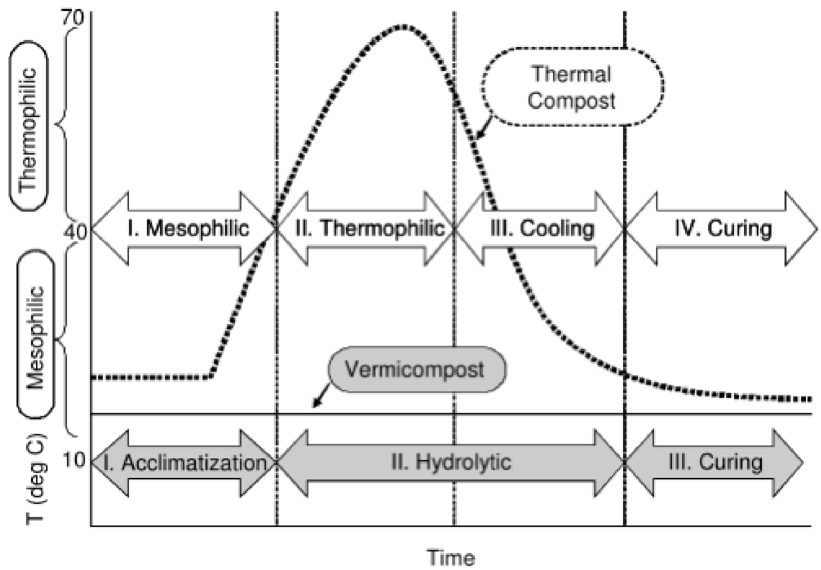


Figure 4: Time vs. Temperature for Compost and Vermicompost (from Jack & Thies, 2006)

One of the attributes of composting over vermicompost is pathogen stabilization. Because compost passes through a thermophilic stage, pathogen populations within the substrate are rendered innocuous. Because vermicomposting is mesophilic, pathogen removal is not guaranteed. There are, however, many studies that provide evidence of pathogen suppression via vermicomposting (Monroy et al, 2008; Singh et al, 2011; Munnoli et al, 2010) and several studies that show *superior* pathogen stabilization (Lazcano et al, 2008). This may be due to specific microbes and enzymes present in vermicast (Nair et al, 2006). Many studies have focused on the possibility of incorporating an initial thermophilic composting stage *before* introducing earthworms into the waste. An initial thermophilic stage would suppress pathogens, eliminate toxic substances that threaten the worms (such as acidic compounds), reduce the waste mass, manage moisture, and reduce the expense and duration of treatment (Lazcano et al, 2008; Tognetti et al, 2005; Nair et al, 2006). Consequently, many vermicompost practitioners combine the two techniques (Jack & Thies, 2006). A 9-day thermocomposting period, followed by 2.5 months of vermicomposting is suggested as the optimum timeframe to achieve pathogen stabilization (Nair et al, 2006).

Nonetheless, vermicomposting has several advantages over traditional composting. Firstly, it has a faster decomposition rate. Sinha et al (2002) found that vermicomposting required 12 days, and composting 64 days, for organic waste to be 50% decomposed. Secondly, vermicomposting is a more attractive alternative given its lack of odors. Gaseous emissions are one of the major drawbacks in composting. During the thermophilic phase, nitrogen is lost through the volatilization of NH_3 (Lazcano et al, 2008). Emissions of NH_3, as well as CH_4 and N_2O, during vermicomposting are three orders of magnitude lower than those released during composting (Lléo et al, 2012). Furthermore, castings are consistently regarded as higher quality than compost (Lazcano et al, 2008; Jack & Thies, 2006; Lléo et al, 2012). Lastly, Tognetti et al (2005) suggest that that market acceptance of vermicompost is higher than that of compost due to its higher quality and visual aesthetics. These costs will be explored in later section.

2.2 Lebanon

2.2.1 Country Description

Lebanon is a small country of 10,452 km^2 located along the eastern shores of the Mediterranean Sea. The country is mostly mountainous, being composed of the Mount-Lebanon and Anti-Lebanon mountain chains running parallel to the sea. The country's population is estimated at 4.1 million people, the bulk of which live in urbanized areas. Beirut, the capital, is home to almost half of the population. The climate is typical of the Mediterranean region, featuring dry, hot summers, and rainy winters. However, Lebanon's precipitation (up to 60 inches a year), distinguishes it from other arid and semi-arid countries in the Middle Eastern region. The country's soil can be described as new, friable, and easily eroded where terrain is sloping. The relief, intensity of the rainfall, and runoff contribute to the erosion and soil loss, particularly in areas where vegetation is minimal (Asmar, 2011; Zurayk, 1994). Lebanon is home to at least 16 different earthworm species but since regular regional earthworm surveys commenced only recently, the species list found in Appendix 2 is only preliminary (Pavlícek et al, 2003).

2.2.2 Agricultural Profile

Approximately 248,000 hectares of land in Lebanon are cultivated, or about 24% of the territory. Of this cultivated land, 56% is rain-fed, 42% irrigated, and 2% is under greenhouse production (MOE, 2001). The most common crops are cereals, fruits and vegetables, citrus fruit, tomatoes, cucumbers, grapes, wheat, apples, cabbages and olives (Hunter, 2008).

Despite extensive cultivation and great biodiversity in Lebanon, the country is, nonetheless, a major food importer, producing just 20% of its own food requirements. This makes it one of the least agriculturally self-sufficient countries in the world (Hunter, 2008; Asmar, 2011). Since 1970, agricultural production in Lebanon has declined by 12%. Agriculture formerly contributed 9% to the GDP, employing 19% of the population. Today, it contributes only 6% to the GDP, employing the same percentage of the population. One of the current objectives of the Ministry of Agriculture is to increase agricultural contribution to the GDP to at least 8% (Asmar, 2011).

2.2.3 Trouble in the Agricultural Sector

A number of factors have contributed to this decline. Agriculture was severely compromised during the 17-year civil war (1975-1992) that left the country politically destabilized. The war disrupted crop and livestock production, destroyed infrastructure such as roads and irrigation systems, and left many lands scattered with land mines.

Today, Lebanese agriculture is characterized by the prevalence of small land holdings that are increasingly parceled for purposes of inheritance. The averages size of landholdings is 1.25 hectares while landholdings in the Beqaa valley and along the coast are slightly larger (Asmar, 2011). Many of the country's rural areas and fertile lands are threatened by encroaching urbanization while the high cost of agricultural inputs such as land, labor, and capital are linked to high rates of land abandonment (20% of usable land). Economic policies favor the import of cheap foods instead of investing in the local market. As such, Lebanon's service-based economy and poor organization of commercial channels does not create a favorable environment for small farmers, hardest hit by the country's declining agricultural sector (Hunter, 2008; Rachid, 2007).

Lebanon is a significant importer of agrochemicals. The country imports an average of 1,530 tons of pesticides and 32,000 tons of fertilizers per year. While measures have been taken to limit some hazardous pesticides, or even phase them out entirely, as in the case of Methyl Bromide, years of unrestricted application have left soils contaminated with persistent chemicals and residues. Several components reinforce the excessive or inappropriate use of agrochemicals. Firstly, small-scale agrochemical vendors or retailers have been known to dilute the chemicals in order to increase revenues, which in turn, forces farmers to apply more and more. Secondly, illiteracy and lack of proper training amongst the farming population often results in application rates that threaten the environment, their own health, and the health of consumers (MoE, 2001). In a study of pesticide poisoning in Brazil, it was found that cotton cultivation consumes the greatest quantity of pesticides (7.4 kg/ha) and is coincidently associated with the highest number of employee poisonings, around 12% (Soares & Porto, 2009). Intensive greenhouse agriculture along the coast of Lebanon is maintained with fertilizer inputs of 1,800 kilograms per hectare per season (Darwish et al, 2005). Table 5 shows pesticide use per crop in Lebanon.

Type of culture	*Cultivated Area*	*Year 2000*	
	Ha	kg/ha	l/ha
Stone fruits	59,515	7.9	2
Citrus		5.9-6.2	n/a
Olive	52,421	5.0	n/a
Tobacco	24,730	10.7	n/a
Sugar beet		8.6	n/a
Vineyards		1.2	3.0-3.3
Banana	n/a	1.1	n/a
Vegetables	45,232	16.7	17.5

Table 5: Pesticide Use Reported in kg/ha or liter/ha of Active Ingredient per Type of Culture (from MoE, 2001)

To make matters worse, the use of some fertilizers, such as Methyl Bromide, depletes the soil of its beneficial microorganisms. Therefore, higher quantities Methyl Bromide necessitate higher quantities of fertilizers. The costs of all these inputs cut severely into the farmers' profits (MOE, 2001).

The soils of Lebanon are typically clayey, calcareous, and slightly alkaline. Fertilizer and irrigation practices that ignore local and regional recommendations lead to excess salt accumulation and hence, saline soils. In addition to poor land management practices, the combination of sloping lands, deforestation, heavy rainfall and relatively shallow soils cause extensive topsoil erosion. All of these factors exacerbate soil degradation and threaten productivity (MoE, 2001; Darwish et al, 2005; Ryan, 1983). Zurayk (1994) points out that strategic soil conservation programs must be implemented if agricultural productivity is to be preserved.

One promising agricultural practice, however, is the application of animal waste for soil fertility. Waste is produced in substantial quantities on farms and has been shown to fetch up to $60-80 per ton. Goat manure has the highest value, followed by cow manure (MOE, 2001).

While many traditional farmers in Lebanon have been farming organically by default for years, organic farming has recently been on the rise in response to growing demand locally and internationally, particularly in Europe. LibanCert is the country's first organic inspection and certification body. The European Commission formally recognized it in 2011 and the export of local produce to Europe commenced a year later

(LibanCert, n.d.). The organic industry in Lebanon is touted to improve environmental conditions and may provide opportunities for producers to bypass local competition from low-value imports (MOE, 2001).

2.2.4 Municipal Solid Waste in Lebanon

Outside of Beirut and Mount Lebanon, local municipalities are responsible for collection, treatment and disposal. However, due to the government's austerity measures, the municipalities rarely have the financial resources to plan and invest in proper solid waste management systems and they often resort to open dumping (MoE, 2010). In the cases of Beirut and Mount Lebanon, municipal solid waste is collected by the private sanitation companies Sukleen and Sukomi. Roughly half the waste is deposited in landfills, a quarter in open dumps, about 12% is recycled and 13% composted. The rate of composting is low considering that the daily organic fraction of municipal solid waste in Lebanon amounts to 55-63%. Sukomi processes about 300 tons of organic waste per day, producing 110 tons of compost offered free of charge to the public (MoE, 2010). However, separating organic waste post-collection guarantees that the compost will be contaminated with synthetic materials and broken glass, resulting in a low-quality product. Therefore, separation-at-source protocols are necessary for maximum efficiency in composting operations.

2.3 The Vermicompost Market

The previous sections have outlined the effectiveness of vermicompost as a soil amendment and the state of agriculture in Lebanon. It is becoming clear that the context is ripe for the establishment of vermicomposting as an alternative to conventional practices. This final section explores the economic dynamics of vermicomposting and, more specifically, considers shaping the practice as a microenterprise for community development.

2.3.1 Characteristics of the Vermicompost Market

A report from 2000 on vermicompost markets in the US reveals the characteristics of this relatively new market. Firstly, most vermicompost buying and selling takes place over the Internet. Secondly, three vermicompost products are sold – worm castings (sometimes in bulk but mostly sold by the bag), worm casting mixtures (for example, Rainbow Potting Soil is a blend of castings, compost, peat moss, and red volcanic rock) and vermicompost tea. Interestingly, there exists a strong do-it-yourself market on the Internet in which worms, worm bins, and various supplies are available for purchase. The conclusion to this market report is that the vermicompost market, as of 2000, remains unestablished and prices vary dramatically, as can be seen in Table 6 below. These findings are reinforced by the fact that only 3% of nurseries or garden centers in Canada sell vermicompost (Munroe, 2005). Nonetheless, the bulk market seems to hold the most promise for producers (Doherty & McKissick, 2000).

Munroe (2005)	North America	$226 /ton for bulk VC $31,000 /ton pure castings
Riggles & Holmes (1994)	North America	$33 /ton for bulk VC $120 /ton for bagged
Shivakumar et al, (2009)	India	$19-24 /ton through the individual farmer $23-27 /ton through commercial supplier
VermiCo (2013)	India	$40-44 /ton through the individual farmer $31 / ton through commercial supplier
Adorada (2007)	Philippines	$100-500 / ton
Sherman (1997)	North America	$25 /ton
Jack & Thies (2006)	North America	10x the cost of compost
Sherman (1997)	North America	7x the cost of compost
Riggles & Holmes (1994)	North America/ Europe	3x the cost of compost (willingness to pay)

Table 6: Specific and relative prices of vermicompost

2.3.2 Vermicompost, a Commodity

Table 6 above underlines the fact that the vermicompost market differs drastically depending on location. In the US, vermicast is an expensive amendment, mostly used as potting media, which creates an image that it is a “luxury” soil amendment. In some parts of India, on the other hand, vermicompost application is a common practice used to alleviate a crippling dependence on synthetic fertilizers and pesticides and remedy degraded soil after years of intensive farming (Jack & Thies, 2006). Monroe (2005) suggests that the difference in price is a reflection of the rate of production. Prices remain high in North America, for example, because production is minimal. If production increases in response to higher demand, however, the price for vermicast can be expected to decrease.

2.3.3 Compost in Lebanon

Considering that over half of municipal solid waste in Lebanon is organic (MoE, 2010), vermicomposting would be a boon for solid waste management. There are currently two large-scale composting facilities operating in the country. The first is Sukomi's Coral facility that produces compost free of charge to the public. The second is Cedar Environmental, a private material recovery facility operating in Bickfaya, also has a composting facility that produces high quality, organic compost, available for $232 per ton (Cedar Environmental, n.d.; Personal Communication, Ziad Abichaker, owner). Lebanon's composting profile reveals that society has, to some extent, embraced the concept of producing and buying organic fertilizer and that the opportunity for a greater value-added product is promising. But how much would consumers be willing to pay for vermicompost? In the absence of a vermicompost market in Lebanon, one can only surmise that prices would fall between that of animal manure ($60-80) and high quality compost – around $150 per ton.

2.3.4 Case Study : India

At this point, it is useful to examine the case of India, which provided inspiration for the microenterprise model proposed in this project. India, in the wake of the Green Revolution, is home to a large sustainable agriculture movement in which vermicomposting has been playing an increasingly significant role. Non-governmental organizations, research institutes, and private entities have trained over a million farmers in on-site vermicompost production (Jack & Thies, 2006). One such example is the

Morarka Rural Research Foundation, an NGO based in Jaipur, India, focused on providing sustainable agriculture development for grassroots beneficiaries. Employing more than 400 full-time workers, present in all of India's 19 states, Morarka boasts of being the largest producer of vermicompost in the world (VermiCo, 2013).

The Foundation offers two kinds of vermicompost training programs. The first is an on-going, free of charge training program offered at any one of the Foundation's 300 establishments. The second is an outreach program in which professionals are sent to communities and offer training over a 2-3 month period at a cost of $110. Farmers who begin vermicomposting operations for their own use are supplied with earthworms free of cost. Farmers looking to sell their product have the option of selling to the Foundation through a buy-back guarantee program. Under this program, the Foundation pays farmers approximately $31 per ton of vermicompost and sells the product for $44 per ton. The Foundation makes no profit, however, because the $13 difference just covers handling and overhead. Thirty-one dollars per ton is modest, and indeed the farmers can sell their product directly on the market for $40-$44, but the buy-back program is intended to encourage new vermicompost producers. Once their confidence is established, the farmers shift to selling their castings on the open market. To date, the Morarka Foundation has disseminated vermicomposting knowledge to over 100,000 farmers and 500 entrepreneurs, yielding a combined productive capacity of over 500,000 metric tons of vermicast per year (VermiCo, 2013).

The economics of vermicomposting microenterprises are more thoroughly itemized in a study by Shivakumar et al. (2009), revealing slightly different figures than those at the Morarka Foundation. The author found that the net returns through direct sales to farmers amounted to $19 per ton of vermicompost. However, the net returns when vermicompost was sold to Bharatiya Agro Industry (which later sold the product to consumers), the producers realized higher prices amounting to $23. It is interesting to note that in Shivakumar's scenario, farmers realize *higher* prices by selling castings essentially through a middle-man, whereas the Morarka Foundation pays farmers *less* than they would be able to realize through direct sales. Shivakumar explains that farmers incur greater marketing costs when they are personally responsible for the transport, loading, and unloading the castings and that the BAI Foundation is able to offer a slightly greater price per ton, thereby making sales through the "middle-man" slightly more profitable (Shivakumar et al, 2009).

2.4 Vermicomposting as a Microenterprise

Drawing on the case study in India, this paper focuses on vermicomposting potential from a microenterprise angle. Microenterprises, however, are dynamic so the following section Orr & Orr (2002) distinguish between three microenterprise scales. These are presented through a vermicomposting context and are accompanied by photos for further illustration.

The first is subsistence microenterprises, which are often seasonal and employ only the owner, assisted by unpaid family members. A subsistence vermicomposting business would most likely be carried out seasonally in the backyard using crates that are mobile and easy to acquire. Vermicompost would be used for home-use or sold to friends, family, and neighbors.

Crate method, Batloun (personal photo)

Then there are stable microenterprises in which profits and investment are greater, they operate year-round, and employment is more formal. A stable vermicompost business could still be located in the backyard but would involve equipment requiring slightly greater investment, under a roof or in a shed, and would employ several people. Vermicompost would be sold through more formal channels to gardeners and to local horticulture centers as a potting soil amendment.

Concrete drums under roof, India (photo: FAO http://www.fao.org/ wairdocs/tac/y4953e/y4953e0b.htm)

The last category is growth microenterprises. These are larger in scale, have formal management systems and may generate an annual income around $3,750. Such a vermicompost microenterprise would require a greenhouse for year-round production, would employ a number of workers and managers, and would require a more formal waste collection system. Vermicompost could be sold locally or over greater distances to gardeners and horticulture centers, but also in large quantities to farmers for their fields.

Larger-scale vermicomposting in India (photo:http://www.biotechpark.org.in/html/vermicomposting.htm

One advantage of vermicomposting technology is that it can be implemented at any one of these scales. For the purposes of this paper, however, vermicomposting will be considered as a potential subsistence microenterprise utilizing source-separated waste, operated by and serving diversified, small-scale farmers.

The following sections have examined the benefits of vermicompost use, provided an overview of Lebanon's agricultural sector, and explored the economics of vermicomposting on both a macroscale (the international market) and on a microscale (India). With a closer look at microenterprise characteristics, this literature review has provided the background and framed the proposal of this paper: Vermicompost can contribute to sustainable agricultural productivity while at the same time benefiting disfavored rural communities through decentralized, home-scale production. The next section discusses why Lebanon is the ideal environment in which to introduce such a vermicomposting program.

2.5 Why Lebanon?

There are many reasons why Lebanon would be an ideal candidate for the implementation of a vermicompost microenterprise program. Lebanon is perfectly positioned in regards to the **input** end of the vermicompost equation. The organic material needed to fuel the operation can be sourced from the daily influx of municipal solid waste, 55 – 63% of which is organic waste (MoE, 2010). The organic portion of municipal solid waste is one of the least desirable at landfills for environmental reasons (space, odors, gas emissions, leachability (Clarke, 2000)), so redirecting it to vermicompost businesses is an especially efficient means of management. Moreover, rural communities tend to generate slightly more organic waste than urban ones (SOE, 2010). While the scope of this research considers only household kitchen waste as the input, it has been demonstrated that byproducts from the olive oil industry are also a suitable substrate for vermicomposting (Munnoli, 2010). What's more, the species hailed for its decomposition efficiency and most widely used in vermicompost systems - *Eisenia foetida* (aka "The Red Wiggler") is present in Lebanon (Pavlícek et al, 2003). There is a host of other species present in the country, as well, though they have not yet been tested for vermicompost potential.

Lebanon is also perfectly positioned to receive the **output** of the vermicomposting system. Most of Lebanon's crops, if not all, have responded positively to vermicast studies. These include banana, grapes, wheat, tomato and okra, just to name a few (Munnoli et al, 2010). Lebanon's heavy dependence on synthetic pesticides and fertilizers to grow these crops further underlines the profits to be had by abandoning their use and shifting to vermicompost. This could alleviate farmers' expenditures, improve health in the farming sector, and improve overall produce quality, all while relieving ecological stress caused by run-off and water contamination from the farming sector. Finally, several studies conclude that clayey soils, such as those of Lebanon, respond best to vermicompost, as compared to red loam or sandy loam soils (Manivannan et al, 2007; Parthasarathi et al, 2008).

Better yet, the benefits go beyond vermicompst input (organic waste) and output (organic fertilizer). The process of turning one into the other is a business opportunity that can benefit rural communities. One study by Purkayastha (2012) investigated vermicomposting as an environmentally sustainable approach to socio-economic betterment and poverty reduction. The results show that vermicompost operations are an ideal strategy to tackle some of the inherent difficulties in marginalized communities and that it adheres to the three pillars of sustainability.

2.6 Objectives Framework

Many scientific studies are vertical in nature in that they pose a question and then structure a deep study that will test the hypothesis. This study takes a more horizontal approach to the question of vermicomposting. Because "exploring the potential" of something can be broadly interpreted and executed, this study attempts to tackle a number of questions associated with vermicompost and, like a puzzle, piece them together to provide a succinct image of what this technology has to offer in the specific context of Lebanon.

A myriad of studies attest to the physical, biological and chemical assets of vermicomposting and a few studies investigate its economic or community strengthening potential. There is nevertheless a surprising lack of studies that address all these concepts simultaneously. In light of this, this study attempts to examine the all facets of the vermicomposting practice in a more holistic manner.

The following objectives framework has been developed in order to thoroughly assess the potential impact of vermicomposting in the Lebanese context and test the ground for its introduction.

- Optimization of the process:

  This objective was partly based on the findings of McKenzie-Mohr (2000). He argues that the proper approach to inciting significant behavior changes is to *break down the barriers* that prevent people from adopting more environmental practices. Because vermicomposting is a relatively new concept, particularly in Lebanon, it is predicted that the lack of know-how and confidence are great hurdles. Thus, the first objective is to test, develop, and systematize two practical aspects of vermicomposting - the compost collection process the vermicompost model. In this way, anyone interested in vermicomposting is spared the time and effort of solving these issues that may otherwise present daunting obstacles. Furthermore, the supplies must be affordable and the operation as simple and assessable as possible for the general public. This will facilitate the implementation of vermicompost systems in Lebanon.

- Verify the effectiveness of vermicompost:

  Despite the abundance of literature confirming the benefits of exotic earthworms, it is important to confirm the benefits of *local Lebanese earthworms*. Given that vermicompost has been most prominent in the horticultural industry in North America and Europe, the second objective is to verify that vermicompost derived from local worms will perform better, or at least as well as, a typical potting mix. This will provide evidence for the potential of vermicast as a partial replacement for costly potting mixes in the horticultural industry. The plants used in the experiment will represent a selection of typical Lebanese crops.

- In-field Trial:

The third objective is to test the knowledge gained from the optimization experiments by applying them in a microenterprise simulation in a rural community. This will test the methods, offer valuable feedback, and help reshape the design of the vermicomposting program to better suit the community it is intended to serve.

- Economic Study:

  An economic study will reveal whether or not a vermicomposting microenterprise is financially feasible and whether the benefits will justify the effort. While an entire environmental impact assessment is outside the scope of this study, a cost-benefit analysis will reveal the financial benefits along various points of the vermicomposting spectrum including landfill alleviation, income generation, enhanced agricultural productivity, and some indirect lifestyle improvements to small farmers.

While these objectives compose the main structure of this paper, additional considerations will be taken into account. Secondary research will provide a background properly situating the problem in its context. Exploration into the social dynamics of such a technology will shed light on social acceptability within the Lebanese culture. The discussion will follow the sustainability framework, analyzing vermiculture in reference to the three pillars (social, economic, environmental).

CHAPTER 3

METHODS & MATERIALS

3.1 Preliminary Studies

The objective of these studies is to optimize the vermicomposting process. Waste collection systems are one part of the process that is commonly left out of "how-to" manuals and is likely to encounter some social obstacles in Lebanon. Collection data will also shed light on waste quantities per household. The subject of vermicompost models, on the other hand, has been relatively well studied and disseminated, but not for semi-arid, Mediterranean climates such as Lebanon's. Using terra-cotta pots in India, for example, may prevent moisture build-up but this may leave the substrate too dry in the case of Lebanon. For these reasons, it is important to experiment with and refine these processes in order to inform the in-field study and to simplify future vermicomposting efforts.

3.1.1 Waste Collection

Engaging on-campus residents unaffiliated with the project offered some insight towards organic waste separation. Three AUB faculty residences, located in vicinity to the greenhouses where the vermicomposting was being conducted, were targeted for the waste collection study. Emails were sent to each household requesting their participation in the vermicomposting project. Seven households responded positively and they were each given a waste bin in which to collect their kitchen waste. The waste bins held a volume of 11.5 liters, had a lid to contain odors, and had a removable interior compartment, similar to a bucket, which was exchanged each collection day.

A small sheet of paper enumerating the “yeses” and “no’s” was pasted to the lid of each bin in order to remind the family which foods to include and exclude (see Appendix 3). As the bin drop-off on November 29th was the first meeting with the households, each family was briefed on the process and their reactions/confidence subjectively observed. In several cases, the person responsible for cooking and composting was a migrant maid. Each household was given a sheet of paper that summarized the project, detailed the separation process, reiterated what to include and exclude, and provided a reminder of the collection days. The author’s email and phone number was included on this sheet of paper and on the pasted “yes and no” sheet on the lid in the event of any questions or complications. In addition to this, constant communication was maintained via email.

Collection was arranged for every Monday, Wednesday, and Friday. In the event of a holiday, it was moved to the following day. The decision to collect three days a week was intended to prevent the occurrence of odors and/or fruit flies. On each collection day, the participants were asked to place their bins outside their apartment doors in the morning. The collector removed the interior bucket containing the waste and replaced it with a clean one. As such, materials included only 7 bins but *14 interchanging buckets*. The collector filled out a collection chart indicating roughly how much waste was collected each day. The quantities were either “--” indicating that the bin was not placed outside, ¼, ½, ¾, or full. This data was later used to calculate the dynamics of the collection experiment, such as organic waste per family, the overall weight of collected waste, and consumption patterns. All of the waste buckets were carried to the greenhouses, were utilized for the model trials, discussed below, and were then washed. Any excess waste was placed in the greenhouse compost pile for later use on AUB grounds. The daily collection process required approximately 30 minutes.

The collection trial lasted for 6 months, from December 3rd to May 24th, 2013. At the close of the trial, a focus group was organized. This served to discern the participants' personal experiences and to generally gauge the social acceptance of waste separation in Lebanon.

3.1.2 Prototype Experiments

The aim of the model experiments is to identify the prototype that allows the most efficient vermicomposting operation. The guiding criterion was that materials should be easily accessible and affordable. As such, the prototypes included vinyl bags, plastic pots, plastic crates, terra cotta pots, and net-material. Besides the actual containers, several strategies were tested, including the incorporation of shredded paper into the substrate, the incorporation of newspaper layers at the bottom of the crate, and covering the waste with a layer of soil.

Because several faculty members had been casually experimenting with vermicomposting in the past, there was already one large vermicompost bin and a supply of worms that had been collected from the Nahr Ibrahim riverside. Upon two occasions during the experiments, worms were collected from AREC farm in the Beqaa to replenish the supply. Nevertheless, the worm species remained unknown. Research indicates the presence of many earthworm species in Lebanon (see appendix 1), among them *Eisenia* *fetida* (Pavlícek et al, 2003), one of the most renowned species for vermicomposting (Singh et al, 2011; Tripathi & Bhardwaj, 2004). Moreover, an earthworm specialist was sent a photo of the worms for identification and although she could not confirm the species, she suspected that it was *Eisenia fetida* (personal communication, Sandra Yanni). Nonetheless, the worms collected in the Beqaa were found fairly deep in the soil, thereby suggesting that they are an anecic species (deep-burrowing) and not epigeic (litter dwellers) as *Eisenia fetida* is reported to be (Munnoli et al, 2010).

Despite the uncertainty surrounding the species of the earthworms, it was considered of little consequence – the aim of the prototype experiments was to test local earthworms since these are by far the easiest and cheapest to obtain. Earthworms especially suited for vermicomposting can be purchased through the internet but high prices and an unreliable postal system make it prohibitive. More importantly, introducing foreign species may disrupt the local soil ecosystem (Singh et al, 2011).

For each prototype, a certain weight of worms was collected from this “mother bin” and added to the organic waste to commence the vermicomposting process. The prototypes were all tested at AUB’s greenhouses between the months of December and May. The kitchen waste used in the experiments was that collected from the faculty residences. A log was kept to record dates, the quantity of worms, decomposition duration, effectiveness, and other notes of interest.

3.2 Plant Growth Experiments

Despite a plethora of scientific literature proving the plant growth properties of vermicast, this project had to, nevertheless, confirm the performance of vermicast as a high quality potting mix equivalent. Producers could potentially supply vermicompost to Lebanon's horticultural industry so this is a market worth exploring.

3.2.1 Description of Plant Growth Experiments

The plants: Plant growth was tested in tomatoes, cucumbers, arugula, parsley, and peperomia, thereby representing a variety of vegetables and leafy greens and one ornamental. Tomato, cucumber, and peperomia seedlings and arugula and parsley seeds were obtained from a local commercial greenhouse.

The treatments: Four soil treatments were prepared. The first treatment was Florava potting media without any vermicompost. This was labeled 0% and served as the control. The other treatments were mixtures of potting media combined with 5, 15, and 25% vermicompost, and labeled as such. Each treatment was composed of five replications. Therefore, with five different species, four treatments, and five replications each, there were a total of 100 plants. Each seedling was planted in a specific soil substrate in a one-liter plastic pot. In the cases of arugula and parsley, ten seeds were planted in each pot, evenly distributed over the surface.

Maintenance: The plants were arranged in a random block design and kept in AUB's plastic greenhouse. They received no additional fertilization and were watered equally 6 times per week.

Measurements: The growing period for tomatoes, cucumbers, and peperomia was 6 weeks, with observations every 2 weeks. The growing period for arugula and parsley was 8 weeks since they were planted as seeds and needed more time to grow.

Observations were bi-weekly commencing 4 weeks after planting. The parameters measured varied for each species.

- Parsley and Arugula: germination, leaf number, and plant height
- Peperomia: leaf number and plant height
- Tomato and Cucumber: leaf number, plant height, flower number, wet and dry weight of the shoot, root length, and wet and dry weight of the roots

Measuring Methods: Germination, leaf number and flower number were counted by eye and height was measured with a ruler or meter stick. For the shoot measurements, the plant was cut just above the roots and the crown (stem, leaves, fruits) weighed. These parts were then oven dried at 60˚C for 48 hours and weighed. Measuring the roots involved extracting them very carefully from the soil substrate and removing as much soil particles as possible. Ultimately, it proved impossible to remove all the dirt so the root weight readings may be slightly overestimated. The length was measured from the beginning of the roots to the longest strand and wet weight was recorded shortly thereafter. They were then oven dried at 60˚C for 48 hours and weighed again to measure dry weight. There was an error in the process of measuring the shoot wet weight for tomatoes so this data was excluded.

The Potting Media: The potting media used in the experiments is Florava professional planting substrate made by Plantaflor of Germany. It is a "mixture of slightly to medium and more strong decomposed raised bog peat and NPK-fertilizer". The chart below describes its composition, as indicated on the bag.

pH	5-6.5
Salt content	<1,0 g/l
Nutrients	Nitrogen: 50-300 mg/l Phosphate: 50-300 mg/l Potassium: 80-400 mg/l

3.2.2 SPSS Analysis of Plant Growth Responses

Analysis: Growth data was subjected to a one-way ANOVA analysis of variance using Duncan's multiple range test (1%) with SPSS software.

3.2.3 Vermicast: Chemical and Physical Analyses

The substrate of the vermicompost used in these experiments is kitchen waste collected every two or three days from three AUB faculty residences. Participants were asked to exclude meat, dairy products, cooked foods and citrus fruits in order to cut down on smells and avoid an overly acidic substrate for the worms. The vermicast was tested to determine its physical, chemical, and biological properties, all of which took place at AUB's lab facilities. The samples included one control (potting mix) and three vermicast samples (taken after thorough mixing). The following are descriptions of the testing methods:

- pH and Electrical Conductivity (EC):

Each vial, containing 25 grams of substrate and 10 mL of distilled water, were shaken on a shaker for 30 minutes before being left to filter overnight. The soil solution was then measured for pH using a ThermoOrion pH meter (Model 410) while the EC was measured using a ThermoOrion EC meter (145 A+). In each case, the solution was measured twice and then averaged in order to ensure accurate results.

- Soil Moisture Content and Bulk Density:

These two parameters were measured using the "can" method. The empty cans and their lids were weighed. Then, samples were collected, filling each can completely, and were weighed again. The weight of the can itself was subtracted. They were then placed in an oven with the lids off for 24 hours at 105 degrees before being measured a second time. Bulk density was calculated using the following equation:

$$\text{Bulk density} = \frac{Weight\ of\ oven\ dry\ soil\ (g)}{Volume\ of\ soil\ sample\ (\text{cm3})}$$

The percent moisture of the samples *on a dry weight basis* was measured using the following equation:

$$\text{Percent Moisture} = \left[1 - \frac{Weight\ of\ wet\ soil - Weight\ of\ Oven\ dried\ Soil}{Weight\ of\ Oven\ dried\ soil}\right] \times 100$$

There was an error in the moisture calculations for sample 2, so it was not included in the final data table.

- Porosity:

  The porosity of the samples was calculated using the bulk density measurements, inserted into the equation below. Particle density is a given 2.65 g/cm^3.

$$\text{Percent Porosity} = \left[1 - \frac{Bulk\ Density}{Particle\ Density}\right] \times 100$$

- Total Nitrogen and Total Carbon:

  These properties were tested using an Ea 1112 compact analyzer at AUB's core lab. Each sample was weighed using a tin capsule and then placed in the auto sampler. The tin capsule holding the sample falls into the reactor chamber. The material is heated to about 990˚C, at which point it is mineralized. Highly pure helium is used as the carrier gas. After combustion, thermal conductivity detects the nitrogen and carbon contents.

- Phosphorous and Potassium:

  Two replications of one control (potting mix) and three vermicompost samples were collected. Five grams of each were mixed with 50 mL of distilled water and placed on the shaker for half and hour. They were then filtered and the solution collected in an Erlenmeyer flask.

The procedure recommended by Watanabe & Olsen (1965) was used to test the water-soluble phosphorous content of the vermicompost. One mL of the solution was mixed with 19 mL distilled water and 5 mL of ascorbic acid, a reducing agent that it turns blue in the presence of phosphorous. Readings were taken with a Spectrophotometer (Optima SP-300) compared to pre-made standards of 2, 5, 10, and 15 ppm phosphorous. The results from the two replications were then averaged.

For water-soluble potassium, the solution was diluted by a factor of 10 and taken to AUB's core lab for analysis using an Atomic Absorption Spectrometer. The sample is aspirated into an air-acetylene flame and once the molecules are atomized, they absorb light in quantities that indicate the amount of the element present. Again, the results from each replication were averaged.

- Organic Matter:

  Organic matter was measured using the loss-on-ignition method. It involves heating the sample at a very high heat in order to destroy all organic material. A sample of known weight is placed in a ceramic crucible and place in an oven at 600˚C for 2 hours. After cooling in a desiccator, the sample is weighed. The organic matter is calculated as the difference between the initial weight and the post-ignition weight times 100.

$$\text{Organic Matter} = \frac{Weight\ of\ dry\ soil - Weight\ of\ oven\ dry\ soil}{Weight\ of\ dry\ soil} \times 100$$

3.3 In-field Trial

While research and experiments are very informative, it is imperative to put the project into actual practice. Additionally, it is crucial that a trial be conducted outside of the social/academic setting of AUB in a more real-world context, more representative of the targeted audience – rural farming communities. An in-field trial will also reveal the social dynamics at play in a simulated vermicompost enterprise. The project evaluation and feedback from the "entrepreneur" will serve to shape or reshape the microenterprise initiative.

3.3.1 Description of the Trial

The preliminary studies were a necessary step to guide the logistics of the in-field trial. Batloun was selected as the trial village due to a distant connection with a resident there, which provided a social entry point into the community. Maysan, a senior citizen of Batloun, agreed to participate in personally conducting a vermicompost operation in her backyard. A payment of $100 per month compensated her time and effort invested in the project. On May 30th, she received a delivery of all of the necessary materials including:

- 70 plastic crates
- A role of recycled lint material
- 10 trash bins
- A supply of worms and a measuring cup for estimating the quantity
- Hand-held shovel

- Plastic gloves
- Scissors (for cutting the lint material)

Maysan was told about the goals of the project and was given thorough directions for how to set up and maintain a vermicompost box. In addition, she was given printed directions, in Arabic (see Appendix 4). Another Batloun citizen contributed her translation skills and also served as Maysan's contact for the first few weeks of the project when she needed the most support.

The training and directions were intended to offer Maysan a solid foundation for how to proceed. She was informed, however, that the goal of the project was to find a system that suits her, the theoretical microentrepreneur. She was to start out following the guidelines, but was free, and even encouraged, to adapt it to her needs. The essence of this trial was not to see if rural farmers could reproduce our model, but to see how it could be tailored to better fit their lifestyles.

Maysan collected her family's kitchen waste, along with that of four other families. She prepared the crates, filled them with waste, added the worms, and monitored the contents as they decomposed. The trial took place from July to November, 2014. Beginning November 2nd, the oldest boxes were harvested. This involved laying out a large sheet of plastic, scooping out the contents of the box onto it, and sorting the vermicast. Worms and eggs were placed back in the "mother box" while larger and

Harvesting with Maysan's granddaughter

more durable organic components, such as twigs and peach pits, were removed. Some of the casts were then given to Maysan for use in her garden while several loads were brought back to the AUB greenhouses.

The author observed the evolution of the vermicompost on a weekly basis between October 6th and November 30th. To quantify the conditions inside the crates, a 1-5 rating system was developed in which 1 indicates no decomposition and 5 indicates total decomposition. During each visit, each crate was opened, examined with a small shovel, and was given a rating. Observations of a particular crate ended once it reached 5. In this way, vermicomposting progress could be numerically illustrated. (Indexes to measure compost evolution exist, but require technical measurements. For example, compost *stability* is related to its resistance to further rapid degradation based on respiration rates while compost *maturity* is related to the C:N ratio (Nair et al, 2006; Tognetti et al, 2007). For the purposes of this study, however, a measuring system based on a rapid visual assessment was deemed more appropriate.) See Appendix 6 for photographic descriptions of the rating system.

To formally analyze the decomposition process, a one-way ANOVA regression analysis was performed using the compiled observation data. This also served to identify the average amount of time needed for kitchen waste to be entirely converted into casts.

In order to understand the less tangible assets Maysan gained throughout her engagement with the project, the skill sets that she acquired were compiled in a table and categorized as technical skills, social skills and economic skills.

Lastly, a qualitative interview was conducted on October 26th, in which Maysan discussed the procedures of vermicomposting, what troubles she encountered, what techniques she developed in response, and her own personal perspective of vermicomposting. Using Maysan's input and personal observations, ways to improve the process are proposed and discussed.

3.3.2 Statistical Analysis of Batloun Trial

The weekly ratings of Maysan's vermicompost crates verify and describe the evolution of the organic waste into vermicast. Nevertheless, a formal analysis is needed to accurately interpret the relationship between waste conversion and time.

The data was analyzed through STATA software using an ordered logit regression model. This model was chosen because it predicts the probability that the waste material is in each of the five conversion stages in relation to the number of days that have passed. For example, after five days have elapsed, the material inside the crate has a 71% chance of being rated 1, a 22% chance of being rated 2, etc. As such, the model illustrates the progression of the material from solid organic waste to pure vermicast as represented by the five ordinal stages.

The regression model was initially specified as a linear function of the number of days elapsed but because research indicates two stages - rapid decomposition and slow decomposition (Jack & Thies, 2006)- it is unlikely that the conversion rate remains constant over time. As such, a *piece-wise* linear model was tested as a better means to describe this process. This model introduces a cut-off value of 50, thereby separating the data into days 1-50 and 50-150. This model shows that the response is linear but with a slope that varies in the two intervals. It was found that incorporating the cut-off value was an effective way of capturing a more precise conversion pattern. A likelihood ratio test was performed to justify this preference for the second model specification and it revealed that, indeed, it was a significant improvement in predictive power (P-value < 0.01) compared to the original linear form.

	Linear			**Piece-Wise**		
Variable	Coefficient	Stand. Error	Z	Coefficient	Stand. Error	Z
Day	.1018	.0095	10.71	-	-	-
Day 1(1-50)	-	-	-	.2009	.0218	9.21
Day 2 (50-150)	-	-	-	.0440	.0098	4.48
Cutoff 1	.3747	.3380	1.1086	1.9077	.4709	4.0512
Cutoff 2	1.5824	.3257	4.8572	3.6374	.5278	6.8916
Cutoff 3	3.5313	.4016	8.7931	6.6632	.7870	8.4698
Cutoff 4	5.9092	.5701	10.3652	9.6382	1.0128	9.5164
# of obs	282			282		
Log Likelihood	-182.73925			-162.42188		
Pseudo R^2	0.4558			0.5163		

Table 7: Likelihood Ratio Test

The Pseudo R^2 value increases substantially from the linear model to the piece-wise linear model. This suggests that the incorporation of the cut-off value is a significant improvement.

Appendix 7 shows the weekly observations while appendix 8 shows the probabilities generated by the piece-wise linear model, the averages of which were used to create a graph illustrating the predicted conversion rate.

3.4 Cost-Benefit Analysis

Confirming the technical and social potential of vermicomposting is important but an economic analysis will ultimately determine if this technology will be embraced. A social (both public and private) cost-benefit analysis of vermicompost production and consumption will attempt to quantify the benefits and reveal profitability.

3.4.1 Identification of Variables

This cost-benefit analysis is not comprehensive. The sectors considered are based on available data and immediate impact. These are the landfill, the microenterprise, and the farm.

By assuming the use of organic kitchen waste in the vermicompost process, a certain quantity of organic waste is diverted from the waste stream. This works to the benefit of the landfill where the waste would otherwise end up, and to the advantage of the government who pays the sanitation companies (Sukleen and Sukomi) for their services or the local municipalities that manage waste directly. The organic fraction of a landfill is particularly undesirable for reasons of general site disamenity (odor, pest attraction), the high moisture content and leachability, the tendency to harbor harmful pathogens and disease vectors, and gas emissions resulting from decomposition (Clarke, 2000; Furedy & Pitot, 2002). Vermicomposting contributes, therefore, to diverting waste from the landfill and reducing its environmental disamenity.

Vermicomposting, as a small-scale enterprise, has been reported to be a profitable, part-time activity (NABARD, 2007; Shivakumar et al, 2009). In India, for example, one analysis revealed a cost-benefit ratio of 3.44, calculated using a discount rate of 12%, and remained desirable after applying a sensitivity analysis accounting for hikes in production costs and decreases in vermicompost price (Shivakumar et al, 2009). The attractiveness of a vermicomposting enterprise lies in the fact that the production costs are minimal (this technology, at least on a small-scale, is very low-tech and can be implemented with everyday materials and supplies).

The last, and perhaps most significant sector for vermicompost revenue, is agriculture. Vermicompost has been shown by a host of studies to boost agricultural production and enhance farm conditions. The aspects considered within the framework of this analysis will include higher yields (in which vermicompost *outperforms* traditional fertilizers), pest suppression, and greater water retention of the soil. Additionally, the savings from discontinuing the use of pesticides and fertilizers will be included, as well as the costs incurred by acute poisonings due to pesticide exposure.

3.4.2 Preliminary Studies

The economic study begins by quantifying the (indirect) benefits of vermicomposting at the landfill level. This is calculated per ton of vermicompost produced. Understanding the financial dynamics of the vermicompost microenterprise requires an initial micro cost analysis. This analysis estimates the investment costs and the price of vermicompost in order to calculate the net returns to the producer. In the absence of a vermicompost market in Lebanon, the price of vermicompost is assumed to be $150 per ton.

The last sector – agriculture – requires an initial small-farmer profile to understand annual expenses on variables such as pesticides, fertilizers, and irrigation. These expenses are then multiplied by the benefits associated to vermicompost (for example, 6% reduced irrigation requirements) to generate the additional financial gains and savings that can be expected.

Benefits on the farm are found to be the greatest but also the least predictable. For this reason, the on-farm impact is explored in greater detail through a discussion of application rates, a cost-benefit ratio, an examination of alternative scenarios, and a final cash-flow scheme, all of which are intended to test the robustness of the analysis.

Once the three individual sectors (landfill, microenterprise, and farm) are examined, they are combined to generate a *social* cost-benefit analysis. This is intended to elucidate the overall impact of the production and consumption of one ton of vermicompost.

CHAPTER 4

RESULTS

4.1 Preliminary Studies

4.1.1 Waste Collection Trial

4.1.1.1 Description of Participants

Upon bin-delivery to each household, the author tried to subjectively observe their comfort level and previous experience. The following is a description of each participating household.

- **The S Household**: American-Lebanese couple

  The S's are the only participants that currently compost, taking their waste to their house in the mountains. Mrs. S admitted that she would like to have been able to compost citrus but agreed that she would bring her citrus waste with her to the mountains instead. She seemed cheerful, confident, knowledgeable, and not inconvenienced.

- **The L Household**: American couple

  The L's had not personally composted before, but were familiar with the idea. Mrs. L seemed slightly hesitant with the composting process, but this may be accounted for by her soft-spoken personality. They became enthusiastic composters, however, expressing their appreciation of the project, asking numerous questions in regards to which foods could be included, and once even filled the waste bin and another plastic bag with kitchen scraps.

- **The M Household**: American couple

  While not having personally composted before, the M's welcomed the idea as a fun learning experience for their two children. Communication with the family was minimal, except once when Mrs. M requested that the "yes & no" label on the bin to be translated into Arabic so that her maid would be able to participate.

- **The A Household**: American couple (with Colombian origins)

  After sending out the request for participation emails, Mrs. A was the first to respond – her husband had forwarded her the email and she contacted the author immediately saying that she used to compost back in Vermont and has been looking for ways to compost here in Lebanon, in vain. She *insisted* on being part of the project. Mrs. A is, by far, the most enthusiastic of the participants. In anticipation of the family's absence during the Christmas holidays, she offered the services of her downstairs neighbor, an avid gardener, to replace their collection for these few weeks. She constantly praised the project and it was in response to her request that the participants were sent occasional updates regarding the project's progress. She even directed a friend of hers, another faculty resident, to get in touch and offer her services. The offer was appreciated, but the quantity of compost collected each week was more than sufficient.

- **The C Household**: Lebanese

  Interaction with the C family was minimal as it was their maid who was in charge of separating the kitchen waste. She said that she was familiar with composting and had past experience.

- **The N Household:** Lebanese

  Other than the face-to-face introduction at the beginning of the project, from which Mrs. N seemed to be enthusiastic, most interaction was via the two maids that handled the compost bins.

- **The J Household**: Lebanese

  Similar to the N's, Mrs. J was very friendly and happy to participate in the project, but it was the maid that handled the waste separation.

<u>4.1.1.2 Collection Analysis</u>

Waste collection occurred between the dates of December 3rd and May 24th. During this 173-day span, waste was collected 65 times. It should be noted that one family (C), stopped participating on February 27th, about halfway through the project. The reason was due to kitchen remodeling that left no room for the waste bin to fit into the cupboards. Table 8 below compiles all of the collection data.

(The kitchen waste per household per day was calculated by dividing the total kitchen waste per household by 173 days of the project. Kitchen waste per person per day was calculated by dividing the per household figure by the household size).

The table shows that the average quantity of kitchen waste generated per *household* was 372 grams per day, which yields an average of 107 grams per *capita* per day. This figure is significantly less than the 420 grams per capita per day average sited by Sukleen (personal communication, Steven Chebaclo, Sukleen). Most likely, the difference arises because the participants were asked not to include cooked foods, citrus, meat, and dairy, which will naturally decrease the true quantity of waste generated per day.

Household	**Kitchen Waste/household per day (g)**	**Household Size**	**Kitchen Waste/person/day (g)**	**Total Kitchen Waste/household (kg)**
A	493	3	164	85.34
L	547	4	137	94.64
J	278	5	56	48.17
S	259	2	130	44.79
M	508	4	127	87.88
N	313	6	52	54.08
C	418	5	84	35.49
Average	372		107	69.15*
Total	2,603			450.39

Table 8: Waste Collection Data

*excluding the C household

4.1.1.3 Waste Generation Patterns

The size and scale of vermicompost operations are largely dependent on the anticipated waste load. Table 8 estimates the average amount of kitchen waste generated per Beiruti family. However, since consumption patterns are seasonally influenced, it is important to try to predict any changes. Figure 5 below attempts to illustrate this relationship and though it is limited to the project's six-month period (and not the whole year) it suggests that there is no correlation between season and the generation of kitchen waste.

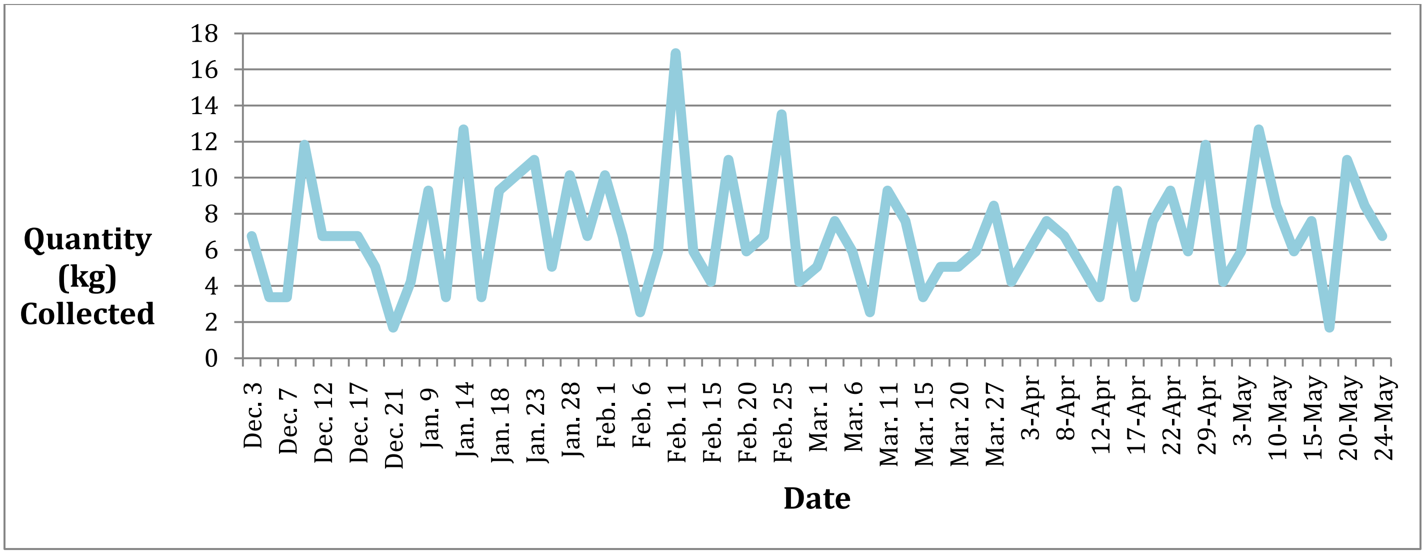


Figure 5: Waste Generation Patterns

4.1.1.4 The Focus Group

Despite all seven of the participants being invited to the focus group meeting, only three households were present – the M's, the S's, and the L's. Each family was asked if, previous to the project, they were familiar with composting and/or vermicomposting. All of them were familiar with composting, having personally composted or known people who did so regularly. They were all unfamiliar with vermicomposting. When asked about their experience during the past six months, they all responded positively. The only disappointment was that citrus fruits, consumed en masse in Lebanon, could not be included in the waste bin. When asked whether *three* collection days per week were sufficient, it was mentioned that twice a week, or even once, would have been adequate. They asserted that odors and insects never posed a problem, except for the S's who had issues with ants. They pointed out, however, that ants have always been a problem for their building. The S's were even impressed with the lack of odors, having left their waste bin in their kitchen for a stretch of time. The families could think of no recommendations to improve the process. A recurring theme throughout the discussion was that now, having had “a taste of composting,” they would like the service to continue. They unanimously agreed that AUB should develop a composting system for the faculty residences, even if the residents were required to deliver their waste to the greenhouse area themselves.

The focus group yielded important information. It revealed that there is, not only willingness, but also a desire to compost. This suggests that the idea may be a novel one, but that people respond positively to the concept of keeping organic waste out of the landfill and putting it to good agricultural use. These findings challenge the presumption that behavioral changes will be an obstacle in soliciting people’s participation in waste separation. Secondly, the participants’ responses confirmed the effectiveness of the pilot collection system. Even the family that dropped out of the project did so not because of negative experiences, but due to extenuating technical circumstances.

While these responses reflect positively on waste separation, they can hardly be considered representative of the population at large. First of all, conclusions cannot be based on feedback from just three of the seven participating households. Had more families come to the meeting, the results would have been more credible. Secondly, it could easily be argued that the biased selection of participants will yield biased results. The AUB community represents educated individuals well acquainted with ecosystem concepts and economically equipped to hand over their organic foodstuffs. Their willingness to participate, their comfort in handling kitchen waste, nor their consumption patterns should be considered at all reflective of the typical Lebanese household. Lastly, when reading the profiles, the *international* composition of the households becomes glaring. This again undermines attempts to make generalizations regarding social acceptance and eating habits within Lebanon.

That said, the findings from the focus group did indeed contribute to the aim of the project. These participants personally tested our pilot system and gave it their "stamp of approval." This served to confirm the waste collection system that would be used in the following step – the in-field trial in Batloun. It was also revealing that of the 60 faculty members contacted for their participation, only seven responded. There are many different reasons why the acceptance rate was so low, such as time constraints, but it does hint at a social stigma towards keeping and handling waste in one's home. Furthermore, the "enthusiasm" of the international community for composting activities accentuates the hesitation on behalf of the Lebanese community. This confirms the hypothesis that vermicomposting will encounter social stigmas in Lebanon.

4.1.2 Prototype Experiments

4.1.2.1 Prototype Descriptions

This experimental stage of the project was performed at the AUB greenhouses between December 7th and May 28th and used the waste from the faculty residences as a substrate. Seven different models were tested. These included:

- Nylon Bags
- Plastic pot
- Lint-lined crate x3 (description below)
- Cotton-lined crate (description below)
- Hanging bag with screen material (description below)
- Small crate lined with screen material
- Terra Cotta Pot

Crates are the plastic containers typically used to transport fruits and vegetables in Lebanon

The lint material used in these experiments is made from 100% post-consumer recycled cloth and textiles. In Lebanon, the material is used produced in sheets, rolled like a carpet, and is used in the “moving industry” to protect furniture from being damaged during transport.

The cotton material is that used at the greenhouses during scientific experiments to protect plants from insects. It is soft and thin, but hard for insects to penetrate.

The screen material is that used to cover several of AUB’s former greenhouses. It is plastic in texture and is slightly more ridged than the cotton material.

4.1.2.2 Prototype Results

- Nylon bags as a vermicomposting model were not successful. Each bag contained a week's worth of kitchen waste and 125 grams of worms. Despite the perforations made in the bags for aeration, the substrate became very odorous, as if it was decomposing anaerobically. Also, the lack of drainage meant that the substrate was significantly too moist for the earthworm habitat. Later trials even included egg carton containers at the bottom of the bag to help absorb excess water, to no avail. Fly infestation was another problem.

- Several plastic pots of different sizes containing 1, 2, and 3 kg of waste, 50 grams of worms, and a handful of dirt. Each pot had several holes in the bottom for drainage. They each became infested with fruit flies so they were covered and sealed with the screen material. The substrate became very odorous and most of the worms died. The contents of the 1 kg plastic pot were recovered, placed in a new plastic pot and mixed with shredded paper and fresh waste at the following ratio:

- 3: paper
- 2.5: old compost
- 4.5: new compost

Despite being covered with the screen material, the substrate was nevertheless infested with flies. After two months, the contents were harvested yielding 7 grams of worms and 522 grams of decomposed/rotten compost/castings. While conditions of this prototype were not ideal, it was slightly more effective than the nylon bags.

- The crate lined with lint material was found to be a success. The contents contained a 7:3 ratio of compost to paper and 50 grams of worms. During monitoring, the substrate was found to be dry so it was occasionally sprinkled with water.

  The lint seems to regulate the moisture, allowing excess water pass while providing a moist, layered habitat for the worms. Also, the lint is about two centimeters in thickness so it is probably providing much needed warmth to the worms during the winter season. On March 27th, the crate was harvested, yielding:

- Worms: 39.44 grams (down from the original 50 grams, so some must have migrated)
- Castings weight: 202.71 grams
- Undigested left-overs: 52.67 grams (this is composed mainly of bits of paper, seeds, eggshells, sticks, and fuzzy cotton from the lint material)
- The empty crate weight: 1 kg

- The cotton-lined crate was also successful. Kitchen waste and shredded paper were placed in the center of a piece of cotton sheet at a 7:3 ratio, along with a handful of dirt and 50 grams of worms. The cotton sheet was then collected, completely "encapsulating" the waste inside, and the ends tied with a rubber band to prevent the infiltration of insects. It was then placed in a small plastic crate. The model weight 1.5 kg. Because the contents are exposed to the air from all sides, they had a tendency to dry out, so water had to be added to keep them moist. There was no smell and very few flies. It was harvested on April 12th, yielding:
    - Worms: 11.25 g
    - Undigested left-overs: 115.67 g
    - Castings: 122.02 g

- The hanging vermicompost bag concept arose out of the concern that insects were invading and worms escaping when prototypes sat on the ground. The "bag", made of out screen material, was filled with waste at shredded paper at a 7:3 ratio, 50 grams of worms, and a handful of dirt. It weighed 2.5 kilograms and was hung on the inside wall of the greenhouse. One concern is that the prototype is very exposed to the light, which the worms don't like. All of the previous experiments were at least semi protected from the light. Similar to the cotton-lined crate, the contents dried quickly so it had to be constantly moistened. The waste included an onion, which resulted in very bad smells. It might be best to exclude onions for the list of acceptable food scraps. There were few flies. Ultimately, the contents were too dry and all the worms died, bringing this trial to an end on March 22.

- A small crate was lined with screen material and the edges were stapled so that it fit tightly. Waste and moistened shredded paper was added at a 7:3 ratio, 50 grams of worms, and a handful of dirt. The contents were then covered with a sheet of lint material that fit over the top of the crate. After several weeks, however, the waste had attracted a lot of flies and many of the worms had either died or had migrated. Even though this system provided aeration, drainage, and warmth from the lint cover, it was deemed a failure. The repeat of this prototype, however, was a success. This time, 70 grams of worms were added and the model weighed 2 kg. The contents were very dry throughout the trial, necessitating constant watering. The harvest yielded:

- 15 grams of worms
- 381 grams of vermicompost
- 43 grams of undecomposed material (shells, pits, etc)

It was noted that there were no flies and no odors.

- The terra-cotta pot experiment did not yield successful results. Terra-cotta is interesting because it is capable of regulating moisture content. Waste and shredded paper, at a ratio of 7:3, were added, along with 70 grams of worms and a handful of dirt. The pot was then covered and sealed with screen material for pest protection. Surprisingly, the contents dried out very quickly and despite water being added occasionally, all the worms died or migrated.

4.1.2.3 Methodology Results

- The shredded paper used in the experiments was sourced from AUB's paper shredder. The test involved two plastic pots, each containing 1 kg of fresh waste and 40 grams of worms. Paper was added to one pot at a 7:3 waste to paper ratio. Each pot was then covered with screen material. It was observed that, ironically, the pot with shredded paper seemed wetter. After two and a half months of decomposition, the harvest yielded:

  With Paper:

  - Worms: 11.5 g
  - Undigested left-overs: 94.9 g
  - Castings/digested material: 106.37 g

  The castings seem to be of poor quality, as if they are half castings and half rotten food.

  Without Paper:

  - Worms: 33.78 g

- Undigested left-overs: 110.98 g
- Castings: 174.99 g

The castings from the "no-paper" pot are of very good quality, at least visually.

- A small crate lined with screen material was prepared. Before adding any substrate, five moistened sheets of newspaper were laid horizontally at the bottom. Waste (7:3 ratio), 50 grams of worms, and a handful of dirt were added and then covered by a square of lint material. Throughout the studies of worm behavior and habitat, it became apparent that worms like to wedge themselves between layers. Adding the moist newspaper sheets at the bottom of the crate might provide a favorable "home" for them, away from the feeding location. Contrary to the hypothesis, however, most of the worms migrated from the crate.

- Given consistent problems with fruit flies, the idea of covering the waste with a layer of soil arose as a potential mitigation measure. A crate lined with screen material was filled with waste and 70 grams of worms. Throughout the weeks, the contents dried out and had to be consistently moistened. However, there was never any odors or flies.

<u>4.1.2.4 The Best-Fit Prototype</u>

The model that emerged as the best fit for vermicomposting was the lint-lined crate. All of the prototypes in which the waste was held in the highly aerated screen or cotton mesh material dried out. Almost all of the prototypes involving non-breathing nylon bags or plastic pots, even terra cotta, seemed to hold too much moisture. The lint material is ideal because it holds moisture without permitting standing water, and it creates an ideal habitat for the worms – dark, layered, moist, and warm. Additionally, adding shredded paper and newspapers along the bottom did not seem to enhance the bin environment. Adding a layer of soil on top of the waste, however, was effective in keeping the odors down, drawing less flies, and it provided the grit that the worms need in their gut to properly digest their food.

Based on these observations, the last trial was the perfected lint-lined crate. A small crate was lined with lint material and then filled with fresh kitchen waste and 90 grams of worms. The contents were slightly moistened. The crate and the lining were weighed in advance (1 kg) and once filled, weighed 2.75 kg. Therefore, 1.75 kg of waste, including a small portion of soil took 90 grams of worms three weeks to digest. The harvest yielded approximately 1 kg of vermicast.

In conclusion, the prototype in the above photo was deemed to be the best. Waste should be introduced and then covered with a thin layer of soil, just enough so that the waste surface cannot be seen. Cover with a fitted lint square for shade and warmth. Periodic check-ups are necessary to monitor the moisture. This is the prototype used in the in-field trial in Batloun, described in the section 3.3.

4.2 Plant Growth Experiments

4.2.1 SPSS Plant Growth Experiments

Tomatoes, cucumbers, arugula , parsley, and peperomia were grown in potting media substituted with 0% (control), 5%, 15%, and 25% vermicompost. A one-way ANOVA analysis revealed that about half of the growth parameters were influenced significantly. In all of these cases, higher quantities of vermicompost were associated with significant *improvements* in these growth parameters except root dry weight for tomatoes, which responded negatively. The other half yielded insignificant changes. However, because the aim of this experiment was to see if vermicompost could replace portions of potting media without detriment to the plant, insignificance confirms that it could, up to a substitution rate of 25%. Table 9 shows the results (all significant values are significant at $P \leq 0.05$ except those indicated in blue which are significant at $P \leq 0.1$).

	VC content			
	0%	5%	15%	25%
Arugula				
Germination	NS	NS	NS	NS
Plant Height	5.838[a]	10.516[b]	13.087[c]	13.047[c]
Leaf Number	35.200[a]	52.600[ab]	53.071[ab]	58.000[b]
Parsley				
Germination	4.400[a]	5.733[b]	5.400[ab]	6.467[b]
Plant Height	7.484[a]	12.985[b]	15.921[b]	13.990[b]
Leaf Number	23.800[a]	54.200[b]	69.700[b]	70.600[b]
Peperomia				
Plant Height	NS	NS	NS	NS
Leaf Number	NS	NS	NS	NS
Cucumber				
Plant Height	NS	NS	NS	NS
Leaf Number	8.400[a]	8.350[a]	10.200[b]	10.050[ab]
Flower Number	NS	NS	NS	NS
Shoot Wet Weight	NS	NS	NS	NS
Shoot Dry Weight	NS	NS	NS	NS
Root Length	NS	NS	NS	NS
Root Wet Weight	NS	NS	NS	NS
Root Dry Weight	NS	NS	NS	NS
Tomato				
Plant Height	NS	NS	NS	NS
Leaf Number	9.150[a]	10.550[ab]	11.850[b]	11.450[ab]
Flower Number	.800[a]	.733[a]	2.133[b]	.467[a]
Shoot Wet Weight	53.0200[a]	63.6200[ab]	76.2000[b]	71.3800[b]
Shoot Dry Weight	NS	NS	NS	NS
Root Length	NS	NS	NS	NS
Root Dry Weight	1.3000[ab]	1.9000[b]	2.7800[b]	.2400[a]

Table 9: Results of one-way ANOVA analysis

For arugula , the data yields seemingly contradictory information. Plant height increases significantly with 5% and 15% vermicompost proportions, but does not change significantly with 25%. Leaf number does not increase significantly with any proportion *until* 25%. This begs the question if perhaps a 20% proportion of vermicompost would bring about the best improvements.

Arugula
From L to R - 25%, 15%, 5%, 0%

For parsley, both 5% and 25% generated greater germination than the control, though 15% did not have a significant influence. Vermicompost significantly improved parsley height and leaf number in all cases, but with no difference between proportions. As such, the best growth response for parsley was achieved with 5% and 25% vermicompost.

Peperomia did not respond significantly to any vermicompost proportions. This may be because peperomia is an especially slow-growing species (Richards et al, 1986) and perhaps the 6-week growing period was not long enough to observe significant changes.

In the case of cucumber, only vermicompost at a 15% dosage positively influenced the leaf number relative to the control. All of the other parameters showed no significant change in the presence of vermicompost. Thus, for this plant, a vermicompost proportion of 15% seems to be best in terms of maximizing leaf number.

In tomatoes, only vermicompost doses at 15% significantly improved leaf and flower number while doses at both 15% and 25% significantly improved the shoot wet weight. Interestingly, the root dry weight in a 25% dose of vermicompost decreased significantly in comparison to 5% and 15% doses, but not to the control. Although the root weights in this experiment were slightly flawed due to complications in removing the soil, these results insinuate that potting mix with 25% vermicompost is unsuitable for tomato cultivation but that a 15% dose is ideal.

These findings are revealing for several reasons. First of all, they confirm that the vermicast of local Lebanese worms performs similarly to commercial potting media that contains compost and synthetic NPK. Since the species of the worms used for vermicomposting are unknown, it is important to confirm that the vermicast they produce will promote plant growth. This study shows that substituting fertilized commercial potting media with 25% vermicompost is possible without detriment to the growth of these five plant species.

Secondly, the current findings correspond to those of Zaller (2007) in that the increase in growth *does not* correlate with increasing vermicompost amendment, as is usually the case in other studies (Singh et al, 2008; Manivannan et al, 2009; Parthasarathi et al, 2008). In the current study, for example, parsley germination increased significantly with 5% and 25% vermicompost, but not with 15%. The lack of a clear relationship between vermicompost proportions and growth response suggests that it is not only the chemical and physical properties of vermicompost that are stimulating growth, but indirect effects such as pathogen inhibition, microflora populations, or plant growth regulators that override nutrient effects alone (Zaller, 2007).

Thirdly, it is important that vermicast maintained or improved growth across a variety of species - two vegetables (cucumber and tomato) and two leafy greens (parsley and arugula) that are prominent in Lebanese cuisine, and one ornamental (peperomia). These findings suggest that vermicompost use could be extended to a number of other species.

Most plant growth experiments add mineral fertilization throughout the growing period to supply needed nutrients (Atiyeh et al, 2000; Edwards et al, 2010). Although the growing period was short (6 weeks) for the tomatoes, cucumbers, and peperomia, the results indicate that vermicompost and potting media *together* offer a well-balanced composition of nutrients and no further supply seems to be required.

Lastly, it is very interesting to consider the specific cases of arugula and parsley. Similar to the other three plants, the results show that an initial supply of nutrients, via vermicompost and potting media, is enough to carry them through a whole growth cycle without further supply. (It could be argued that because arugula and parsley enjoyed a longer growing period - 8 weeks as opposed to 6 - that these plants had more time to respond positively). Additionally, the significantly improved leaf number, flower number, shoot, and root weights of tomatoes and cucumbers is relatively inconsequential, as these parts do not contribute to yield (i.e. are not consumed). Significant improvements in average height, leaf number, and germination in the leafy greens are extremely relevant as these parameters are directly related to yield. As such, these results suggest that substituting potting media with 5%, 15%, and 25% vermicompost significantly improves *growth and yield* of parsley and arugula . Moreover, they both showed drastic improvements visually, thereby suggesting that quality may be another parameter

Parsley
Bottom to top: 0%, 5%, 15%, 25%

positively related with vermicompost.

The results highlight several recommendations for further study. Future plant growth experiments should investigate the effects of higher proportions of vermicompost. The results of the current study prove that doses up to 25% of vermicompost are possible, but begs the question of how plants would respond to higher quantities. As such, no sweeping conclusions can be drawn regarding vermicompost substitution in peat media. Furthermore, this study focused on growth, but a longer growing period would allow observations of fruit yield and quality for crops. Finally, much evidence points to biologically stimulated plant growth, so it would be revealing to measure the microorganism populations in vermicompost-amended soils.

4.2.2 Vermicast Sampling Results & Discussion

The following Table shows the results of the vermicast tests. Note that the control is Florava Potting Mix containing decomposed peat and synthetic nitrogen, phosphorous, and potassium. As a reference, the composition data in grey represents the findings of another study from India, as well as two sets of standards as a reference. Munnoli et al, (2010) propose the ideal vermicompost composition while Lléo et al (2012) combine a number of standards from compost regulations in Spain and the Compost Quality Council of California).

Property	Control	VC 1	VC 2	VC 3	Seenappa (2011)	Munnoli et al (2010) ideal composition	Compost Quality Standards (Lléo, 2012)
pH	4.51	5.91	6.47	4.86	7.30	7-8.5	6.5-8
EC (mS)	7.71	7.12	7.21	7.17	-	-	≤6
Moisture (%)	90.2	98.43	-	96.6	40	15-20	30-40
Bulk Density (g/cm^3)	0.12	0.20	0.21	0.19	-	-	-
Porosity (%)	95.47	92.45	92.08	92.83	-	-	-
Total N (%)	0.47	1.52	1.44	1.38	1.78	1.5-2.0	-
Total C (%)	21.3	39.6	38.4	38.5	18	20-30	-
C:N ratio	45:1	26:1	27:1	28:1	15:1	15 – 20:1	-
Potassium (%)	0.06	1.40	1.63	1.74	0.60	1-2	-
Phosphorous (%)	0.07	0.07	0.08	0.09	0.54	1-2	-
Organic Matter (%)	71.29	53.74	57.80	56.38	31	-	>35

Table 10: Vermicompost Composition with References

The physical and chemical analysis of the vermicompost is a more thorough means of determining its value as a soil amendment. Firstly, it is clear that the vermicompost made and used in this project has a lower pH than the other studies. The reasons for this are unclear, given that acidic citrus fruits were excluded from the waste. It is possible that coffee grounds, tea bags, and onions, all acidic, were collected in such quantities as to bring down the pH of the vermicast. This premise, however, is contradicted by Singh et al (2005) who found that vermicompost was brought more or less to neutral despite the initial pH of the feedstock. On the other hand, it could be argued that these low pH readings may not satisfy the criteria presented here, but could be an added advantage for Lebanon's alkaline soils (MoE, 2001). In addition to the pH being particularly low, the EC was slightly high. Again, the reasons for this are unclear, but this parameter should be closely monitored in the future as very slight increases in EC can cause significant stress to plants (Gardiner & Miller, 2004; Jack & Thies, 2006).

The moisture content of vermicompost is clearly much higher than recommended, but this is relatively inconsequential as it can be dried easily over a short period of time. The bulk density and porosity of the vermicompost and the potting media were nearly equivalent.

The bulk density measurements of the vermicompost correspond to typical potting mixtures. Plants grow best in soil densities below 1.4 g/cm^3 so the vermicompost, with an average bulk density of 0.2 g/cm^3, is sure to improve compacted soils for better root penetration and aeration. Porosity measures a material's void spaces. It typically increases as particle sizes decrease. The findings above suggest that vermicompost has a porosity of 92%, very similar to the porosity of the potting media. Like bulk density, a porous soil amendment will promote drainage and aeration (Gardiner & Miller, 2004).

The nitrogen content of the vermicompost is equal to, or just slightly lower, than the standards while the carbon content is greater. These properties produce a C:N ratio that is higher than ideal, suggesting that the vermicompost was not especially well decomposed. Organic matter with ratios in this range supply sufficient nitrogen for microorganisms to feed on, but do not leave much for plant use (Gardiner & Miller, 2004). It is possible that the C:N ratio of the vermicompost can be decreased if it is allowed more time to decompose (Singh et al, 2011).

The potassium content of the vermicompost fell within the range of ideal composition and was considerably higher than the potassium content of the potting media. Phosphorous content, on the other hand, was surprisingly low compared to the ideal composition, but was equal to the phosphorous content of the potting media control. Lastly, the vermicompost has a high organic matter content, well above the minimum stipulated by the standards.

In conclusion, the vermicompost produced through the trials at AUB does not meet all the standards of an ideal soil amendment. Some parameters, such as moisture content, are of less importance. Other properties, notably low pH and high EC, may be of concern and the causes should be further investigated. The findings of this study suggest that further testing on variables such as substrates and decomposition time is needed in order to fine-tune vermicompost composition. Nonetheless, this study reveals that in a number of cases, the properties of vermicompost are *superior* to Florava potting media. Vermicompost has a more desirable pH, slightly lower EC, higher nitrogen and potassium content and a better C:N ratio (though these improvements were not tested for significance). This explains, to some extent, the improved growth of plants in potting media amended with vermicompost.

4.3 In-field Trial

4.3.1 Description of Batloun

Batloun is a typical rural village and was chosen as the site of the in-field component of this project thanks to community connections and a climate conducive to summer/fall vermicomposting activities. The village is located in the El Shouf Caza, on the western slopes of Mount Lebanon. It covers an area of 3.5 km^2, is at an average altitude of 1,080 meters, and is approximately 40 km from Beirut. The area is composed of steep slopes, rocky outcrops and cliffs. The climate can be characterized as moderate with dry summers and winters of snow and intense rainfall. The population of Batloun is estimated at 3,500 though about 38% of villagers reside outside the village (Rachid, 2007).

The vermicomposting project took place between July and November. Figure 6 shows the average temperatures during this span.

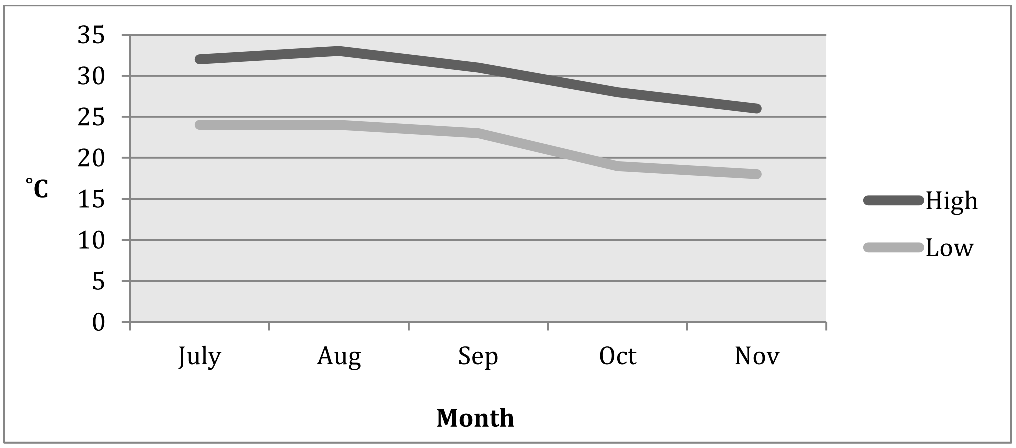


Figure 6: Average Temperatures in Batloun (July – November 2013)

4.3.2 Statistical Analysis Results

While the on-campus trials were useful for developing the individual prototype, the Batloun trial presented the first opportunity to formally implement it as a functioning system. Simple, hand calculations could have yielded a general pattern describing conversion patterns but an ordered logistic regression analysis is a more sophisticated means of analyzing the data and predicting a model that is both parsimonious and predictive. Because the observation period (Oct-Dec) spanned only half of the trial period (July – Dec), a regression analysis also helps account for these data imbalances. Overall, a regression analysis legitimizes the results of the trial and confirms the success of the prototype, the local Lebanese worms, and the suitability of the Batloun climate. The findings are illustrated in the Figure 7.

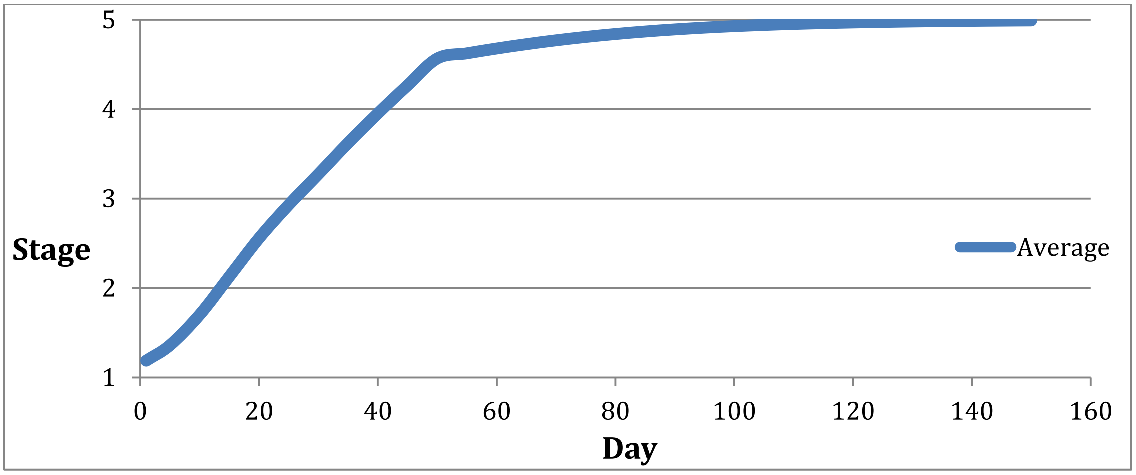


Figure 7: Average vermicompost conversion over time

The graph indicates that complete conversion requires about 100 days. The piece-wise linear model approach is particularly informative - it reveals that conversion progresses rapidly during the first 50 days. From this point on, the conversion is nearly complete and the process slows and nearly plateaus before finally reaching stage 5 around day 100. This graph corresponds to the three stages of vermicomposting, in which the worms first adapt to their new substrate, then rapidly degrade the waste before moving on to the more recalcitrant matter in the final "curing" process (Jack & Thies, 2006). In the Batloun trial, the worms added to the crate were already adapted to organic kitchen waste and thus, the last two stages were of the most importance.

The significance of this study is that it reveals that 50 days is sufficient to achieve a decent vermicast in stage "4.5." Beyond 50 days, the vermicast enters a curing phase, which according to the model, will yield only incremental improvements in structure and consistency.

4.3.2.1 Interview

The interview with Maysan took place on Saturday, October 26th. See appendix 9 for a description of the interview questions.

Maysan lives in Batloun with her husband and her two grandchildren and throughout the span of the project, it became clear that she is at the head of the household – she is in charge of the impressive backyard garden, she cooks and cleans and keeps an eye on the grandchildren playing behind the house. A proponent of alternative medicine, Maysan also distills her own herbal remedies made from wild plants. She is convinced that this botanical knowledge and connection with nature contributed to the project's success.

Although Maysan didn't ever practice composting, she had previous knowledge of it. She was familiar with the concept of burying tree leaves in the ground and leaving it for several months to decompose. Regarding earthworms, however, she had quite a different perspective prior to the project. As a gardener, she was always told that worms were bad for plants and that the worms around a weak plant should be removed so that it could recover.

When asked about the waste collection process, Maysan explained that she had been utilizing the combined waste from two neighbors, from the households of her two daughters, and from her own. The waste amounted to approximately two buckets per family per week. The only problem she mentioned was the odors from the waste. The neighbors that were saving their waste for her were not always happy about the smells that it generated in and around the house. Nonetheless, she admits that it was only during the handling of the waste that there was an odor. Once everything was placed in the plastic boxes and covered with soil, there were no more odors.

Maysan followed the vermicomposting instructions very well. She lined each box with the lint material, which simultaneously served to contain the earthworms and retain the moisture. She added the waste, followed by a layer of soil, and then added the appropriate quantity of worms. Each box was placed on top of an empty one in order to keep it elevated from the ground and minimize contact with other insects. The boxes were stacked two or three high and then an empty box placed on top for shading purposes. Maysan exhibited particular care in monitoring the contents for earthworm activity and moisture content. She said that during the summer when it was hot, she looked at the boxes each day to check the moisture, adding water when necessary. As the weather cooled and the air became less dry, she would check the moisture only twice per week. Each box took between 45 minutes to an hour to prepare and she prepared an average of two boxes per week.

Despite the success of the trial, Maysan *did* encounter several problems. Firstly, she reported that ants and snails were occasionally problematic, while fruit flies were a continuous issue for one box in particular. Curious, she is determined to find out exactly how this box differs from all the others to make it so attractive to flies. A second problem was that after about four months, the worms in the “mother box” had consumed all of the waste and were becoming unhealthy in their environment of highly digested vermicast. She noticed that they were not reproducing as before, were smaller in size and generally seemed unhealthy. So she decided to start a new “mother box” with fresh waste and she transferred the remaining worms into it. Later, she was resupplied with worms, which further regenerated the population.

When asked about improvements that she would make to the system, she indicated that bigger boxes would provide easier access and that it would be a good idea to cover the boxes with some sort of netting. She also mentioned that she was not fond of the stacking procedure. The boxes were often so heavy that it became difficult to lift them high onto the stack. She would personally prefer to keep them more spread out, a more horizontal operation as opposed to vertical.

Given the novelty of this technology and the unsavory reputation of worms, it was especially pertinent to understand the social reaction to the project. Before even touching upon the subject of worms, the issue of separating organic waste at the household level was expected to be a hurdle. Surprisingly, Maysan said her neighbors responded well and were happy to participate. Separation was a new concept, but she was pleased that they quickly caught on. She said that they quickly learned to distinguish between waste that should go in the bucket and waste that should go to Sukleen. Moreover, she said that one of her neighbors developed a new technique for easy disposal into the compost bin. She would spread a piece of newspaper on the counter while she was cooking and would place all of the accumulated food waste on top of it. Once finished, she would wrap the waste and place it in the bin. As for the actual vermicomposting, many people found, and still find, the idea repulsive and didn’t understand what could possibly come of such a project. Her neighbors, even those not involved in waste collection, were nevertheless accepting.

Maysan proved to be surprisingly investigative. She was able to observe that the worms have preferences when it comes to the food they consume. They prefer vegetables to fruits and particularly like watermelon and radishes. They don't tolerate the cold very well and reproduce less when their environment is too wet. She was even able to observe that they take approximately ten days to mature.

Maysan's experience with this project has, she happily admits, changed the way she views worms. When asked if she would be willing to continue vermicomposting on her own, she said yes, but that she hasn't yet been convinced of vermicast performance. She would want to test it before feeling confident in applying it to her own garden or selling it to others. Naturally, she still has reservations towards this new product whose benefits she has yet to see with her own eyes. She even started outlining how she or I should go about testing it – try growing plants in different ratios of soil to vermicast, another trial involving a slow increase in vermicast quantities, and comparisons to plants grown with traditional fertilizer.

During a previous visit, she had asked how to apply the vermicast and had been told that it is best to mix it into the soil at a proportion of about 10%. She had clearly ruminated on this number and later admitted that she wasn't quite sure if vermicomposting would be worth the effort – according to her calculations, one box would have to supply the needed quantity to 50 plants if it is to be profitable. Personally, however, Maysan felt very dedicated to the project and appreciates the benefit that it could offer for the natural ecosystem. She was concerned, though, that someone who doesn't have the intimate connection with nature that she has might not be as successful. She said that she would have appreciated more support at the very beginning of the project, as she was not confident that she was preparing the boxes properly, but it is clear that she has mastered the vermicomposting process and would be capable of carrying on independently.

Maysan's constant monitoring, her observations of earthworm activity, the initiative that she took in overcoming the "mother box" issue, and her profitability calculations attest to her industriousness and entrepreneurship. It shows that she went above and beyond the simple tasks that were asked of her and reveals that she felt personally implicated in the success of the worm boxes. She has demonstrated that with some initial guidance and support, she possesses the knowledge, skills, and drive to become a vermicast producer. This trial illustrates that, given the right person, vermicomposting could be successfully implemented as a microenterprise.

4.3.2.2 Skills Development

The following table attempts to compile the skills that Maysan acquired while vermicomposting. While an economic analyses focuses on the financial gain of a microenterprise, table 11 elucidates the less tangible value it offers.

Technical	How to separate organic waste from regular waste How to efficiently/conveniently collect compost How to set up a box (lined with cotton, filled with soil & compost, labeling) How to judge and maintain proper moisture in the boxes Worm observation (behavior, reproduction, preferred foods, etc) Monitoring
Social	Understanding people's aversion to or acceptance of separating waste Interaction with neighbors/immediate community Overcoming social stigmas regarding worms and stinky compost Comfort handling worms and waste

Economic	Understanding the economy of recycling waste

Table 11: Skills Development

4.3.2.3 Evaluation of the Trial

The interview was very informative. The vermicompost system developed earlier needed to be put into practice to test its effectiveness and identify flaws and modifications. Just short of actually implementing a micro-enterprise, this trial served as a microenterprise *simulation* in which Maysan's monthly earnings represented possible income that could be generated from a business.

By monitoring the weekly decomposition of the waste, the author was able to personally make several observations. The first was that the worms did not favor sticks and leaves (yard waste). This corresponds to the findings of Sinha et al, (2010) that kitchen waste is preferred to garden waste. Everything else in the crate will be eaten before these materials and therefore, they should be excluded unless a longer decomposition period is anticipated. The second observation was that fruits and vegetables left exposed on the surface will not be eaten. Due probably to a combination of drying out and exposure to light, these components are not tempting to the earthworms, though they certainly are to fruit flies. As such, it is reiterated that waste should be *entirely* covered by a layer of soil.

Several improvements to the vermicompost microenterprise system stem from Maysan's own suggestions. The idea of stacking the boxes stemmed from the concern that a vermicompost operator may not have much space to spare. The boxes stack nicely, but when filled with waste, they become very heavy and are hard to lift on to a high stack. In instances where space is not an issue, stacking may not be necessary. The felt material used to line the crates was very effective at regulating moisture and housing worms, but because it is one of the most costly and inconvenient inputs, basic cardboard could be a suitable replacement.

Additionally, extensive research recommends pre-composting the organic waste before introducing the earthworms. Nair et al (2006) recommend that kitchen waste thermocomposts for 9 days, followed by 2.5 months of vermicomposting. Section 2.1.7 discusses the attributes of an initial composting period for enhanced vermicast quality and pathogen reduction. It has also been suggested that pre-composting would enable the earthworms to handle, to a certain extent, citrus and acidic wastes (Nair et al, 2006). Given the high rates of lemon, orange, coffee and tea consumption in Lebanese households, the capacity to handle these wastes presents a significant advantage. The downside to pre-composting is that it is a separate process requiring additional training and management. Compost tends to emit odors and attract insects, pests, and rodents. While the social and logistical hurdles of pre-composting may not justify its benefits, it remains a recommendation for anyone with the means to integrate this step into the vermicomposting process.

Lastly, the box system has proven to be efficient for a subsistence enterprise. The characteristics of such an enterprise are that it is seasonal (indeed, vermicomposting in Batloun had to be halted at the beginning of winter because the worms would not have survived the cold) and run by unpaid family members (Maysan collected waste from family and neighbors, and her grandchildren were the “harvesters”). The consumers of a subsistence vermicompost enterprise would most likely be limited to home-use, neighbors and family members. It became apparent, however, that if this subsistence microenterprise were to grow into a stable one, characterized by a more formal investment and employment, the box system would no longer be suitable. For economies of scale, large immobile concrete drums would be more appropriate than dividing the waste into small crates. Furthermore, these drums could most likely be situated under a roof for protection from sun and rain while a greenhouse would create a more suitable habitat for the worms. Besides adopting a new model, the vermicomposting process would remain more or less the same. See the photos and descriptions of enterprise scales that are possible for vermicomposting in section 2.4.

4.3.2.4 Rate of Bioconversion

The rate of conversion (organic waste to vermicast) can be estimated using the waste generation data, the vermicompost experiments, and the Batloun findings. The bioconversion rate in Table 12 is based on the waste generated by one household of four people per week, approximately 3 kilograms.

Waste (kg)	Quantity/weight of Earthworms (g)	Rate (g. waste/worm/day)	Length of Time (days)	Vermicast Quantity (kg)
3	250	1.6	7	1.5

Table 12: Rate of Bioconversion

Thus, 250 worms that consume their weight and a half in waste per day will convert a week's worth of waste in a week's time. The short vermicomposting period does not consider worm reproduction, so when vermicomposting over a longer time, the weight of earthworms can be multiplied by 2. These rates are very generalized and will certainly vary with weather conditions, substrate content, reproduction dynamics, etc. but they do correspond to the findings of Seenappa (2011).

4.4 Cost-Benefit Analysis

The Cost-Benefit Analysis was prepared by first calculating the average per ton benefit of vermicompost across the three sectors. For this study, the sectors include the landfill (which benefits from less organic waste to treat and process), the microenterprise (the profits from a production business), and agriculture (the benefits of using vermicompost at the farm level) and for the reader's convenience, each is color-coded (blue, green, and orange, respectively). The individual per ton benefits are then combined in the social cost-benefit analysis, which shows the benefit of vermicompost to society. It is then followed by a discussion of the results. The studies that were used to compile the data are listed under "sources" as well as the country of origin. Priority was, of course, given to studies specific to Lebanon when available. Pieces of data were often greatly contrasting and are, in these cases, presented as a range.

4.4.1 Calculating the Benefits at the Landfill Level

Category	Component	Sources	Country	Benefit	Average Benefit / ton VC / yr
Landfill Benefits	Environmental Disamenity	Clarke, 2000	Australia	$7	$14 (7 x 2)
	Closure Costs	Clarke, 2000	Australia	$0.02	$0.04 (0.02 x 2)
	Operational Costs	Clarke, 2000	Australia	$16	$32 - 240 (16 x 2) (120 x 2)
		EPA, 1997	USA	$120	
	Waste Collection	State of the Environment, 2010	Lebanon	$24	$49 (24.5 x 2)
		EPA, 1997	USA	$25	
Total					**$95 - 303**

Table 13: Calculating the Landfill Benefits

4.4.1.1 Explanation of Calculations

The above table shows the benefits of diverting organic waste from the waste stream. The environmental disamenity of one ton of organic waste has been valued at $7 per ton. In this case, the environmental disamenity, as defined by Clarke (2000), accounts for leachate into the environment, gas emissions and odors. This number is then multiplied by 2 because earthworms consume organic waste and reduce its volume by approximately 50% (Adhikary, 2012). In other words, each ton of vermicompost is the product of two tons of organic waste. Closure costs, although minimal, value the money that must be spent managing the landfill after closure. Organic waste is so troublesome that decreasing its quantity after the landfill has closed represents savings, however modest. Likewise, operational and waste collection costs are predicted to decrease in response to diverted organic waste.

In the case of the landfill, the benefits of vermicomposting are indirect, since vermicast itself has no impact on the landfill. Moreover, the benefits are averted costs, not profits. Adding the average benefits in Table 13 reveals that for every ton of vermicompost produced, between $95-303 of costs are averted at the landfill. Because the landfill sector doesn't pay for vermicompost (or organic waste diversion) this particular sector reaps only the benefits of the vermicompost program.

4.4.2 Calculating the Benefits at the Enterprise Level

The data collection for the microenterprise involved a micro cost analysis intended to understand the financial dynamics of a vermicomposting enterprise. More specifically, it estimates the input costs required to initiate and sustain a business compared to the anticipated profits. For example, if the profits for the entrepreneur are minimal, vermicomposting enterprises may not be the best choice for diversifying agricultural livelihoods. The data used in this analysis was compiled with data from commercial suppliers and from the prototype experiments of the present study. It represents an annual expenditure.

This micro cost analysis is based on the crate model proposed in this project. It should be recognized that a variety of vermicomposting methods and materials exist that may increase or decrease the capital costs. For example, one of the findings from the Batloun field-trial was that this crate prototype is appropriate for very small-scale operations (production of vermicompost for home use or sale to family and neighbors) but that a slightly larger, more formal operation would most likely take a different shape and incur different costs.

Because there is significant variability in possible input costs, two scenarios are considered – a conservative estimate and a more generous estimate. The typical components of a vermicompost microenterprise are listed, along with their prices and the estimated quantity needed for the operation. The estimated quantities are based on the production of one ton of vermicompost per year. The calculations are described below.

Component	**Cost ($)**	**Quantity**	**Conservative Subsistence ($)**	**Generous Stable ($)**
Greenhouse structure	375	1	-	375
Compost bins	8	15	-	120
Plastic crates	2.71	36	-	49
Imputed rent		-	-	4
Worms			-	50
Miscellaneous (scissors, plastic bags for distribution)			15	15
Total Fixed Costs			15	613
÷5 years Operational Costs			3	123
Lint material	$0.8/m^2$	$70\ m^2$	56	56
Soil	5/bag	5	-	25
Water			Negligible	Negligible
Total (Fixed ÷ Operational Costs + variable costs)			59	204

Table 14: Estimated Yearly Input Costs of a Vermicompost Enterprise

The components in light green are the fixed costs or the costs that remain the same irrespective of the output level. They are also the items that represent an initial investment and not a yearly expenditure. The components in white are variable and their quantities will vary according to output. In order to account for the difference between fixed and variable costs, the total fixed cost is divided by five since the materials and supplies can be expected to last about five years. This initial investment cost is, therefore, spread out throughout the first five years of operation.

The conservative microenterprise scenario (representative of a subsistence microenterprise), assumes some resourcefulness on behalf of the entrepreneur. Operating on the entrepreneur's own land negates rental payments (imputed rent) and greenhouses are only necessary at specific altitudes for year-round production. The compost bins are a convenient, but costly accessory so it can be assumed that the entrepreneur will be able to find alternatives free of cost. Similarly, plastic fruit and vegetable crates are very accessible, and can be recovered at no cost. Likewise, it can be assumed that the entrepreneur will be able to find a free source of soil, used to cover the waste in each crate and will be able to dig for his/her own worms.

The second scenario is a more generous estimate of input costs and could represent a stable microenterprise. This scenario still assumes the same production rate (1 ton vermicompost per year) but under a more formal, permanent production system. It assumes the purchase of a greenhouse structure, rental payments, bags of soil, and new compost bins and plastic crates. Additionally, it may be preferable to pay someone to dig for worms.

4.4.2.1 Explanation of Calculations

If the vermicompost takes three months to decompose (a conservative estimate – section 4.3.2 indicates that it should take about two months), then 4 cycles could be completed throughout the year. In order to produce 1000 kg (1 ton) of vermicast, the producer would need a yield of 250 kg per cycle. Based on the trial in Batloun, a crate filled with kitchen waste yields 7 kg of vermicast. By dividing 250 kg per cycle by 7 kg per crate, it becomes clear that the producer would need about 36 crates.

The imputed rent was calculated by assuming yearly rental costs at 3% of land value. If land is valued at approximately $100 per square meter, a 4x4 greenhouse plot would cost $1,600. Rent per year would be $48 so the monthly imputed rent would be $4.

In both cases, the cost of water (used for maintaining moisture and washing the compost bins) is considered negligible and the lint material, reused for multiple cycles during a year, would require annual replacement.

The last step is to estimate the possible price of a ton of vermicompost. Given that the most expensive compost in Lebanon is $230 per ton (Cedar Environmental, n.d.) and that farmers typically pay about $70 per ton for animal manure (MOE, 2001), it is reasonable to conclude that vermicompost would cost around $150 per ton.

	Conservative Scenario ($)	Generous Scenario ($)
Output (price realized)	150	150
Input Costs	59	204
Producer Net Returns	91	-54

Table 15: Generating Net Returns for the Vermicompost Enterprise

To determine the net returns, the input costs are simply subtracted from the selling price. It is clear that according to the conservative scenario, a producer could expect to make $91 after initial investments. The generous scenario, however, yields a negative number, indicating that a vermicompost business would only be profitable if the producer is able to be resourceful and avoid some of the extravagant costs associated with an expensive greenhouse, formal compost bins and new crates.

4.4.3 Calculating the Benefits at the Farm Level

Taking a closer look at the agricultural benefits of vermicompost is pertinent not only as a contribution to the overall economic benefits, but because this is the sector that will be creating demand for vermicompost. Many scientific studies attest to the effectiveness of vermicompost to stimulate plant growth and yield, but none of them have attempted to put a dollar value on these improvements. If the net returns to the consumer (in this case, the farmer or gardener who purchases the product) are positive, then the potential market demand for vermicompost is essentially confirmed. Of course, there are many other factors at play, such as social stigmas and behavioral changes, but this specific study is more or less the keystone of the entire vermicompost concept.

Calculating the benefits on the farm requires first compiling a small-farmer profile. This profile attempts to particularize how much the farmer spends per hectare per year in Lebanon. Based on this information, it will become clear how much money is to be gained or saved with the use of vermicompost.

It should be noted that the data is based on *sugar beet* farmers. A cost-benefit analysis based on one individual crop, instead of the typical small-farm, provides more specific and accurate data when attempting to measure the vermicompost effect. Sugar beet is a typical crop grown throughout the country, particularly in the Beqaa. Industrial crops (sugar beet, tobacco, and vineyards) constitute about 10% of the cultivated land in Lebanon and they require middle-of-the-road quantities of pesticides as compared to other crops (Refer to Table 5 for national pesticide use patterns). As such, the cost-benefit analysis is tailored to sugar beet cultivation but was chosen so as to be representative of many different crops.

It is important to keep in mind that the numbers in Table 16 are approximate estimates. The studies that form the basis of these estimates are included in the chart, along with the year of publication and the country, to show relevance.

Component	Source	Source Country	Cost ($) /hectare /yr	Average $ /hectare/yr
Fertilizer Costs	Ali (2004)	USA	136	136 - 260
	Albayrak et al (2010)	Turkey	260	
Pesticide Costs	Ali (2004)	USA	215	138 - 220
	Albayrak et al (2010), Patterson (2009) MoE (2001)	Turkey/USA/ Lebanon	60-224	
Irrigation Costs	Karaa et al, 2004 ; World Bank, 2010	Lebanon	425	425
Pesticide Health Costs	Soares & Porto, 2009	Brazil	(8 – 84% x $87.58)	7 - 74
Average Small Farm Income	Personal Communication	Lebanon		4,800

Table 16: Estimated input costs for small-scale sugar beet production in Lebanon

4.4.3.1 Explanation of Calculations

Fertilizer costs are assumed to be between $136 and $260 based on studies by Ali (2004) and Albayrak et al (2010). Although Ali (2004) is a study of beet production in the United States, the numbers included here for fertilizer and pesticide costs are those estimated for low-earning, small family farms, a more valid comparison to small farmers in Lebanon.

The estimated pesticide expenditures of the Lebanese small farmer are compiled by averaging two prices – that of Ali (2004) and a second estimation generated from multiple sources. In the United States, the cost of pesticides for sugar beets is approximately $7/kg (Patterson, 2009) while they are approximately $26/kg in Turkey (Albayrak et al, 2010). The range, therefore, is $7-26 / kg of pesticides in sugar beet production. Knowing that 8.6 kg/ha of pesticides are used annually in sugar beet fields in Lebanon (MOE, 2001), this yields a price range between $60 and $224 per hectare. So, the final estimated cost of pesticide use is the average of these numbers and that proposed by Ali (2004).

Sugar beets in the Beqaa require approximately 850 mm of water per year (Karaa et al, 2004), equal to 8,500 m^3 per year (850 mm x 100 m x 100 m). If the volumetric price of water in the Beqaa is $0.05 per m^2 (World Bank, 2010), this means that the average beet farmer spends $425 per year for irrigation.

The study by Soares and Porto (2009) attempts to quantify the benefits of pesticide use in relation to the cost of health problems. Their study in Brazil found that pesticide use increases maize productivity by $87.58 per hectare but that health costs average anywhere between 8-84% of this sum, or $7-74 per hectare. For the purposes of this study, it is assumed that these calculations apply in Lebanon, as well. Therefore, the medical costs incurred as a result of pesticide exposure ranges from $7 to $74 per hectare.

No data could be found regarding the average income of the small, sugar beet farmer. Multiple sources at AUB's Faculty of Agriculture and Food Science suggested that $600 per month is the minimal subsistence wages that could support a small family, of which 2/3 is probably derived directly from agriculture and the other 1/3 from other forms of employment. (Diversified employment in the agricultural sector is a trend confirmed by Figure 9 in section 5.1). An approximate income of $600 per month indicates a $7,200 yearly income, of which $4,800 is revenue from agriculture. Although the average farm size in Lebanon is about 1.25 hectares (MoE, 2001), this can be rounded to one hectare such that one sugar beet farm (of one hectare) yields the farmer $4,800 per year.

4.4.3.2 Quantification of On-Farm Benefits

The next step is to quantify the agricultural benefit of vermicompost use. For the purposes of this study, the impact of vermicompost use is measured by enhanced productivity, reduced irrigation requirements (because soil amended with vermicompost has a higher water retention capacity), the foregone costs of chemical inputs (fertilizer and pesticide), and the forgone costs of pesticide-related illness.

The “Benefit” column shows the percent benefit or gain per ton of vermicompost applied. The last column shows how much money this represents as a function of the farmer’s yearly income.

Category	Component	Sources	Country	% Benefit / ton VC	Average $ gain / ton / ha VC
On-farm Benefits	Higher Yields	Manivannann et al, 2009	India	11%	$528
		Parthasarathi et al, 2008	India		
		Singh et al 2008	India		
	Reduced Irrigation Requirements	Manivannan et al, 2009	India	6%	$26
		Parthasarathi et al, 2008	India		
		Adhikary, 2012	India		
Averted Costs (Fixed)	Chemical Inputs	(fertilizer & pesticide costs from Table 16)	USA,Turkey Lebanon		$274 - 480
	Savings on Pesticide Illness	Soares & Porto, 2009	Brazil		$7 - 74
Total Benefit					**$835 – 1,108**

Table 17: Benefit / ton / hectare of vermicompost

The scientific studies listed in Table 17 compare the effects of various vermicompost treatments, using plants treated with inorganic fertilizers as the control. Therefore, the improvements in yield are not compared to untreated soil, but soil already treated with traditional chemicals. Vermicompost has also been shown to drastically decrease incidence of disease, disorder, and damage by pests (Jack & Thies, 2006; Singh et al 2008; Arancon et al, 2005; Edwards et al, 2010). It is therefore assumed that vermicompost performs as well as inorganic pesticides in terms of enhancing marketable yields and will replace pesticide use without added benefits or incurred losses. However, the forgone costs of expensive pesticides and the forgone health expenses associated with them will factor into the analysis as fixed averted costs. As such, the scenario represents *additional income* to a small farmer, accounting for previous agrichemical use.

Because the on-farm benefit calculations are complex, the following section provides an example of how the % benefit / ton / hectare of vermicompost was generated (the second to the last column in Table 17 above).

- In a study by Parthasarathi et al (2008), the authors tested the influence of vermicompost on the yield of blackgram (lentil) as compared to the yield when grown in a regular dose of inorganic fertilizers.
- The control plot yielded 1,600 grams per plant while the plot treated with vermicompost (applied at 5 tons/hectare) yielded 2,100 grams per plant.
- The difference (500 grams) was divided by the control (1600) to reveal that vermicompost, applied at the aforementioned rate, will enhance the yield by 31%.
- In order to find the % improvement *per ton*, 31% was divided by 5, indicating an improvement of 6% per ton.
- This was then averaged with the results of other studies using the same application rate and the final benefit/ton was determined to be approximately 11% increased yields.
- All the calculations used to generate the 11% yield increase are articulated in Appendix 10.

The average $ gain (last column) translates the percent benefits into a dollar value based on the information compiled in the small-farmer profile (Table 16). The "higher yields" benefits were calculated by multiplying 11% by the farmer's yearly income. This means that fertilizer use could be abandoned and sugar beet productivity would not only be matched by vermicompost, it would be enhanced by an additional 11%. This translates to an extra $528 per year for the farmer.

The irrigation benefits are generated by multiplying 6% by the price of water ($425). This indicates that the enhanced water holding capacity of the vermicompost-treated soil could save the farmer $26 per year in irrigation requirements.

The "Averted Costs" section of the table represents the savings in health costs associated with pesticide abandonment ("Savings on Pesticide Illness") and the foregone costs of fertilizer and pesticides (collectively referred to as "chemical inputs" in the table.) These figures are fixed because they are incurred irrespective of how many tons of vermicompost are applied.

Lastly, what are the net returns to the farmer when he/she uses vermicompost? This can be deduced by adding the value of enhanced production and the fixed savings and then subtracting the estimated cost of vermicompost. Note that these net-returns are *additional* to the farmer's previous income.

Total Benefits	$835 – 1,108
Cost of Vermicompost	$150
Net-Returns (Benefits minus Costs)	$685 – 958

Table 18: Net Returns for the Farm Level

The results show that one sugarbeet farmer applying one ton of vermicompost stands to gain between $685 to $958 per year.

Will the benefits be this great with each vermicompost application? No, because the fixed savings occur just once (the costs of forgone chemical inputs is not a function of vermicompost application rates). Beyond the first ton per hectare, it is only the benefits from enhanced yield and irrigation savings that would accrue. This raises the question of application rate. The greater the quantity of vermicompost the farmer applies to his fields, the greater the benefits he/she will reap, to a certain point. Eventually, the gains will plateau. Vermicompost doses beyond 7.5 tons/ha do not influence growth parameters significantly, most likely because this dosage supplies the optimal amount of growth-promoting substances (Singh et al, 2008). Beyond a certain tipping point, vermicompost will actually become detrimental to plant growth. What is the tipping point? For plants grown in pots, it has been found that vermicompost quantities of 60% and 80% decrease yield significantly. This may be due to high soluble salt concentrations, heavy metal toxicity, plant phytotoxicity, or poor aeration (Arancon et al, 2004, b).

4.4.3.3 Robustness of On-Farm Benefits

Because the on-farm benefits are the greatest, they are worth closer analysis. One of the weaker points of the analysis, in the author's opinion, is the assumption that yields would increase at such a great extent. Indeed, the great benefits that vermicompost purports to offer has a great influence on the $499 gain from higher yields. As was explained earlier in the mathematical calculation section, these numbers were reached by multiplying the per ton benefit by the yearly income of the farmer, accounting for former agrichemical use. Although a host of scientific studies support similar projected increases in yield (Manivannan et al, 2009; Singh et al, 2008; Arancon et al, 2004, a) it is more sensible to consider that crops may not respond as well or as immediately as anticipated. Table 19 below considers the net returns with the original premise of high yield increases. It then considers the net returns when these increased yields are divided in half and when they are zero (meaning that the vermicompost will perform no better and no worse than fertilizers and pesticides).

On-farm Net Benefits (total enhanced productivity)	$685 – 958
On-farm Net Benefits (1/2 enhanced productivity)	$571 - 844
On-farm Net Benefits (zero enhanced productivity)	$307 - 580

Table 19: Different Productivity Scenarios (1 ton/ha)

This table is significant because it shows that even in the worst-case scenario – that post vermicompost productivity remains the same as pre-vermicompost productivity - the farmer still stands to gain from its use. Replacing expensive fertilizers and pesticides with one, less expensive product will alone justify a shift to a vermicompost program. It is made even more profitable when the irrigation and health savings are factored in.

Next, a cash flow chart will help to illustrate an adjusted scenario over time that may be more realistic than the original findings. Table 20 shows the farmer’s financial input and output flows and the accumulated net returns, when the vermicompost offers only *gradual* improvement. As specified in the last column, the scenario assumes no change in productivity the first two years, and half the anticipated productivity gain in the following three years, as per Table 19 above.

Year	Input	Output	Net	Quantity of yield increase
1	$150	$307	$157	zero
2	$150	$307	$314	zero
3	$150	$571	$735	half
4	$150	$571	$1,156	half
5	$150	$571	$1,577	half

Table 20: Cash-flow table showing adjusted scenario (1 ton vermicompost, lower benefit estimate)

This scenario confirms that the net value of one ton of vermicompost may be as high as originally predicted ($685 – 958), but would remain positive even if the product doesn't meet these expectations. It should be noted, furthermore, that the farmer is never indebted and therefore, no need to wait for payback. For several reasons, this scenario could be considered more reasonable. Firstly, the scientific studies that show the benefit of vermicompost compared to traditional fertilizers are all performed in the field, but the crops may be "pampered" for accurate observations. It is possible that crops treated with vermicompost on a real farm will be subjected to harsher conditions. Secondly, it is reasonable to assume that the benefits of vermicompost will not be immediate, but will accrue over time, particularly due to any "shock" from the fertilizer-compost transition.

4.4.3.4 Social Cost-Benefit Analysis

Up to this point, each sector has been examined separately. While the cost-benefit analyses for the vermicompost enterprise and for the farmer are clearly private, the landfill sector is public, as it is a service to society. For waste management in Beirut and Mount Lebanon, vermicomposting initiatives would reduce the need for Sukomi's collecting and composting services. Hence, the government would be the beneficiary in this case. Outside of these two regions, the local municipalities would benefit through reduced waste management expenses.

A social cost-benefit analysis usually takes into account the private benefits as well as contribution to the greater good of society (van Kooten, 2013). For purposes of complexity, all environmental and social benefits that vermicomposting can provide could not be taken into account. However, combining the benefits from the two private sectors and the one public sector is one way to present a more meaningful, cross-sector social cost-benefit analysis of a vermicomposting program in Lebanon.

Table 21 below summarizes the entire economic analysis. The Net Returns are generated by subtracting the costs from the benefits. The Net Returns are then totaled to show the anticipated social benefit resulting from the production and consumption of one ton of vermicompost applied on one hectare of sugar beets. The cost-benefit ratio is generated by dividing the benefits by the costs. It indicates the benefit per dollar invested, so if the ratio is greater than one, the project will increase real wealth.

Sector	Benefits (S)	Costs ($)	Net Returns ($)	Cost –Benefit Ratio
Landfill	95 - 303	0	95 - 303	n/a
VC Enterprise	150	59	91	2.5
On-Farm	835 – 1,108	150	685 – 958	6 - 7
Total			**871 – 1,352**	

Table 21: Social Net Returns ($ benefit / ton of vermicompost / hectare)

Clearly, the net returns are not only positive, but are high, indicating that vermicompost production and consumption could be a very lucrative and promising national investment. Gains between $871 and $1,352 would be spread across the three sectors. The cost-benefit ratio can't be generated for the landfill sector as it incurs no cost. The vermicompost consumer (the farmer) has the highest ratio, as his/her gains are high with a minimal investment. The vermicompost producer has a lower projected ratio – every $1 investment will yield $2.50 in profits. This ratio corresponds to that of Shivakumar et al (2009) who predict 3.44, figuring a discount rate of 12%.

4.4.3.5 Limitations

Firstly, in the interest of being more scientifically precise, the exact quantities of fertilizers used in the studies should be compared and adjusted to the quantities currently used by farmers in Lebanon. This would make the percent benefit of vermicompost over fertilizers more accurate. Chemical application rates on local farms are, unfortunately, hard to come by, but it can be generally assumed that they are similar to the NPK and pesticide used in the studies as these were designated as the "common dose."

Likewise, another weakness is the assumption that vermicompost can replace pesticides with the same results. There is a strong body of evidence showing impressive pest and disease prevention properties of vermicompost. For example, Singh et al (2008) found that a 7.5 tons/hectare dose of vermicompost increases the marketable yield of strawberries by 58.6%. Another study found that vermicompost can replace 75% of chemical pesticide needs (Sinha et al, 2010). Nonetheless, further research would be necessary to compare vermicompost and pesticide performance.

Another issue when dealing with the weight of vermicompost is its moisture content. In other words, one *ton* of vermicompost may represent different *volumes* of vermicompost. As such, volumetric measurements may be more accurate measure.

There are several reasons to assume that the cost-benefit analysis is an underestimate of vermicompost attributes. In this study, the direct benefits of vermicompost to the farmer are defined by an increase in crop yield, a decrease in damage via pests and disease (assumed to be on par with former pesticide use) and a decrease in irrigation requirements. However, several responses that were not measured are the *enhanced quality* of crops and *faster* growth. Singh et al (2008) report significantly fewer days taken for strawberry plants to flower when treated with vermicompost. Also reported are significant improvements in fruit firmness, color, quality (as defined by TSS, ascorbic acid, and acidity levels; Singh et al (2008), sugar and protein content (Parthasarathi et al, 2008; Manivannan et al, 2009) and micronutrient content (Peyvast et al, 2008). Keeping quality is enhanced, as well (NABARD, 2007). While these characteristics are certainly important in judging the overall benefit of vermicompost application, they are not included in the study due to price complexities.

The cost-benefit analysis was designed to calculate the benefit of applying one ton of vermicompost to one hectare of land per year. One study, however, found that one single vermicompost treatment (dosage unknown) improved the yield of cherry trees *for three consecutive years* (Sinha et al, 2010). Less frequent applications of vermicompost represents significant savings as compared to yearly- or seasonally-applied fertilizers and pesticides. Another assumption is that the farmer transitions 100% from former agrichemical use to total reliance on vermicompost although another scenario in which they supplement half of their agrichemical inputs with vermicompost may be more realistic. Indeed, several studies test the plant growth response to the *combination* of synthetic fertilizers and vermicompost and have found better results than vermicompost or fertilizers alone (Manivannan et al, 2009; Parthasarathi et al, 2008). Nonetheless, another element that must be taken into consideration is that this study in which agrichemical use is completely abandoned, coincidently represents a transition to organic agriculture. As such, the farmer is theoretically eligible to receive premiums for their products that could significantly increase his/her revenue.

The greatest limitation to this study is, as previously mentioned, its narrow scope. One reason is that private cost-benefit analyses generally exclude externalities (in this case, the externalities are positive - decreased river contamination, greater populations of pollinators, etc). Another reason is that food waste, water, topsoil, and of course vermicompost itself, are all natural resources that have a certain value to society and the environment but must be dealt more manageable market prices (Van Kooten, 2013). Consequently, this cost-benefit analysis is hopefully accurate as a *private* analysis, but is a gross underestimate as a *social* one.

Clearly, there are many variables to take into consideration and many assumptions to make when exploring the potential of vermicompost in Lebanon. This analysis considers only the short-term, direct social savings that vermicomposting could offer and is the first known attempt to measure these benefits on a national, country-specific level. Yet, there is assurance in the fact that the social net returns ($871 – 1,352) are so high that undesirable conditions (for example, higher vermicast prices for the farmer or reduced waste management fees) are unlikely to bring them below zero.

CHAPTER 5

DISCUSSION

The introduction and literature review of this paper provides essential background information about vermicomposting and proposes a structure for its implementation – via microenterprises intended to benefit disfavored rural farming communities. The methodology of Chapter 3 describes the experiments and studies, as outlined in the objectives, that would help develop the structure of a vermicompost program as suitable to the Lebanese context. Chapter 4 explains the results of these experiments and studies and provides a brief discussion of their significance. Chapter 5 is intended to delve more deeply into the historical and socio-economic factors that have shaped this proposed vermicompost scheme. It is followed by an analysis of the scheme through the three pillars of sustainability framework and finally, the conclusion.

5.1 Socioeconomic Hardship and Prospects in Lebanon

5.1.1 Lebanon's Agricultural Sector

While Lebanon has a long history of traditional agriculture dating back to 5,000 BC, this sector has undergone a considerable transformation. Unstable political and security situations throughout the past decades (notably the Civil War from 1975-1992) may be greatly to blame for poor land management and unchecked pollution. Soil is being eroded, underground water reserves are being depleted, pollution is rampant, and land is being lost to unbridled urbanization (MoE, 2001; Zurayk, 1994).

Rachid (2007) argues, however, that the collapse of the traditional agricultural system is a repercussion of economic policies. These policies can be described as neo-liberal or laissez-faire whereby government intervention and regulation in the local economy are de-emphasized allowing for the entry of foreign capital and corporate influence. "The bank secrecy policy, the decrease of imports' tax, the dependency on World Bank and International Monetary Fund funds and strategies without strategic plans to avoid debt accumulation, and the continuous struggle to open markets by accession to the WTO and other trade forums are responsible for the socio-economic status of the country. This was also aided by the absence of government intervention to protect social discrepancies and support the agricultural sector." It is believed that the private sector, enjoying a particularly close relationship to government, redirected investment towards one sector of the economy – trade, banking, and service – to the detriment of the production sector. This was particularly startling as it is typically recognized that development of a country's productive capacity precedes socio-economic growth and development. As such, much of the farming community lags behind socio-economically while, Lebanon, once relatively self-sufficient, has become heavily dependent on food imports (Rachid, 2007).

5.1.2 Profile of the Small Farmer in Lebanon

So how have neoliberal trends in Lebanon affected the small farmer? Troubles began in the early half of the 20th century with the collapse of two important agrarian pillars: mulberry for the silk industry and wheat cultivation. Firstly, the emergence of bigger silk production systems in Europe brought down the selling price of silk threads in the mountain villages, eventually bringing about the end of this once-thriving industry. Around the same time, wheat imports from Syria and Egypt proved to be cheaper than labor-intensive, local production, leading to the abandonment of this cultivation as well. Later, the openness of the local market created poorly balanced competition. Small farmers cannot compete with the low prices of agribusiness, be they local or international. Coupled with minimal, if any, government support and no social insurance services, the gap between the large and small businesses increases exponentially. Estimates suggest that 40% of Lebanon's 200,000 farmers produce too little for their products to even enter the Lebanese market. As such, the small family farm is further marginalized and slowly squeezed out of their agricultural livelihoods. Several strategies have evolved in response to such hardship and they will be discussed in the following section. It is worth noting that these adverse impacts of neo-liberal policies on the small farming sector are in no way unique to Lebanon and have been observed consistently in many other countries around the world (Rachid, 2007).

5.1.3 Coping Strategies and Diversification

Could vermicomposting play a role in mitigating some of the environmental and socioeconomic problems within Lebanon's small-farming sector? What is the most appropriate form for it to take?

Hardship in smaller-scale agricultural has brought about three general coping mechanisms. The first is intensification in which productivity is enhanced. For some, this involves a shift away from subsistence crops towards cash crops. The chart below correlates the collapse of the mulberry sector and rise of apple cultivation – a cash crop (Rachid, 2007).

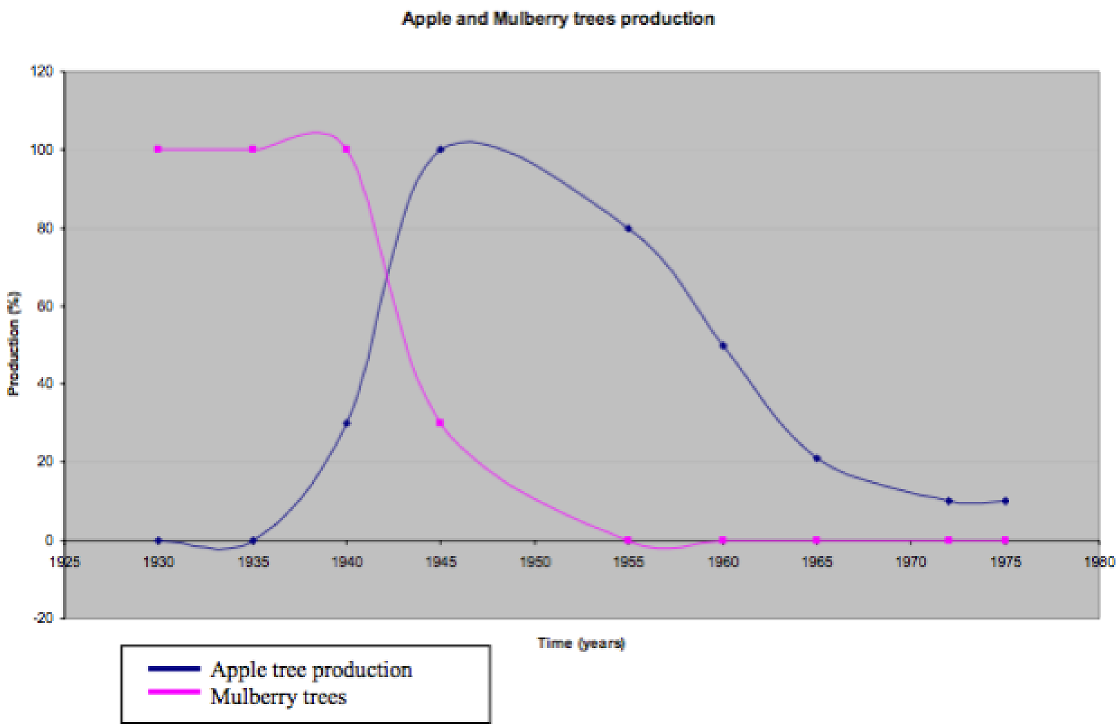


Figure 8: Apple and Mulberry Trees Production (from Rachid, 2007)

For many small-farmers, though, this is not a realistic option since they do not have the means to afford large quantities of fertilizers, pesticides and labor required of such intensive operations. Migration, or the abandonment of agriculture, is the opposite strategy. Lebanon has witnessed a considerable migration from rural, agricultural communities to the bigger cities or abroad in search of non-farm employment. Rural-to-urban migration often contributes to urban poverty and puts additional stress on fragile city infrastructure (Rachid, 2007; Zurayk, 1994). The third, or "middle road" strategy is livelihood diversification. This can be defined as "the process by which rural families construct a diverse portfolio of activities and social support capabilities in order to survive and improve their standards of living". Diversification can take many forms, such as obtaining remittances, earning a salary, or intiating a microenterprise and is not necessarily an involuntary response to a crisis, but can also arise as a deliberate household strategy (Ellis, 2007).

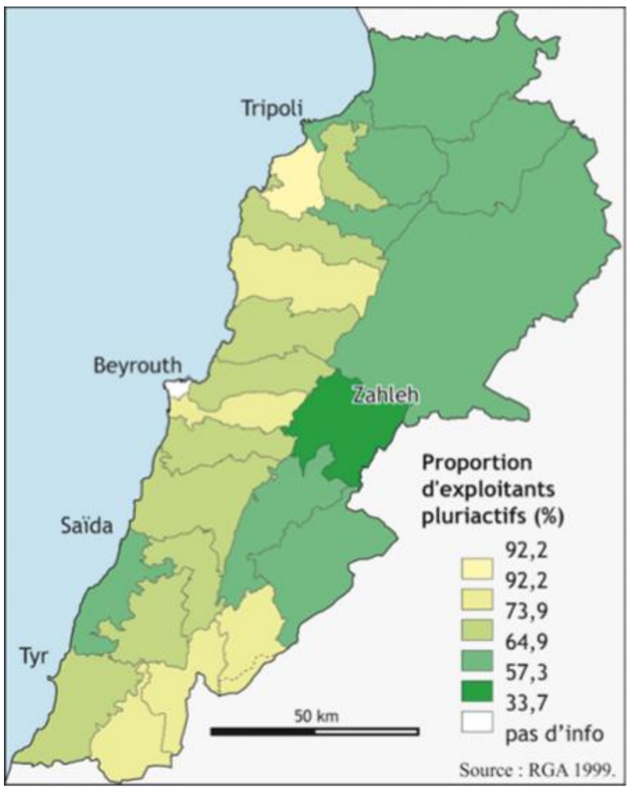


Figure 9: Map of Agricultural Diversification in Lebanon (from Asmar, 2011)

The map above illustrates the high rate of diversification within the agricultural sector in Lebanon. Liveliehoods are seldon based soley on commercial agriculture. They are usually accompanied by other economic inputs (Asmar, 2011).

The following matrix illustrates the relationship between agriculture and microenterprise endeavors and links different options with livelihood security.

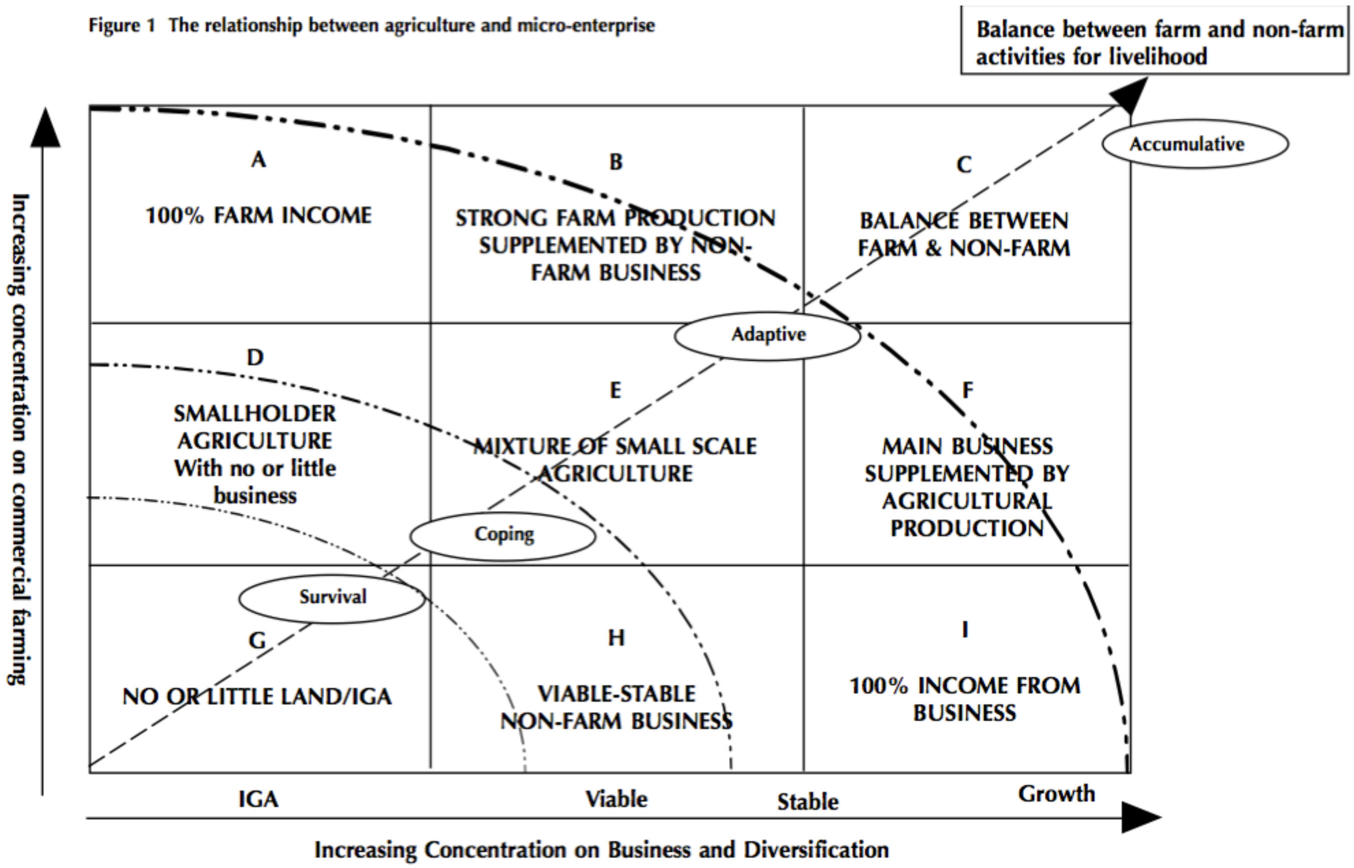


Figure 10: The Relationship Between Agriculture and Micro-Enterprise (from Orr & Orr, 2002)

The Y-axis shows the level of household income generated from agriculture while the X-axis shows the level of income from microenterprise. With the typology of four livelihood strategies interposed on the matrix, it becomes apparent that greater integration of agriculture and microenterprise is indicative of elevation from survival or coping livelihoods to more adaptive or even accumulative livelihoods (Orr & Orr, 2002).

So how do microenterprises enhance livelihood security? When a microenterprise is introduced into a predominantly agricultural livelihood, it helps to spread the risk and absorb the shocks typical of agriculture, such as competition, crop failures, and volatile market prices. It has even been suggested that non-farm income sources have a "disproportionately beneficial indirect impact on small farm output compared to large farm output." This may be due to the tendency of non-farm income to enable poor households to overcome credit and risk constraints on agricultural innovation (Ellis, 2007).

Who is most likely to start a microenterprise? Orr & Orr (2002) identify several variables indicative of successful start-ups, including natural ability (having a heart for business, hardworking), growing up in a household with a business, international travel, and being attracted to running an enterprise instead of being pushed into it by circumstance. In the case of women, it is important to have family support, particularly from husbands, and to have confidence, which they sometimes lack (Orr & Orr, 2002).

There are, nevertheless, several drawbacks to microenterprise. A number of studies reveal that microenterprises are surprisingly short-lived. Many countries have witnessed an explosion in subsistence microenterprises, for example, but because many households consider them as short-term or seasonal sources of income, they rarely have the opportunity to grow (Orr & Orr, 2002). Another argument could be made that non-farm occupations may "distract" from agricultural activity and investment (Ellis, 2007). However, because the non-farm activity in this case is actually the production of a direct agricultural input, vermicompost enterprises are anticipated to *stimulate* agricultural activity.

The current study, and others (Adorada, 2007; Purkayastha, 2012) have demonstrated that vermicomposting has great potential as a livelihood alternative and source of additional household income.

5.2 Discussion of Sustainability and the Three Pillars:

Sustainability as a concept slowly began to permeate the public sphere in the seventies and eighties but was first directly addressed in the Brundtland Commission and its report *Our Common Future* in 1987. "Sustainable development" was described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This report was the first of its kind to recognize that poverty is not merely economic and that the environment is not merely biophysical and that they are inherently interconnected. In the wake of this important, but admittedly ambiguous description, arose an industry intent on deciphering, prescribing, and advocating a more comprehensive definition of sustainability. The 2002 World Summit on Sustainable Development expanded the concept based on three "interdependent and mutually reinforcing" pillars of sustainability: economic development, social development, and environmental protection (Gibson, 2006; Kates et al, 2012).

Despite criticism that the three-pillar approach *fragments* what should be an *integrative* approach (Gibson, 2006), it is nevertheless a valuable lens through which to assess the soundness of the vermicompost scheme proposed here. The following sections describe the environmental, economic, and social considerations that shaped the proposed vermicompost scheme.

5.2.1 Environment

The environmental attributes considered within this paper were limited, but included waste stream alleviation, enhanced agricultural yields, natural protection against crop diseases and pests, reduced water demand, and improved health on the farm. The most evident ecological advantage of adopting vermicompost is the offset of agrichemical damage to the environment. A discontinuation, even just a reduction, of synthetic fertilizer and pesticide use would have a resounding and positive impact on water and soil systems, macro- and micro-fauna, and the health of the farmers and consumers (Soares & Porto, 2009; Pimentel, 2005). Vermicompost can also be a solution for soil conservation:

- Soil treated with vermicompost lowers soil salinity (Manivannan et al, 2009; Parthasarathi et al, 2008).
- Vermicompost replaces the need for fertilizers and reduces the need for irrigation, two practices that normally contribute to salt accumulation in the soil (Darwish et al, 2005) (Manivannan et al, 2009; Parthasarathi et al, 2008; Gardiner & Miller, 2004).
- Vermicompost brings alkaline soil to more desirable pH levels, between 6 and 7 (Manivannan et al, 2009; Parthasarathi et al, 2008).
- Vermicompost spread on top of soil prevents erosion (Gardiner & Miller, 2004).
- Vermicompost improves the structure of fine-textured soils (such as Lebanon's clayey soils) for better air and water flow (Gardiner & Miller, 2004).
- Vermicompost provides nutrients that support beneficial microorganisms (Gardiner & Miller, 2004).

Vermicomposting is not an invention - rather, it is the harnessing of the earthworm's natural capacities in order to meet human needs. It is a fundamentally ecological strategy to manage two problems at once – the accumulation of burdensome organic waste on one hand (Kumar et al, 2009; Lleó et al, 2012; Murthy & Naidu, 2012) and maintaining or boosting agricultural productivity on the other (Atiyeh et al, 2000; Arancon et al, 2005; Chaudhary et al, 2004). With extremely minimal technological or fossil fuel requirements and no hazardous by-products, the process of vermicomposting is environmentally sound and sustainable.

5.2.2 Economy

This study considers the economic benefits of vermicomposting in three sectors – waste management, private enterprise, and agricultural production. This report estimates that one ton of vermicompost has a minimum value of $871 – 1,352 to society through more efficient waste management, entrepreneurial opportunities, and improved agricultural ecosystems. These impacts, however, are only the most immediate and measurable ones that can be anticipated.

Not to be overlooked is the promise of vermicompost enterprises on a *community* level. Local businesses spend more money locally on such things as management, services, and advertising. Their profits tend to be reinvested locally, thereby stimulating, however modestly, the local economy and minimizing economic "leakage". Some studies show that a local business yields two to four times the total local economic impact as compared to a non-local business. Besides keeping profits within the community, they reestablish the relationships between producers and consumers, contribute to social cohesion, and reduce negative ecological impacts associated with long-distance trade (namely fossil fuel emissions) (Roseland & Soots, 2007). Vermicompost practitioners in the Philippines reported that their businesses resulted in better relationships within the community (Adorada, 2007).

The importance of this project is that it takes advantage of what is currently a market failure - the linear production-to-consumption-to-waste stream and makes it circular. The principle of circular economies was first introduced in the early 1990's and is widely promoted throughout Asia today. In such circular systems, "benefits will be obtained, not only by minimizing use of the environment as a sink for residuals but – perhaps more importantly – by minimizing the use of virgin materials for economic activity" (Andersen, 2007). For example, vermicomposting alleviates society's dependence on the environment as a sink for waste via the commodification of the waste stream. Organic waste is transformed into vermicast - a resource for the agricultural industry that otherwise depends on unsustainable inputs (phosphorous extraction for fertilizers (Schröder et al, 2009) or peat in potting mix (Zaller, 2007)). The following diagram illustrates a simplified circular economy in which resources (R) is needed for production (P) which stimulates consumption (C) whose purpose is utility (U). These steps all lead to the creation of waste (W), a burden passed onto the environment, acting as a sink. But a circular economy involves recycling (r), allowing for some waste to be converted back into resources. In the case of vermicomposting, agricultural inputs are the resource that supports agricultural production for ultimate human consumption. Waste resulting from production (by-products from olive oil and palm oil mills and the coffee industry (Munnoli et al, 2010) (Singh et al, 2011) (Murthy & Naidu, 2012)) and consumption contribute to the waste stream, which in Lebanon, is mostly deposited in landfills and open dumps. About 13% of incoming waste is composted (MoE, 2010), however, so it could be argued that circular economy principles are not foreign, just underfunded.

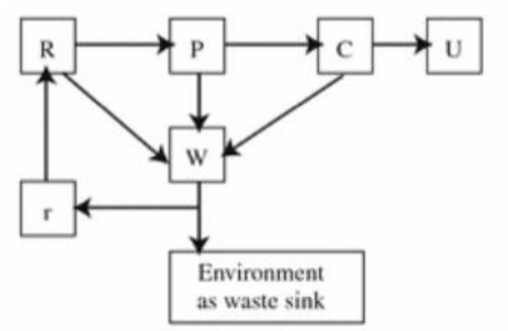


Figure 11: The Simplified Circular Economy (from Andersen, 2007)

But if businesses are rational and profit-seeking, shouldn't recycling and reuse already have been incorporated into their operations? Unfortunately, the price of natural resources and environmental services is currently too low to incentivize recycling and reuse. As such, the first step towards producing a more circular economy is to focus on the possible net benefits, *in spite of* a market economy that undervalues important environmental goods (Andersen, 2007). This is precisely what the cost-benefit analysis of vermicomposting attempts to do, albeit on a very preliminary level.

5.2.3 Social Development

Building on the discussion of circular economies above, the strength of the vermicomposting program is that recycling (r) is a business opportunity best suited for rural, farming communities. History shows that Lebanon's small farmers have been increasingly marginalized by the country's laissez-faire economic policies (Rachid, 2007). Political instability and environmental pressures exacerbate the situation (MOE, 2001; Zurayk, 1994) and many are being forced to abandon their agricultural livelihoods and seek alternative employment or migrate to urban centers (Rachid, 2007). Given these circumstances, the vermicomposting scheme has not been proposed in its high-tech, large-scale, corporate form, similar to that of North America, but in its decentralized, micro-scale form resembling that of India. As such, the microenterprise opportunity at any of its three levels (subsistence, stable, or growth) is captured by those who need it most. Yet it should be recognized that it is not out of charity that disfavored rural communities should be the benefactors, but because it is commercially sensible to take advantage of the reserve of traditional, agricultural knowledge and to engage people who will be financially *and personally* invested in the operation.

There are more off-site, long-term, far-reaching elements of social development to consider. In this report, the benefits of vermicomposting are mainly considered in terms of enhanced yields on *commercial* farms. Subsistence farming, on the other hand, can be characterized as labor-intensive, low-input food production intended for household consumption. In the face of a precarious market and an absence of insurance, subsistence farming is sometimes an economically reasonable choice for the poor. Additionally, subsistence farming often has positive health and ecology-related impacts in that they provide diverse healthy foods and medicines while at the same time serving as “repositories of biodiversity”(Hunter, 2008). The potential role of vermicomposting in contributing to the food security of disadvantaged households should not be overlooked.

By contributing, however modestly, to enhanced food security and local economies, vermicomposting could be a mechanism for improved social wellbeing. It could also preserve less tangible resources, such as the country’s culinary traditions

(Hunter, 2008) and agrarian heritage and livelihoods (Zurayk, 1994). Reinforcing rural development would ideally slow the rural-to-urban migration to cities that are already compromised by fragile infrastructure and rapid population growth. Hence, vermicomposting supports government policies committed to a balanced approach to development (The Lebanese Constitution, 1995) and raising the agricultural sector's contribution to GDP by 2% (Asmar, 2011).

5.3 Challenges

5.3.1 Behavior Changes

While the social aspects associated with vermicomposting were not explored directly, inferences can be drawn from several of the individual studies within this report. Considering the participants' nationalities in the on-campus waste collection project, the concepts of home waste separation and composting seem to resonate most with the ex-patriot community, and less with the Lebanese. The interview with Maysan in Batloun revealed that her friends and family were startled that she would be handling worms and waste. Moreover, she had believed that worms were *harmful* to plants and that they should be removed around sick plants so that they could recover. It seems that negative perceptions of earthworms and waste are commonplace and may present a hurdle for the advancement of vermicomposting.

In relation to social stigmas, it is worthwhile to briefly explore the phycology of decision-making and behavior that might influence the public's acceptance of vermicomposting. Behavioral economists recognize several phenomena in decision-making, one of which is the public's tendency to stick to the status quo. "Due to limits on time, resources, and intellectual energy, most people do not change their habits unless there are pressing reasons to do so. Research verifies that when confronted with a complex or difficult decision, and in the absence of full information about the alternatives, individuals usually stick with their current position" (Moseley & Stoker, 2013). This is linked to cognitive dissonance - people generally seek consistency between their behavior and their beliefs, but when the two become incompatible, people will sooner alter their beliefs than their behavior (Moseley & Stoker, 2013). These studies underline that the behavioral changes required for separating kitchen waste, initiating earthworm operations, and embracing vermicompost may be difficult to achieve.

It is also important to consider societal attitudes towards worms and waste. These two items are not of neutral value – attitudes, taboos, and religious beliefs underpin many reactions towards waste reuse practices. Negative values in one society may thwart efforts to adopt new treatment and reuse techniques while other societies may recognize waste as a resource, particularly where resources are scarce. It is also important to consider that people's positive attitudes towards recycling and conserving resources do not guarantee compliance or changes in their practical behavior. This is true of developed countries, but is more marked in developing countries where there are typically fewer resources available to influence public behavior. The slow process of convincing and educating large numbers of residents in meticulous separation-at-source has often led initiatives or NGO's to seek out single-source organics, such as vegetable markets (Furedy & Pitot, 2002).

Despite these hurdles, there is reason to remain "cautiously optimistic" about organic waste reuse technologies: In principle, most people desire good waste management. Furthermore, customs of organic reuse are still very present in both rural and urban settings of the developing world. In rural communities in particular, wastes are widely exploited for fuel, fodder, and fertilizer and are not regarded as “wastes” at all, but free goods (Furedy & Pitot, 2002).

Although home composting results in improved waste management on a neighborhood level and contributes to individual environmental awareness, there is no immediate incentive to compost. Backyard vermicomposting is one way to address this issue, as vermicast can be sold at a profit (Shivakumar et al, 2009; Purkayastha, 2012). But for community-based vermicomposting, how can many households be convinced to separate their waste? One successful waste management program in the Philippines has shown that households are generally willing to separate organic waste in return for door-to-door garbage pickup (Furedy & Pitot, 2002).

5.3.2 Vested Interests

Another great hurdle is vested interests. The propagation of vermicompost, a natural, home-made alternative to chemical fertilizers and pesticides, is in the least interest of agribusinesses. Very large sums of money are at stake in continuing with the status quo, that is, capital-intensive farming in which farmers are reliant upon input suppliers. “Clearly, immense profits would be lost if a move to alternatives and indigenous development paths were to lead to lowered dependence of farmers on off-farm inputs. This potential profit loss makes the entire agrarian system very resistant to change” (Rosset & Altieri, 1997).

5.4 Recommendations

5.4.1. Policy Recommendations

One important strategy that would contribute immensely to vermicompost programs is canceling pesticide subsidies. Pesticide subsidies are available for specific crops or in reaction to pest outbreaks. While such policies are most likely designed to aid small farmers, minimizing subsidies would ideally push them to seek alternatives, such as integrated pest management and/or vermicompost use (Furedy & Pitot, 2002; Hunter, 2008).

A second recommendation that could spur investment in farm innovation is the expansion of agricultural credit. Lebanon is one of the only developing countries without specialized agricultural credit systems. Most bank loans are relatively expensive, short-term, and dependent on proficient management skills and collateral, neither of which many farmers possess. Only 1% of bank loans to the private sector fund agricultural activities, mostly on large farms and agro-food industrial facilities (Hunter, 2008). A study in Malawi revealed that a lack of credit was one of the most commonly cited barriers to starting a microenterprise. Micro-credit providers may be able to cater more closely to the needs of potential entrepreneurs (Orr & Orr, 2002).

5.4.2 Vermicompost Campaign Recommendations

Political inefficiencies and government instability underline the importance of regarding farmers and rural communities themselves as key players in agrarian development. Non-governmental organizations commonly implement conservation initiatives through the participatory approach with great success, both in Lebanon and internationally. Such partnerships between communities and NGO's are even promoted by major developmental agencies such as USAID and FAO (Zurayk, 1994) and should, therefore, be considered as one avenue through which vermicomposting could be promoted throughout the country.

Another strategy to promote microenterprises is apparent – just one positive example of a well-functioning, profitable vermicompost enterprise could provide the inspiration needed to convince the public. "Successful demonstration of new techniques, with adoption by community leaders or substantial segments of a population, documentation of community and household gains with communication of results, spurs wider adoption." Inhibitions and prejudices can be overcome once the public is convinced that a treatment is safe and beneficial (Furedy & Pitot, 2002). As for applying vermicompost, potential consumers must be shown proof that the product is effective, as the interview with Maysan confirmed. Not everyone has access to the leading scientific studies, so vermicompost benefits must be demonstrated.

Lastly, when shaping an initiative appealing the public's environmental conscience, it is essential to consider public psychology. When attempting to foster sustainable behavior, the most typical avenues are through information campaigns (enhancing knowledge of an issue) and economic motivation (highlighting the economic advantages of a certain activity). It has even been proposed that the public responds more strongly to negative prospects than to positive prospects, or what will be *lost* by not participating as opposed to what will be *gained* (Moseley & Stoker, 2013). Both information campaigns and economic motivation, however, are limited in their ability to foster significant change, which has led to the emergence of social marketing. The principle of social marketing is to identify and target people's perceived barriers to engaging in an activity and strategically designing programs to overcome them (McKenzie-Mohr, 2000). These studies underline the importance of psychology in initiatives, such as a future vermicomposting campaign, that attempt to promote sustainable behaviors.

5.5 Further studies

One study of paramount importance would be an environmental/social cost-benefit analysis exploring the internalized and externalized environmental and health benefits of replacing traditional agrichemicals with vermicompost in Lebanon. A similar study on the United States found that annual pesticide use results in approximately $12 billion in environmental and social costs. If the study were able to account for all costs, the $12 billion figure would most likely double (Pimentel, 2005). Such broad, long-term studies reduce the perceived profitability of pesticides.

Another invaluable study that, unfortunately didn't fit within the scope of this project, is gauging farmers' acceptance of and willingness to pay for vermicompost. For this report, the price had to be extrapolated from the existing prices of compost and animal manure. Surveys, focus groups, and/or workshops would help better gauge demand and pricing while at the same time, sensitizing the public about vermicomposting.

Additionally, it is imperative to identify the species of earthworms used for vermicomposting. This way, vermicomposting efficiency could be optimized according to the specific needs of the worm species (substrate pH, temperature, etc).

Lastly, this report focuses specifically on home-scale vermicomposting systems utilizing household kitchen waste, but a host of other approaches could be investigated. One recommendation is to upgrade from the crate system to a slightly more elaborate concrete drum system for intensified production. Cooperative-style management, in which individual members share the profits and the risks of an operation, is another promising approach to vermicompost microenterprises (Purkayastha, 2012). Also, in Lebanon, there is great potential for coupling vermicomposting with specific waste-producing industries, such olive oil mills (Munnoli et al, 2010), slaughterhouses (Sinha et al, 2010), or restaurants. On-site waste treatment via earthworms would manage waste accumulation, generate a valuable by-product, and improve the industry's environmental image. Urban settings, where vermicomposting could be carried out on the balcony, are another frontier worth exploring.

5.6 Conclusion

This study attempts to bring attention to Lebanon's linear production-to-consumption-to-waste market economy and propose a more sustainable solution. The value of earthworms in the environment and the services they provide are often overlooked. Yet a substantial body of evidence is emerging that demonstrates how earthworms can be used to manage waste and create a good that stimulates agricultural production, thereby establishing a circular economy. The aim of this study was to test this biotechnology in the Lebanese setting. Research and experimentation have revealed efficient and affordable methods for vermicomposting, effective microentrepreneurial approaches, social dynamics, and promising markets (agricultural sector, horticultural industry, home consumption) that will trigger positive economic impacts, all of which compose a sustainable framework that can guide future vermicompost efforts in Lebanon.

REFERENCES

Adhikary, S. (2012). Vermicompost, the Story of Organic Gold: A Review. Agricultural Sciences, 3 (7): 905-917

Adorada, J.L. (2007). Assessment of Vermicomposting as a Waste Management Technology and a Livelihood Alternative in the Philippines. *Journal of Environmental Science and Management*, 10(2): 28-39

Albayrak, M., Gunes, E., Bulent, G. (2010). The effects of irrigation methods on input use and productivities of sugarbeet in Central Anatolia, Turkey. African Journal of Agricultural Research, 5(3) 188-195.

Ali, M.B. (2004). Characteristics and Production Costs of U.S. Sugarbeet Farms. United States Department of Agriculture, Statistical Bulletin n. 974-8.

Andersen, M.S. (2007) An Introductory Note on the Environmental Economics of the Circular Economy. *Sustain. Sci* (2) 133-140.

Arancon, NQ, Edwards, CA, Bierman, P, Welch, C, Metzger, JD. (2004). Infuences of vermicomposts on field strawberries: 1. Effects on growth and yields. *Bioresource Technology* 93: 145-153 (a)

Arancon, N.Q., Edwards, C.A., Atiyeh, R., Metzger, J.D. (2004) Effects of Vermicomposts Produced from Food Waste on the Growth and Yields of Greenhouse Peppers. *Bioresource Technology* 93: 139-144 (b)

Arancon, N.Q., Galvis, P.A., Edwards, C.A. (2005). Suppression of Insect Pest Populations and Damage to Plants by Vermicomposts. *Bioresource Technology* (96) 1137-1142.

Asmar, F. (2011) Country Pasture/Forage Resource Profiles. Food and Agriculture Organization.

Atiyeh, R.M., Subler, S., Edwards, C.A., Bachman, G., Metzger, J.D., & Shuster, W. (2000). Effects of vermicomposts and composts on plant growth in horticultural container media and soil. *Pedo biologia*, 44, 579-590.

Catania, K. (2008). Worm Grunting, Fiddling, and Charming – Humans Unknowingly Mimic a Predator to Harvest Bait. Plos One. 3(10).

Cedar Environmental (n.d.) Retrieved from: http://www.cedarenv.com

Chaudhary, DR, Bhandari, SC, Shukla, LM. (2004). Role of Vermicompost in Sustainable Agriculture – A Review. *Agric. Rev* 25 (10): 29-39

Clarke, W. (2000) Cost-Benefit Analysis of Introducing Technology to Rapidly Degrade Municipal Solid Waste. Waste Management Resources, 18: 510-524

Darwish, T., Atallah, T., El-Moujabber, M., Khatib, N. (2005). Salinity Evolution and Crop Response to Secondary Soil Salinity in Two Agro-Climatic Zones in Lebanon. *Agricultural Water Management* (78): 152-164

Doherty, BA & McKissick JC (2000). *Market Opportunities for Biosolids-Based Vermiculture in Georgia*. Center for Agribusiness and Economic Development at the University of Georgia, Center Special Report No. 9

Edwards, C.A., Arancon, N.Q., Vasko-Bennet, M., Askar, A., Keeney, G. (2010). *Pedobiologia* (53) 141-148

Ellis, F. (2007) *Household strategies and rural livelihood diversification*. *The Journal of Development Studies*, 35:1, pp 1-38.

Environmental Protection Agency. (1997). Full Cost Accounting for Municipal Solid Waste Management: A Handbook. Retrieved from: http://www.epa.gov/osw/conserve/tools/fca/docs/fca-hanb.pdf

Furedy, C. & Pitot, H-A (2002-2007). Social Factors in the Treatment and Use of Organic Wastes in Developing Countries. Biotechnology [ed. H. Hoelle and E. J. DaSilva] UNESCO-EOLSS (Encyclopedia of Life Support Systems): Cambridge, U.K.

Gajalakshmi, S., & Abbasi, S.A. (2004). Earthworms and vermicomposting. *Indian Journal of Biotechnology*, 3, 486-494.

Gardiner, D.T. & Miller, R.W. (2004). Soils in Our Environment (10th ed.). New Jersey, USA: Pearson Education, Inc.

Gibson, R.B. (2006). Beyond the Pillars: Sustainability Assessment as a Framework for Effective Integration of Social, Economic, and Ecological Considerations in Significant Decision-Making. *Journal of Environmental Assessment Policy and Management*, 8:3, 259-280.

Jack, A.L.H. & Thies, J.E. (2006) Compost and Vermicompost as Amendments Promoting Soil Health. In Norman Uphoff (Ed.), *Biological Approaches to Sustainable Soil Systems* (pp. 453–466). Boca Raton, FL: CRC Press

Karaa, K., Karam, F., Tarabey, N. (2004). Participatory Water Saving Management and Water Cultural Heritage: Lebanon Country Report. In : Hamdy, A. (ed), Tüzün, M. (ed), Lamaddalena, N. (ed), Todorovic, M. (ed), Bogliotti, C. (ed). *Participatory water saving management and water cultural heritage*. Bari:

CIHEAM, 2004. p. 185-198 (Options Méditerranéenes: Série B. Etudes et Recherches; n. 48)

Kates, R.W., Parris, T.M, Leiserowitz, A.A. (2012). What is Sustainable Development? Goals, Indicators, Values, and Practice. *Environment: Science and Policy for Sustainable Development*, 47:3, 8-21.

Kumar, P.R., Jayaram, A., & Somashekar, R.K. (2009). Assessment of the performance of different compost models to manage urban household organic solid wastes. *Clean Techn Environ Policy*, 11, 473-484.

Lazcano, C., Gómez-Brandón, M., Domínguez, J. (2008). Comparison of the Effectiveness of Composting and Vermicomposting for the Biological Stabilization of Cattle Manure. *Chemosphere* 72: 1013-1019.

The Lebanese Constitution (1995). Retrieved from: http://www.presidency.gov.lb/French/LebaneseSystem/Documents/Lebanese%20 Constitution.pdf

LibanCert (n.d.) Retrieved from: http://www.libancert.org/1/

Lleó, T., Albacete, E., Barrena, R., Font, X., Artola, A., & Sánchez, A. (2012) Home and vermicomposting as sustainable options for biowaste management. *Journal of Cleaner Production*, article in press, 1-7.

Manivannan, S, Balamurugan, M, Parthasarathi, K, Gunasekaran, G, Ranganathan, LS, (2009) Effect of vermicompost on soil fertility and crop productivity – beans (Phaseolus vulgaris). *Journal of Environmental Biology* 30 (2): 275-281

McKenzie-Mohr, D. (2000). Promoting Sustainable Behavior: An Introduction to Community-Based Social Marketing. *Journal of Social Issues*, 56(3): 543-554

Meerabai, M., Jayachandran, B.K., Asha, K.R. (2007). Biofarming in Bitter Gourd (*Momordica charantia* L.). *Acta Hort*. (ISHS) 752: 349-352

Ministry of the Environment. (2010). State of the Environment Report

Ministry of the Environment. (2001). State of the Environment Report

Moseley, A. & Stoker, G. (2013). Nudging Citizens? Prospects and Pitfalls Confronting a New Heuristic. *Resources, Conservation, and Recycling* (79) 4-10

Munnoli, P.M., Teixeira da Silva, J., Bhosle, S. (2010). Dynamics of the Soil-Earthworm-Plant Relationship: A Review. *Global Science Books*.

Munroe, G. (2005) Manual of On-Farm Vermicomposting and Vermiculture. Organic

Agriculture Centre of Canada. Retrieved from: http://www.organicagcentre.ca/docs/vermiculture_farmersmanual_gm.pdf

Murthy, P.S. & Naidu, M.M. (2012). Sustainable Management of Coffee Industry By-Products and Value Addition – A Review. *Resources, Conservation, and Recycling* (66) 45-58

National Bank for Agriculture and Rural Development (NABARD; 2007). Retrieved from: https://www.nabard.org/english/home.aspx

Nair, J., Sekiozoic, V., & Anda, M. (2006). Effect of pre-composting on vermicomposting of kitchen waste. *Bioresource Technology*, 97, 2091-2095.

Ndegwa, P.M., Thompson, S.A., & Das, K.C. (2000) Effects of stocking density and feeding rate on vermicomposting of biosolids. *Bioresource Technology*, 71, 5-12.

Orr, A. & Orr, S (2002). *Agriculture and Micro Enterprise in Malawi's Rural South*. Agricultural Research & Extension Network. Network Paper No. 119.

Parthasarathi, K, Balamurugan, M, Ranganathan, LS (2008) Influence of Vermicompost on the Physico-Chemical and Biological Properties in Different Types of Soil Along with Yield and Quality of the Pulse Crop- Blackgram. *Iran Journal of Environmental Health, Science, and Engineering*. 5 (1): 51-58.

Patterson, P.E. (2009). The Economics of Growing Sugarbeets in Southern Idaho: A Short Run Gross Margin Analysis. University of Idaho; Agricultural Economics Extension Series No. 09-01.

Pavlícek, T., Csuzdi, C., & Nevo, E. (2003). Species richness and zoogeographic affinities of earthworms in the Levant. *Pedobiologia*, 47, 452-457.

Peyvast, G., Olfati, J.A., Madeni, S., Forghani, A. (2008). Effect of Vermicompost on the Growth and Yield of Spinach (*Spinacia oleracea* L.). *Journal of Food, Agriculture & Environment*, 6(1):110-113

Pimentel, D. (2005) Environmental and Economic Costs of the Application of Pesticides Primarily in the United States. *Environment, Development, and Sustainability*, 7, 229-252.

Purkayastha, R.D. (2012). Forming Community Enterprises Using Vermicomposting as a Tool for Socio-Economic Betterment. 2012 International Conference on Economics, Business and Marketing Management (29).

Rachid, G. (2007*) Evolution of Natural Resource Management in Mount Lebanon: The Case of Batloun 1935 – 2005*, Masters Thesis, The American University of Beirut, Lebanon.

Richards, D, Lane, M., Beardsell, D.V. (1986). The Influence of Particle-Size Distribution in Pinebard:Sand:Brown Coal Potting Mixes on Water Supply, Aeration and Plant Growth. *Scientia Horticulturae* (29) pp 1-14.

Riggle, D. & Holmes, H. (1994). New Horizons for Commercial Vermiculture. *BioCycle* 35 (10) pp. 58

Roseland, M. & Soots, L. (2007) *Strengthening Local Economies*. State of the World 2007: Our Urban Future. Worldwatch Institute.

Rosset, P. & Altieri, M. (1997). Agroecology Versus Input Substitution: A Fundamental Contradiction of Sustainable Agriculture. *Society & Natural Resources* 10(3), 283-290

Ryan, J. (1983). Soil Conservation in Lebanon. *Journal of Soil and Water Conservation* 38(5): 404-406.

Schröder, J.J., Cordell, D., Smit, A.L., Rosemarin, A. (2009). Sustainable Use of Phosphorous. Plant Research International, Report 357.

Seenappa, S. (2011). Transformation of Wet Garbage of Indian Urbanites at Household Level. *Universal Journal of Environmental Research and Technology*, 1(2)169-175.

Sherman, R. *Snapshots of Selected Large-Scale Vermicomposting Operations* (1997) Retreived from http://www.bae.ncsu.edu/topic/vermicomposting/vermiculture/snapshot.html

Shivakumar, C., Mahajanashetti, S.B., Murthy, C., Basavaraja, H., Hawaldar, Y.N. (2009) Production and Marketing of Vermicompost in Karnataka: A Case of Dharwad District, Masters Thesis, Dharwad University of Agricultural Sciences, India.

Singh, R.P., Embrandiri, A., Ibrahim, M.H., Esa, N. (2011). Management of Biomass Residues Generated from Palm Oil Mill: Vermicomposting a Sustainable Option. *Resources, Conservation, and Recycling* (55) 423-434

Singh, R, Sharma, RR, Kumar, S, Gupta, RK, Patil, RT. (2008) Vermicompost Substitution Influences Growth, Physiological Disorders, Fruit Yield and Quality of Strawberry (*Fragaria* x *ananassa* Duch.). *Bioresource Technology*, 99: 8507-8511

Singh, N.B., Khare, A.K., Bhargava, D.S., Bhattacharya, S. (2005). Effect of Initial

Substrate pH on Vermicomposting Using *Perionyx Excavtus* (Perrier, 1872). *Applied Ecology and Environmental Research 4*(1): 85-97.

Sinha, R., Herat, S., Agarwal, S., Asadi, R., & Carretero, E. (2002). Vermiculture and waste management: study of action of earthworms *Elsinia foetida, Eudrilus euginae* and *Perionyx excavatus* on biodegradation of some community wastes in India and Australia. *The Environmentalist*, 22, 261-268.

Sinha, R.K., Herat, S., Valani, D.B., Chauhan, K.A. (2009). Environmental-Economics of Crop Production by Vermiculture: Economically Viable & Environmentally Sustainable Over Chemical Agriculture. *American-Eurasian Journal of Agriculture and Environmental Science*, 5(S): 1-55

Sinha, R, Agarwal, S, Chauhan, K, Chandran, V, Kiranbhai Soni, B. (2010) Vermiculture Technology: Reviving the Dreams of Sir Charles Darwin for Scientific Use of Earthworms in Sustainable Development Programs. *Technology and Investment*, 1:155-172.

Soares, W.L., Porto, M.F.S. (2009) Estimating the Social Cost of Pesticide Use: An Assessment from Acute Poisoning in Brazil. *Ecological Economics* 68: 2721 – 2728

Tognetti, C., Laos, F., Mazzarino, M.J., & Hernandez, M.T. (2005). Composting vs. Vermicomposting: A comparison of end product quality. *Compost Science & Utilization*, 13(1), 6-13.

Tognetti, C. Mazzarino, M.J., & Laos, F. (2007). Improving the Quality of Municipal Organic Waste Compost. *Bioresource Technology*, 98, 1067-1076.

Tripathi, G. & Bhardwaj, P. (2004). Decomposition of kitchen waste amended with cow manure using an epigeic species (*Eisenia fetida*) and an anecic species (*Lampito mauritii*). *Bioresource Technolog*y, 92, 215-218.

Van Kooten, G.C. (2013). Climate Change, Climate Science and Economics: Prospects for an Alternative Energy Future. Dordrecht, Netherlands: Springer Science + Business Media

VermiCo. “The Single Largest Producer of Vermicompost in the World” (Jan10, 2013) Retrieved from: http://www.vermico.com/the-single-largest-producer-of-vermicompost-in-the-world/

Watanabe, F.S. & Olsen, S.R. (1965). Test of an ascorbic acid method for determining phosphorus in water and sodium bicarbonate extracts from soil. *Soil Science Proceeding*. p 677.

World Bank. (2010). Republic of Lebanon Water Sector: Public Expenditure Review.

Retrieved from: http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2010/07/16/000334955_20100716015831/Rendered/PDF/520241LB0ESW0B110Disclosed0July0141.pdf

Zaller, J. (2007). Vermicompost as a substitute for peat in potting media: effects on germination, biomass allocation, yields and fruit quality of three tomato varieties. *Scientia Horticulurae*, 112(2), 191-199.

Zurayk, R. (1994). Rehabilitating the Ancient Terraced Lands of Lebanon. *Soil and Water Conservation* 49(2), pp 106-112.

APPENDICES

Appendix 1: Various Earthworm Technologies (from Sinha et al, 2010)

Vermifiltration
With world water demand on the rise and scientific studies warning of a limited water supply, the treatment of wastewater has become a necessity. Conventional wastewater treatment, however, generates a byproduct called sludge which often poses a challenge for disposal. *Vermifiltration* is a recently innovation recruiting the services of waste-eating earthworms. Suspended solids are added to a vermifilter to be processed by the worms and other soil microbes. The ingestion and degradation of the sludge results in a 90% decrease in biological oxygen demand (BOD), a 80-90% decrease in chemical oxygen demand (COD), a 90-92% decrease in total dissolved solids, and a 90-95% decrease in total suspended solids. Additionally, studies indicate that the worms also remove heavy metals and pathogens from wastewater. In short, vermifiltration has been proven capable of rendering wastewater reusable for non-potable purposes. The low energy requirements and the mitigation of odor problems makes this an even more appealing technology and indeed, commercial vermifiltration plants have already appeared throughout much of South America and India.

Vermiremediation
The remediation of chemically contaminated sites have traditionally involved soil excavation and disposal in secured landfills. Admittedly, this process is costly and merely shifts the problem elsewhere. Vermiremediation, introducing earthworm species especially tolerant to specific chemicals, has proven itself as a low-cost, and efficient alternative for land remediation that addresses the problem *on-site*. Due to the physiology of the earthworm, these invertebrates are able to take up contaminated soil matter either through ingestion or through passive absorption. Once the pollutants are within the earthworm body, they are subject to either biotransformation or biodegradation and are later excreted in a less harmful form. Earthworms are endowed with an especially high quantity of metal binding proteins, thereby making them particularly efficient at remedying heavy metal pollution. Furthermore, studies have shown them to efficiently reduce quantities of polycyclic aromatic hydrocarbons (PAH’s, polychlorinated biphenyls, agrochemicals, and the hydrocarbons from petroleum and crude oil spills.

Vermiculture for Industry
Certain biological compounds found in earthworms. Steric acid, for example, is widely used as additives and lubricants in industrial preparations and has also found applications in the soap, cosmetics, food packaging, and rubber industries. Of greater consequence, many pharmaceutical and medicinal uses have been found for earthworm compounds. Specific isolated compounds have been shown to have “clot-dissolving” and immune-boosting properties in clinical tests. One report shows that the earthworm’s coelomic fluid has anti-pathogenic activities and can be used in the production of antibiotics. The list of earthworm compounds for medical use is extensive

Because earthworms are unusually rich in protein as well as vitamins A and B, they can and have been fed to cattle, fish, and poultry as a probiotic feed. Although it would require a stretch of the imagination, the high protein content (higher than in any product) and the lower fat content (approximately 2% lower than meat) would make earthworms ideal for human consumption, particularly amongst populations that are protein-deprived.

Appendix 2: Earthworm Species Confirmed in Lebanon (from Pavlícek et al, 2003)

Allolobophora (s.I.) aharonii
Aporrectodea caliginosa caliginosa
Aporrectodea caliginosa trapezoides
Aporrectodea jassyensis Michaelsen
Aporrectodea rosea
Bimastos syriacus
Dendrobaena byblica
Dendrobaena kervillei
Dendrobaena orientalis
Dendrobaena samarigera
Dendrobaena semitica
Dendrobaena veneta veneta
Eiseniella tatraedra neapolitana
Eiseniella tetraedra tetraedra
Helodrilus patriarchalis
Criodrilus lacuum Hoffmeister
Metaphire californica

Appendix 3: Waste Separation Reminder for On-Campus Participants

كلا	**نعم**
الحمضيات (البرتقال و الحامض...)	الفواكه، الخضار، العفنة منها والتالفة فيما يتضمن البذور والقشور
اللحوم	قشور البيض
الأجبان والالبان	تفل القهوة
المأكولات المطبوخة	أكياس الشاي
	قشور المكسرات

No	Yes
Citrus (lemons, oranges)	Fruits and vegetables, they can be rotten or moldy, including seeds and peels
Meat	Egg shells
Dairy products (cheese, milk, yogurt)	Coffee grounds and tea bags
Cooked foods	Nuts and nutshells

Appendix 4: Vermicomposting Guidelines (English)

The Collection

1.) Collect kitchen waste. Kitchen waste can include any kind of raw fruits, vegetables, seeds and peels even if they are rotten or moldy. Eggshells, tea bags, coffee grounds, nuts, and nut shells an all be included. Do not collect meat, dairy products or cooked foods, and keep citrus fruits, such as lemons and oranges, to a minimum.

The Vermicomposting Crate

2.) Create a "mother" crate using the steps below. This crate will hold the worm population and will supply the other crates.
3.) Cut the cloth material to line the plastic crate.
4.) Place the crate on top of an empty overturned one so that it isn't touching the ground.
5.) Fill the crate with waste until it is nearly full.
6.) Add a layer of soil on top of the waste so that the waste is covered and can't be seen.
7.) Add the worms from the mother crate- about one coffee cup worth of worms, or a small handful.
8.) Add a label to the crate that shows the date.
9.) Place another empty crate on top for shade and protection.
10.) Monitor about once every two weeks. Gently dig in the corner of the crate to uncover the waste. Check that it is decomposing and that the worms are healthy and active. Plants may start to sprout, but they can be left in place.
11.) If the contents are dry, add some water. If the climate is hot and dry, water may need to be added more often. The vermicompost should always be slightly moist.
12.) After about two months, check the contents. If it looks like dirt, has a fine texture, and is dark in color, it is probably ready for harvesting. There will probably be some especially hard waste, such as pits and eggshells, that don't completely decompose. This is normal.
13.) If you can still see and identify pieces of produce, let the vermicomposting continue for another few weeks.

The Harvest

14.) Lay a sheet of plastic on the ground or on an outdoor table. Pour or shovel the contents of the crate onto the plastic sheet. If using a shovel, dig carefully so you don't injure the worms.

15.) Remove as many worms and eggs from the vermicompost as realistically possible. Add them to the mother crate or to a new batch of waste.
16.) Any worms or eggs left in the vermicompost will be an added benefit to the consumer.
17.) Undecomposed materials can be removed and placed in a new crate for further decomposition.
18.) Let the vermicast dry in the sun.
19.) Put it in a bag and label it.
20.) The cloth material is probably holding many worms and eggs. It can be reused in a new crate.

The Application

21.) For potted plants, replace approximately 15% of the soil in the pot with vermicompost and mix.
22.) For a garden or field pre-sewing, spread vermicompost and incorporate into the soil. Recommended doses range between 2-5 tons per hectare.
23.) If plants have already been sown, spread the vermicompost, incorporate it where possible, but otherwise, let lay on the surface.
24.)If seedlings are being transplanted, add a small handful of vermicompost in the hole with the plant.
25.) Don’t worry if there are worms in the vermicompost. Worms are good for the soil.

Vermicomposting Guidelines (Arabic)

الـ جمع عمـلـ ية

والـ بذور والـ خـ ضروات الـ طازجة الـ فواكه من نـ وع أي تـ شمل أن يـ مكن الـمط بخ نـ فايـ ات .الـمط بخ نـ فايـ ات اجمع
الـ شاي، وأكـ ياس الـ بـ يض، قـ شر جمـ يع تـ شمل أن عـ لـى .مـ تـ عـ فـ نة أو فـ ا سدة كـ انـ ت لـ و حـ تى والـ قـ شور
يـ جب و الـمط بوخة، الأطـ عمة أو الألـ بان ومـ نـ تجات الـ لحوم تـ جمع و لا .الـ جوز وأ صداف والـمكـ سرات، والـ قهوة،
.الأدنـ ى الـ حد عـ ند والـ برتـ قال، الـ لـ يمون مـ ثل الـ حمـ ضـ يات، ابـ قاء

الـ فرمكمـ بـ سـ تـ نغ قـ فص فـ ي

الـ صـ نادي ق و سـ يزود الـ دود سـ يحمل الـ قـ فص وهذا .أدنـ اه الـ خطوات بـ ا سـ تخدام "الأم"الـ قـ فص بـ إنـ شاء قـ م
.الأخـ رى

.الـ بلا سـ تـ يك قـ فص حدود لـ ر سم الـ قماش مادة قـ طع

.الأرض يـ لامس لا إنـ ه بـ حـ يث وفـ ارغ مـ قـ لوب أخر قفصٍ رأس عـ لى الـ قـ فص ضع

.مم تـ لـئ شـ به يـ صـ بح حـ تى بـ الـ نـ فايـ ات الـ قـ فص املأ

يـ مكن و لا الـ نـ فايـ ات، يـ ةتـ غطـ يـ تم بـ حـ يث الـ نـ فايـ ات من الـ عـ لوي الـ جزء عـ لى الـ تربـ ة من طـ بـ قة أ ضف
.بـ عد رؤيـ تها

. صغـ يرة حـ فـ نة أو الـ ديـ دان، من قـ هوة فـ نجان حوالـ ي- الأم الـ قـ فص من الـ ديـ دان أ ضف

.الـ تاريـ خ فـ يه يـ ظهر قـ فص إلـ ى تـ سمـ ية أ ضف

.والـحمايـة الـظل أجل من فـ وقـه آخرا فارغاً قفصاً ضع

تـ حـقق .الـ نـ فايـ ات عن لـ لـكـشف الـ قـ فص زاويـ ة فـ ي بـ لطف إحـ فر .أ سـ بوعـ ين كل واحدة مرة بـ الـمراق بـة قـ م أن يـ مـكن ولـ كن بـ الـ نمو، الـ نـ باتـ ات تـ بدأ قـ د.ونـ شـ يطة جـ يدة صـحـ ية بـ حالـة هي الـديـ دان وأن مـ تحـلـلة أنـها .مكانـها فـ ي تـ ترك

الـماء إ ضافـ ة إلـ ى تـ حـ تاج قـ د وجافاً، حاراً الـمـ ناخ كـان إذا .الـماء بـ عض أ ضف جافـ ة، الـمحـ تويـ ات كـانـ ت وإذا .الأحـ يان أكـ ثر فـ ي

.قـ لـ يلا رطب الـدود سماد دائماً كونِي أن يـ نـ بغي

فـ من الـ لون وداكـ نـة نـ اعم، نـ سـ يج ولـها الاو ساخ، مـ ثل بـ دت إذا .مـحـ تويـ اتـ ها من تـ حـ قق شهريـ ن، حوالـ ي بـ عد الـ حـ فر مـ ثل ، الـ صلـ بة الـ نـ فايـ ات بـ عض هناك يـ كون أن الـمحـ تمل من .لـ لـحـ صاد جاهـزة تـ كون أن الـمحـ تمل .يـ عيطب أمر وهذا .تـ ماما تـ تحـ لل لا الـ تي الـ بـ يض، وقـ شر

أ سابـ يع لـ بـ ضعة عمـلـه يـ كمل الـدود سماد دع الـمـ نـ تجات، من قطعاً وتـ حدد تـ رى أن تـ سـ تطـ يع تـ زال لا كـ نت إذا .أخرى

الـ حـ صاد

محـ تويـ ات بـ جرف قـ م أو صب .الـطـ لق الـهواء فـ ي طاولـة عـلـى أو الأرض عـلـى الـ بـ لاسـ تـ يك من ورقـ ة ضع .الـديـ دان تـ جرح لا تـ ىح بـ عـ نايـ ة إحـ فر مجرفـ ة، ا سـ تخدمت إذا .الـ بـ لاسـ تـ يك من ورقـ ة عـلـى الـ قـ فص

من جديـ دة مجموعة إلـ ى أو الأم الـ قـ فص إلـ ى ا ضـ فها . الـدود سماد من وبيضاً ديداناً الإمـ كان قـ در عـلـى أزل .الـ نـ فايـ ات

.لـ لمـ سـ تهلك مـضافـ ة فـ ائـ دة الـدودبـ مـ ثابـ ة سماد فـ ي الـمـ تـ بـقي الـ بـ يض أو الـديـ دان من أي سـ يكون

.الـ تحـ لل من لـمزيـ د دجدي قـ فص فـ ي وو ضعها مـ تحـلـلة الـ غـ ير الـمواد إزالـة يـ مـكن

.الـ شمس فـ ي يـ جف الـدود سماد دع

. بـ تـ سمـ يـ ته وقـ م كـ يس فـ ي ضعه

قـ فص فـ ي ا سـ تخدامها إعادة ويـ مـكن .والـ بـ يض الـديـ دان من الـ عديـ د تـ حمل الـ قماش مادة أن الارجـ ح عـلـى .جديـ د

الـ تطـ بـ يق

الـدود بـ سماد وعاءال فـ ي الـ تربـ ة من ٪15 من يـ قرب ما بـ إ سـ تـ بدال فـ قم بـ وعاء، الـمحـ فوظة الـ نـ باتـ ات أما .واخـ لطها

الـمو صى الـجرعات تـ تراوح .الـ تربـ ة فـ ي وإدمجه الـدود سماد إنـ شر ، الـ بذر عمـلـ ية قـ بل ما حـ قل أو لـ حديـ قة .الـواحد لـ لهكـ تار طن ٥-٢ بـ ين بـ ها

دع ذلـك، خـلاف عـلـى ولـ كن ممكـ نا، ذلـك كـان حـ يـ ثما إدمجه ، الـدود سماد انـ شر الـ نـ باتـ ات، زرع بـ الـ فعل تـ م إذا .الـ سطح عـلـى يـ ظهر الـ سماد

.الـ نـ بات مع الـ حـ فرة فـ ي الـدود سماد من صغـ يرة حـ فـ نة أ ضف الـ شـ تلات، زرع تـ م قـ د كـان إذا

.لـ لـ تربـ ة يـ دةج هي الـديـ دان . الـدود سماد فـ ي الـديـ دان هناك كـان إذا تـ قـلق لا

Appendix 5: SPSS Results Showing Significance

Arugula

Average Height per Pot

Duncan[a]

Percentage	N	Subset for alpha = 0.05		
		1	2	3
0%	10	5.838		
5%	10		10.516	
25%	10			13.047
15%	10			13.087
Sig.		1.000	1.000	.952

Leaf Number

Duncan[a,b]

Percentage	N	Subset for alpha = 0.05	
		1	2
0%	15	35.200	
5%	15	52.600	52.600
15%	14	53.071	53.071
25%	15		58.000
Sig.		.071	.585

Parsley

Plant Number

Duncan[a]

Percentage	N	Subset for alpha = 0.05	
		1	2
0%	15	4.400	
15%	15	5.400	5.400
5%	15		5.733
25%	15		6.467
Sig.		.089	.085

Average Height per Pot

Duncan[a]

Percentage	N	Subset for alpha = 0.05	
		1	2
0%	10	7.484	
5%	10		12.985
25%	10		13.990
15%	10		15.921
Sig.		1.000	.060

Leaf Number

Duncan[a]

Percentage	N	Subset for alpha = 0.05	
		1	2
0%	10	23.800	
5%	10		54.200
15%	10		69.700
25%	10		70.600
Sig.		1.000	.213

Cucumber

Leaf Number

Duncan[a]

Percentage	N	Subset for alpha = 0.05	
		1	2
5%	20	8.350	
0%	20	8.400	
25%	20	10.050	10.050
15%	20		10.200
Sig.		.053	.856

Tomato

Leaf Number

Duncan[a]

Percentage	N	Subset for alpha = 0.05	
		1	2
0%	20	9.150	
5%	20	10.550	10.550
25%	20	11.450	11.450
15%	20		11.850
Sig.		.061	.291

Flower Number

Duncan[a]

Percentage	N	Subset for alpha = 0.05	
		1	2
25%	15	.467	
5%	15	.733	
0%	15	.800	
15%	15		2.133
Sig.		.581	1.000

Shoot Wet Weight

Duncan[a]

Percentage	N	Subset for alpha = 0.05	
		1	2
0%	5	53.0200	
5%	5	63.6200	63.6200
25%	5		71.3800
15%	5		76.2000
Sig.		.172	.126

Root Dry Weight

Duncan[a]

Percentage	N	Subset for alpha = 0.05	
		1	2
25%	5	.2400	
0%	5	1.3000	1.3000
5%	5		1.9000
15%	5		2.7800
Sig.		.167	.072

Appendix 6: Photos of five decomposition stages

Stage 1

(From: http://en.reset.org/act/home-composting-india-new-thing-do)

Stage 2

source: http://www.treehugger.com/slideshows/readers-photos/readers-composting-vermicomposting-systems/

Stage 3

source:
http://www.thedailygreen.com/environmental-news/latest/back-to-school-projects#slide-1

Stage 4

source:
http://cltampa.com/dailyloaf/archives/2010/11/24/vermicomposting-101-super-fertilizer-from-worm-poop-video#.UuEmePb8Iy4

Stage 5

Source: http://permaculturenews.org/2013/03/20/worm-bin-and-chicken-poop-compost-catch/

Appendix 7: Decomposition Observations (grey indicates the day the vermicompost was harvested)

Box #	6-Oct	13-Oct	21-Oct	26-Oct	2-Nov	9-Nov	16-Nov	23-Nov	30-Nov
24-Aug	3	5	5	5	5	5	5	5	5
24-Jul	2	3	4	4	5	5	5	5	5
21-Sep	1	2	3	4	4	4	5	5	5
18-Jul	4	4	5	5	5	5	5	5	5
23-Sep	1	2	3	3	4	4	5	5	5
30-Aug	2	3	4	5	5	5	5	5	5
6-Oct	1	1	2	3	4	4	4	4	5
12-Jul (1)	5	5	5	5	5	5	5	5	
16-Jul (1)	5	5	5	5	5	5	5	5	5
9-Sep (1)	3	4	5	5	5	5	5	5	5
12-Jul (2)	5	5	5	5	5	5	5	5	5
16-Jul (2)	5	5	5	5	5	5	5	5	5
12-Jul (3)	4	4	5	5	5	5	5	5	5
9-Sep (2)	3	3	4	5	5	5	5	5	5
2-Jul	5	5	5	5	5				
3-Sep	3	4	4	5	5	5	5	5	5
8-Jul	5	5	5	5	5	5	5	5	
15-Sep	1	2	4	4	4	4	5	5	5
5-Jul (1)	5	5	5	5	5	5			
5-Jul (2)	5	5	5	5	5	5			
22-Jul (1)	4	4	5	5	5	5	5	5	5
7-Jul	4	4	4	4	5	5	5		
22-Jul (2)	5	5	5	5	5	5	5	5	5
5-Jul (3)	5	5	5	5	5	5	5		
30-Sep	1	1	3	3	4	4	5	5	5
16-Aug	4	4	5	5	5	5	5	5	5
1-Sep	3	3	4	4	5	5	5	5	5
3-Sep	3	3	4	5	5	5	5	5	5
13-Oct		1	1	2	3	3	4	4	4
21-Oct			1	2	3	3	4	4	4
25-Oct (1)				1	1	2	2	2	2
25-Oct (2)				1	1	2	2	3	3
30-Oct (1)					1	1	3	3	4
30-Oct (2)					1	3	3	3	3
6-Nov (1)						1	1	2	4
6-Nov (2)						1	2	3	3
13-Nov (1)							1	3	3
13-Nov (2)							1	3	3

Appendix 8: STATA Results of Ordered Logit Regression

Day	Score=1	Score=2	Score=3	Score=4	Score=5	Average
1	84.641941	12.240643	2.9615407	0.14790544	0.00796935	1.186393176
5	71.158893	22.135522	6.3580699	0.3297153	0.01779968	1.359120063
10	47.465141	36.127486	15.464052	0.89472795	0.04859241	1.699341429
15	24.860311	40.244048	32.361003	2.4020524	0.13258469	2.127025491
20	10.806395	29.783014	52.779887	6.2694702	0.36123345	2.555961321
25	4.2481913	15.763556	63.745238	15.262686	0.98032742	2.929633984
30	1.5987032	6.7939463	56.984564	31.990373	2.6324135	3.272638473
35	0.59142657	2.6545672	37.633888	52.244774	6.875344	3.62158041
40	0.21739112	0.99623723	18.991413	63.016388	16.778571	3.951425116
45	0.07971693	0.36815022	8.0377531	56.006935	35.507445	4.264942417
50	0.02920653	0.13526612	3.1195229	36.660279	60.055726	4.565780535
55	0.02343914	0.10859049	2.520531	32.147703	65.199736	4.623917051
60	0.01881041	0.08716894	2.0338703	27.848067	70.012084	4.677474472
65	0.01509562	0.06996896	1.6394199	23.855471	74.420044	4.725953972
70	0.01211436	0.0561601	1.3203271	20.231243	78.380155	4.769111629
75	0.00972182	0.04507476	1.0625992	17.006112	81.876492	4.806945769
80	0.00780176	0.0361764	0.85469788	14.185106	84.916218	4.839657622
85	0.00626089	0.02903397	0.68716101	11.753745	87.523799	4.867597869
90	0.00502432	0.02330122	0.55226247	9.6843207	89.735091	4.89121152
95	0.00403198	0.01870009	0.44371563	7.9414496	91.592103	4.910988925
100	0.00323563	0.01500733	0.35641922	6.4864865	93.138851	4.92742709
105	0.00259656	0.01204366	0.28624298	5.2807224	94.418394	4.941002724
110	0.00208371	0.00966517	0.22984876	4.2874847	95.470918	4.952154891
115	0.00167215	0.00775636	0.18454238	3.4733535	96.332676	4.96127606
120	0.00134188	0.0062245	0.1481519	2.8087253	97.035556	4.968709278
125	0.00107684	0.00499515	0.11892794	2.2679309	97.607069	4.974749196
130	0.00086415	0.00400859	0.09546252	1.8290735	98.070591	4.979645179
135	0.00069347	0.00321686	0.07662311	1.47371	98.445757	4.983606215
140	0.0005565	0.00258151	0.0614991	1.1864597	98.748903	4.986805706
145	0.00044658	0.00207163	0.04935868	0.95459581	98.993527	4.989386841
150	0.00035837	0.00166246	0.03961382	0.76765277	99.190713	4.991467008

The left-hand column shows the number of days that have past. The uppermost row is the decomposition stages 1-5. All these numbers represent the probability that the crate contents would have reached a specified stage in relation to time.

Appendix 9: Guideline Interview Questions for Maysan

General Questions
How do you feel about the project?
What are your personal feelings towards vermicomposting? (Rewarding, difficult...)
*without asking: Education achieved, former profession?

Previous Knowledge
What did you know about earthworms and their role in agriculture/gardening before the project?
Were you familiar with composting and/or burying organic waste?
Had you heard of vermicomposting before the project?

What Has She Learned?
What are some of the observations regarding the worms and the vermicomposting process that you've made?
How did she structure the waste collection? (How many families did she collect from? How often? Was it stinky)
What kind of skills have you developed during the course of the project?
*without asking: Could she be independent?

Social Experience
How did your neighbors respond when you asked for their kitchen waste? Were they willing to separate?
How did your friends and family respond to the vermicomposting project?
Did having this "part-time job" change any aspect of her home life? (Earning money, taking up time?)

Personal Perception
Knowing what you now know about vermicomposting, would you continue it on your own? On a home scale or for sale?
As a gardener, would you be willing to use/buy vermicompost for your garden?
Do you have any complaints, comments, suggestions that would improve the process?

Appendix 10: Studies and Calculations to Measure Enhanced Yield With One Ton of Vermicompost

Study	Control	Vermicompost @ 5 t/ha	Difference	Increase per 5 tons	Increase per ton	Average
Manivannnn et al, 2009 India # bean pods/plant	9	19	10	111%	22%	
	7	18	11	157%	31%	
Parthasarathi et al, 2008 India Blackgram (lentil)	1600	2100	500	31%	6%	**11%**
	2200	2750	550	25%	5%	
	2100	2250	150	7%	1%	
Singh et al 2008 India Strawberry g/plant	298.5	347.1	48.6	17%	3%	

The Vermicompost yield minus the control yield indicates the difference. The difference is then divided by the control, which calculates the percent increase. This percent increase is only relevant when 5 tons of vermicompost are applied, however, so to find the per ton increase, it must be divided by 5. All of the data under "increase per ton" is then averaged to generate 11%. This means that fertilizer use could be abandoned and the productivity would not only be matched by vermicompost, it would be enhanced by an additional 11%.