Developing an Integrated Approach for Assessment and Utilization of Biomass for Improving City Sustainability

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SUMMARY

About 40% of total world's food production, which uses precious land and water resources, goes as waste. Improved methods for foodwaste management are needed. In principle, converting enormous amount of foodwaste produced globally into soil amendment can reduce the application of chemical fertilizers considerably if the appropriate methods are adopted for recycling foodwaste into soil amendment. These methods have enormous potential for enhancing sustainable agriculture system.

Recycling of organic wastes including foodwaste and green waste has received a greater level of interest recently. Many waste treatment processes such as windrow composting and anaerobic digester are promising technologies; however, the fate of food-borne pathogens in these methods is not well understood. Further, extensive time, infrastructures, and space are needed to adopt these methods in urban environment.

There is a need to improve the existing food and green wastes treatment methods for enhancing the sustainability of urban environment, and derive advanced methods for converting urban waste into a soil amendment. We have executed a series of studies in three different parts of the world (Davis, California, USA; Beirut, Lebanon; and Birzeit, West Bank, Palestine) to improve the understanding of foodwaste, grass clipping, horse manure, and palm tree waste conversion into a soil amendment. The work was executed in collaboration of University of California Davis, Davis, California, USA; American University of Beirut, Beirut, Lebanon; Birzeit University, Birzeit, West Bank, Palestine; and Diamond Developers, Co LTD, Dubai, UAE.

This study executed five different types of composting processes (in-vessel composting, static composting, aerated composting, plowed composting, and vermicomposting) at University of California-Davis, Davis, California. In addition, a model was developed to estimate the organic waste production of a sustainable city. Further, we developed a dynamic model to verify the progression and the quality of composting process at Tadweer Waste Treatment LLC, Dubai, UAE. The research team at American University of Beirut has executed an intensive study, which was focused on understanding the social acceptability, environmental benefits, and economics of vermicomposting. Another research team at Birzeit University, West Bank, Palestine performed a windrow composting research.

The report is presented in **three parts**. The **first part**, which has four chapters, presents the work of Davis. The Chapter 1 has focused on in-vessel composting system. The findings of aerated, plowed, and static heating (and composting) systems are presented in Chapter 2. Vermicomposting research is presented in Chapter 3. Chapter 4 describes modeling work. The **second part** has two master's theses focused on vermicomposting work carried out at Beirut. The **third part** presents the windrow composting work performed at Birzeit.

This report provides in-depth insight of various waste treatment methods, potential hurdles, and new novel methods, which are potentially useful for converting foodwaste and green waste into a pathogen free soil amendment. The developed waste treatment processes will pose no/minimum health risk to the public and environmental health.

University of California-Davis's work showed that in-vessel composting is the most suitable method for inactivating pathogens (*E. coli* and *Salmonella*) of organic waste within 24 hours. In addition, the results showed that this processed produced a high quality soil amendment. Another work, which studied in-house composting with an external heading and aeration system, produced *Salmonella* free mature compost in 70 days. The lab and field scales vermicomposting experiments provided important insights to convert food and green waste into a matured soil amendment. The developed mathematical provided the

method to verify the composting process, and test the quality of the compost product. Further, the model calculates the waste production of a sustainable city.

American University of Beirut's work assessed public perception and attitude towards the vermicomposting in Lebanon. The work also developed an innovative and economic system to raise the worms in household for converting household waste into soil amendment. Though the residents showed a greater level of interest in vermicomposting, a general view was to carryout vermicomposting at municipality level instead of at a home. Further, the work showed that one ton of vermicast will yield an estimated US$871-1,352 across three sectors: landfill operations, the private vermicompost, and agriculture.

Birzeit University's study investigated the feasibility of a windrow composting of domestic organic waste recycling for overcoming the problems related to waste collection and disposal. The results of five compost piles under five different mixing conditions showed that the windrow composting was controlled by moisture content, temperature, and pH. The compost quality met the USEPA standards after 3.5 months of windrow composting. Lab results showed that a 95% of total coliforms were removed during the process.

PART 1

CHAPTER 1: In-vessel composting systems for converting food and green waste into pathogen free compost – A pilot study

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Abstract

To better understand the impacts of in-vessel composting on foodwaste treatment, a series of experiments were conducted using both pilot-scale (200 L) and bench-scale (1 L) in-vessel systems. The effects of additives on the digestate quality and pathogen inactivation were tested by comparing the results with and without additives. External heat and continuous mixing were provided for achieving the typical composting temperature (≈58- 60 °C). The feedstock included food waste, horse manure, palm-tree waste, and green waste. To evaluate the efficacy of composting, the digestate was tested for the inactivation of pathogen (*Salmonella enterica* serovar Typhimurium) and pathogen indicator (*E. coli*). We also evaluated the changes in pH, moisture level, variations in carbon (C) content, and carbon to nitrogen (C: N) ratio. Results showed that the proposed method produced a pathogen free compost (i.e., as a soil amendment) from the feedstock. The survival of *E. coli* was prolonged considerably compared to *Salmonella*. The inactivation models for *E. coli* and *Salmonella* were developed to calculate pathogen inactivation time. The authors anticipate that the results will be useful for deriving the improved and accelerated method for converting foodwaste into soil amendment with a minimal pathogen risk to the public and environmental health.

Keywords: digestate quality, foodwaste treatment; in-vessel composting; pathogen inactivation

1. Introduction

The disposal of excess foodwaste produced in urban environment is a serious issue (Kim et al., 2008; Li et al., 2013; Pandey et al., 2015), which requires identifying improved and accelerated treatment methods. More than 40% of food, which is produced using precious land and water resources, goes as a waste (Gustavsson et al., 2011; Gunders, 2012). A major portion of the foodwaste, the second largest category of municipal solid waste (MSW), reaches to landfills (USEPA, 2015). Currently, increasing amount of foodwaste in the United States (US) not only puts stress on limited landfills but also increases greenhouse gas (GHG) emissions (USEPA, 2015). Therefore, identifying improved foodwaste treatment methods which are capable of converting wastes into useful end products such as soil amendments are needed. Eventually these methods will help to control the excess foodwaste reaching into landfills. In addition, by controlling the influx of organic carbon (C) and nutrients into landfills, these methods will help in reducing GHG emission from landfills.

The two conventional foodwaste treatment methods are composting and anaerobic digestion (AD) (Parthan et al., 2012; Tsilemou & Panagiotakopoulos, 2006). The major advantage of AD method is the production of bio-methane, which can be captured and utilized as a renewable energy source (Lins et al., 2014; Pandey et al., 2011; Zhu et al., 2014). Composting is a natural treatment method and requires minimal external energy input to complete the process (Goldstein, 2014; Watteau & Villemin, 2011; Zhou et al., 2014). Both of these processes produce end products which are useful for fertilizing the crops (Pandey et al., 2011; Razali et al., 2012; Sangamithirai et al., 2015; Zhu et al., 2014). However, currently there is a growing public concern about the potential linkage between organic soil amendments and pathogen contamination (Larney et al., 2003; Pandey et al., 2015). A major drawback of composting and AD processes is that these are slow processes, and often require 60-90 days to complete the process (Iyengar & Bhave, 2006; Kim et al., 2008; Lins et al., 2014; Pandey et al., 2011), and importantly, elimination of pathogen is uncertain. Because these processes are slow, relatively a large space is needed to design AD and composting facilities, which is cost prohibitive for the foodwaste treatment (Parthan et al., 2012; Tsilemou & Panagiotakopoulos, 2006). Additionally, the space is often limited in urban areas, and the establishment of such a large infrastructure in the vicinity of cities poses numerous challenges.

While traditional composting such as windrow system is recognized for treating organic wastes, the little understanding of relationships among pathogen inactivation, composting time, and temperature are a common concern (Larney et al., 2003; Pandey et al., 2015). Previous studies showed that in-vessel composting can accelerate the composting process (An et al., 2012; Antizar-Ladislao et al., 2005; Iyengar

& Bhave, 2006; Kim et al., 2008; Sangamithirai et al., 2015; Walker et al., 2009) and reduce the composting time. Iyengar and Bhave (2006) used in-vessel (mixed and non-mixed) composting system for converting household wastes (in 60 days) into humus which is useful for improving the soil nutrients. An et al. (2012) used in-vessel composting system to evaluate the composting of agro-industrial and industrial wastes, which contain coal ash and uric acid. The authors reported that the presence of coal ash and uric acid in foodwaste elevate the compost temperature and pH considerably compared to the compost without any coal ash and uric acid contents. A matured compost product was obtained just in 25 days of composting process. The presence of coal ash and uric acids also improved the thermophilic and mesophilic microorganisms suitable for composting process. Kim et al. (2008) used a pilot-scale in-vessel composting system for foodwaste treatment and reported that the manure compost suitable for agricultural application was obtained in 30 days of composing process compared to tradition composting, which requires more than 90 days.

Walker et al. (2009), in their study compared an in-vessel composting of MSW under thermophilic AD conditions with a static composting system and reported that an in-vessel treatment combined with anaerobic phase showed an improved hydrolysis and oxidation rates and product stability (within 10-12 days). Another study by Sagamithirai et al. (2015) used in-vessel composting system for co-composting of yard waste mixed with vegetable, fruit, paper, and coffee wastes. The authors reported that they achieved a mature compost (no heavy metals at toxic levels) with C:N less than 30:1 between 8 and 15 weeks. These studies provided important insight about in-vessel composting system; however, the pathogen inactivation during the in-vessel composting process is not well understood. In addition, the temperature profiles during non-heated in-vessel composting system are uncertain. The uncertainty of reaching essential optimum temperature (≈60 °C) for pathogen inactivation during composting process increases the possibility of pathogen contamination in mature compost. The in-vessel composting system with the provision of heating can be an option to reduce the pathogen risk.

The increased emphasis on controlling food-borne pathogens and the public health risk requires application of soil amendment with minimum pathogen risks to the health of soil and crops, animal, environment, and human (Angulo & Mølbak, 2005; Heringa et al., 2010; Pandey et al., 2015; Park & Diez-Gonzalez, 2003). The compost with elevated level of pathogens will subsequently increase the influx of pathogens in cropland if the contaminated compost is applied as a soil amendment (Heringa et al., 2010; Li et al., 2013; Pandey et al., 2015).

To better understand the potential benefits of in-vessel composting system and to develop an advanced in-vessel composting system for treating common urban complex waste streams such as foodwaste, grass clippings, horse manure, and palm tree wastes, a series of pilot-scale and lab-scale experiments were executed. The objectives were to: 1) evaluate the performance of in-vessel composting on foodborne pathogen inactivation; 2) assess the quality (pH, carbon, and C: N ratio) of digestate produced during in-vessel composting system; and 3) develop the predictive models for calculating pathogen inactivation in in-vessel composting system.

2. Material and methods

2.1. Pilot-scale and bench-scale systems

The pilot-scale study was conducted at Teaching and Research Animal Care Services (TRACS), and the bench-scale study was conducted at Extension lab of School of Veterinary Medicine, University of California, Davis (UC Davis), California, USA. The schematics of pilot-scale and bench- scale experiments are shown in Figure 1.

The bench-scale experiment was carried-out in two reactors (each 1000 mL capacity). The pilot-scale experiment involved a bio-digester of 200 L capacity (BioMixer-200L, Daega Powder Systems Co., Ltd). The bench-scale reactors were designed in lab using two sterile glass beakers, a 10 L isotemp water bath (Thermo Fisher Scientific, Waltham, MA, USA), and two overhead mixers. In bench-scale experiment, mixing was provided using a digital mixer system (Cole-Parmer, Vernon Hills, Illinois, USA), while in pilot-scale system an in-built 2.2 KW motor (within bio-digester) provided continuous mixing. Both bench-scale and pilot-scale experiments were repeated independently (Run 1 & Run 2) to understand the variability of the process adopted for foodwaste treatment.

2.2. Feedstock

Horse manure was collected from the UC Davis Center for Equine Health, and grass and palm tree wastes were collected from the UC Davis Arboretum. Foodwaste was collected from Yolo County Food Bank, Woodland, California. A total of 76 kg feedstock was prepared from the mixture of foodwaste (vegetables, fruits, and bakery), horse manure, grass, and shredded branches of palm tree at a ratio of 12:4:2:1. The feedstock was mixed in the biodigester at room temperature for 45 minutes for homogenization. Later on, total feedstock of 76 kg was divided into two batches (each 38 kg). One batch was mixed with the two packs (each weight 180 g) of a commercially sold additive, BM1, enzymes. The BM1 contains naturally occurring thermophilic

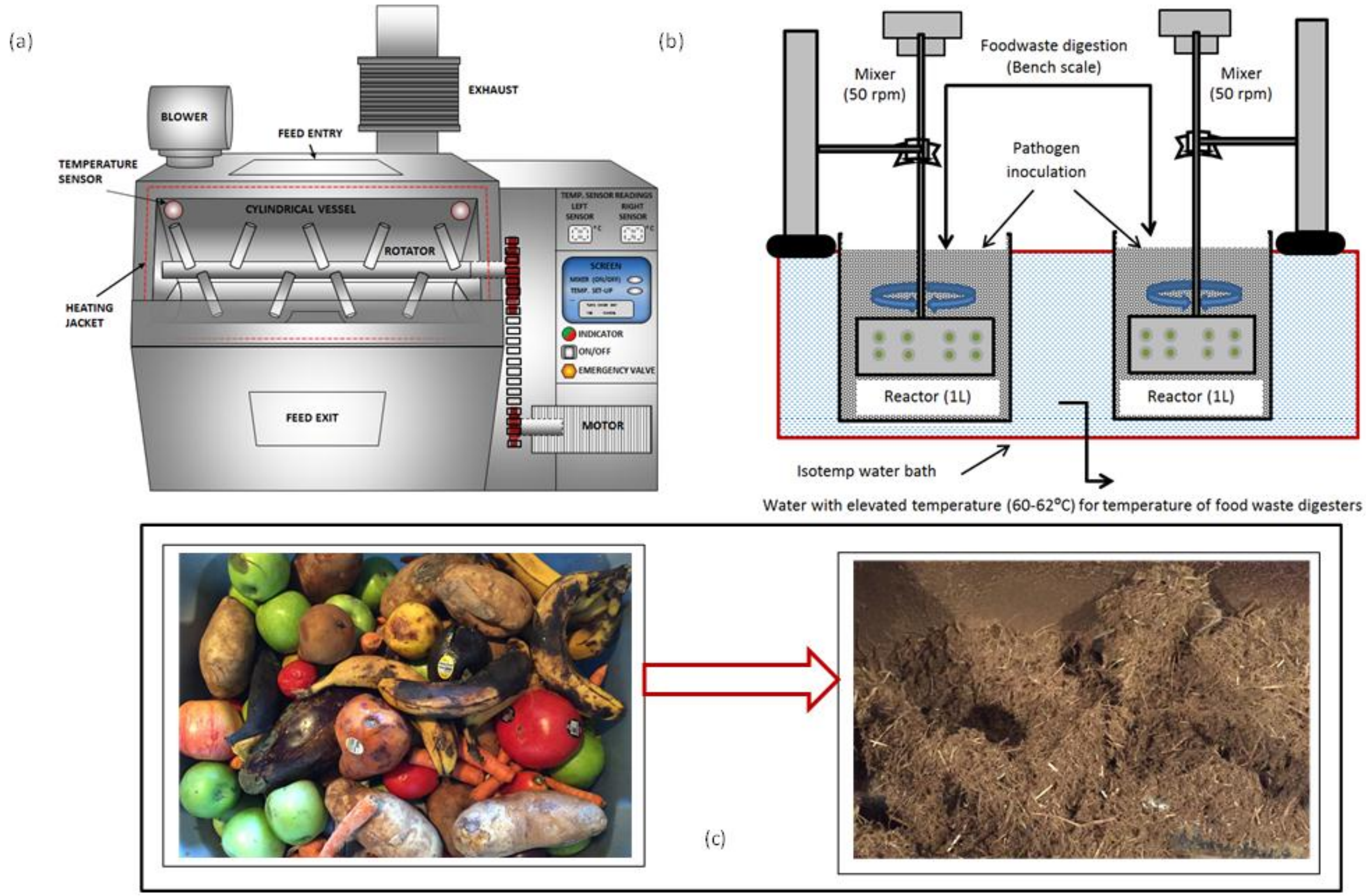

Figure 1. Schematic of biodigester used in the pilot-scale experiment: a) pilot-scale system; b) bench-scale system; c) conversion of foodwaste into soil amendment.

microorganisms, useful for breaking down complex organic compounds (at thermophilic temperature) of the organic waste (Biomax, 2015). From each batch (feedstock mixed with enzyme and without enzyme) of pilot-scale experiment, approximately 2 kg of feedstock (each) was separated for the bench-scale experiment. The pilot-scale experiment with additive was named as PFA, and without additive was named as PFNA. The bench-scale experiment with additive was named as BFA, and experiment without additive was named as BFNA. To run bench-scale experiment, a slurry of feedstock was created by blending 300g of feedstock and 600 mL of deionized water. A residential grade blender (Ninja model BL800) was used for forming the slurry. The slurry in the reactors was continuously mixed using overhead mixer (50 rpm). Two bench-scale reactors (one with feedstock mixed with enzyme, and another with feedstock without enzyme) were ran simultaneously. While at pilot-scale experiment, firstly the foodwaste experiment was run with enzyme, and later the foodwaste without enzyme. The mixing speed of pilot-scale experiment was 5 rpm. During the foodwaste digestion process, 5.5 L additional water was added in pilot-scale experiment in Run 1, however, in Run 2 no additional water added during the experiment.

2.3. Pathogen inoculation and measurement

Pure strain of *Salmonella* Typhimurium LT2 was grown in Luria-Bertani (LB) broth, and subsequently the culture (1350 mL) (used as an inoculum) was mixed into feedstock in each pilot-scale run. In bench-scale experiment, 80 mL of pure culture of *Salmonella* was inoculated into feedstock. Pathogen enumeration in the pure culture and digestate was conducted following the Bacteriological Analytical Manual (BAM) procedures (US FDA, 2005). The source of *E. coli* in the feedstock was naturally occurring *E. coli* in horse manure. To enumerate pathogens in digestate, the digested slurry samples were serially diluted in Phosphate Buffer Solution (PBS), and the diluted samples (10^{-1} to 10^{-6}) were plated in the respective agar for *E. coli,* and *Salmonella*. When no growth of pathogen occurred at 10^{-1}, the pathogen level was considered as non-detectable level. The detection limit of pathogen was 10 CFU/g of raw and digested waste sample. The pH of feedstock was measured using a hand held pH meter (Omega Engineering, INC., Stamford, CT, USA). Moisture content, carbon (C) content, and nitrogen (N) content were measured using American Public Health Association (APHA) standard protocol (APHA, 2005). *Salmonella enterica* serovar Typhimurium in digestate was measured using Xylose Lysine Desoxycholate (XLD) agar (Difco, Becton, Dickinson and Company, Sparks, MD, USA) plates, while *E. coli* was enumerated using MacConckey II agar with sorbitol (BBL, Becton, Dickinson and Company, Sparks, MD, USA).

3. Results and discussion

3.1. Temperature, moisture, and carbon content of pilot-scale digester, and bench-scale reactors

Figure 2 shows increment of temperature during pilot-scale and lab-scale experiments, and the results indicate that the desired temperature (≈ 55-60 °C) in pilot-scale experiment was obtained within 20-30 minutes, while in bench-scale the come-up time was 50-60 minutes. The difference in time needed for achieving composting temperature could be due to the fact that in pilot-scale system heat was applied with the help of in-built heating jacket (close contact between feedstock and heating element), while in bench-scale system heat was applied with the help of water bath. The variations in moisture content of pilot-scale (PFNA and PFA) and bench-scale (BFNA and BFA) experiments are shown in Figure 3a & 3c. In both BFA and BFNA moisture content varied from 86 to 93%. Moisture variation in pilot-scale experiment was relatively greater (Fig. 3c). The moisture content of the PFA varied from 58.0 to 65.0% in Run 1, and 35.8 to 76.1% in Run 2 (Fig. 3c & 3d). In PFNA, moisture content varied 64.0-80.0% and 37.7-76.2% in Run 1 and Run 2, respectively. Carbon content of feedstock in bench scale experiment (Fig. 3c) was slightly higher in Run 1 (≈ 6.0%) compared to Run 2 (≈ 4.0%). In pilot scale experiment, the average carbon content was 17.0% in both Runs.

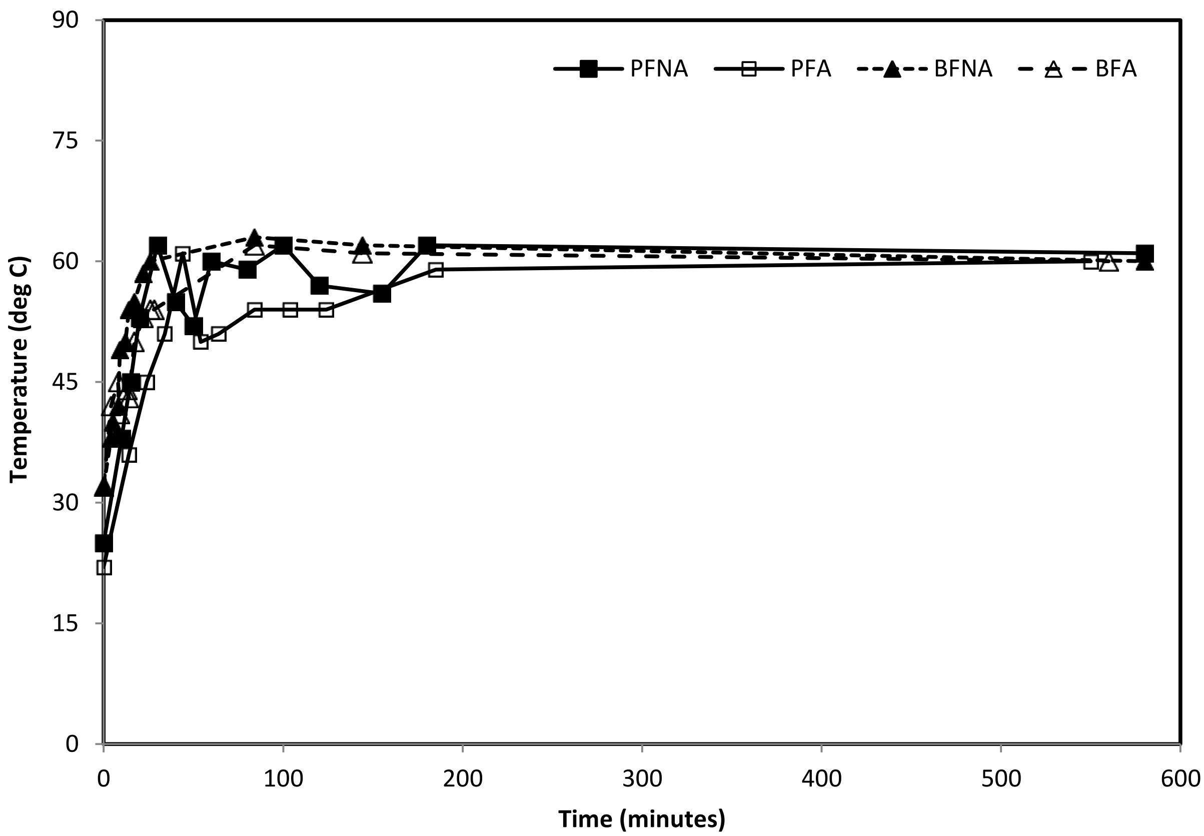

Figure 2. Temperature increment in pilot-scale and bench-scale system (PFA = pilot-scale with additive; PFNA = pilot-scale without additive; BFA = bench-scale with additive; BFNA = bench-scale without additive).

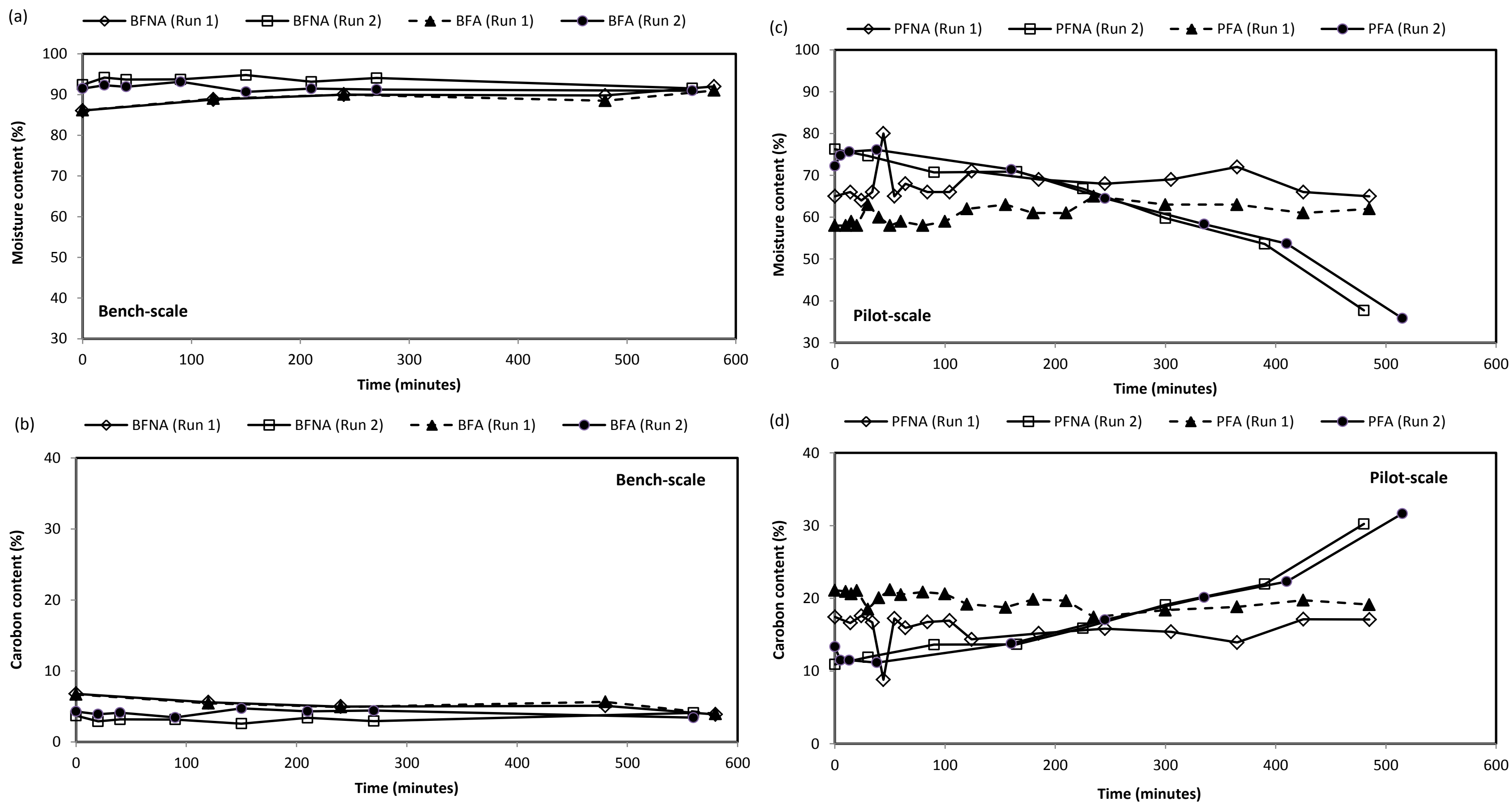

Figure 3. Moisture and carbon changes: a & b) bench-scale system; c & d) pilot-scale system

3.2. Changes in E. coli and Salmonella levels in bench-scale and pilot-scale experiments

Variation in *E. coli* levels in bench-scale and pilot-scale experiments are presented in Figure 4. In bench-scale systems Run 1, *E. coli* levels (Fig. 4a) varied from 5 to 8 orders of magnitude, and 4 to 10 orders of magnitude in Run 2. In both BFNA and BFA, *E. coli* was detectable (4-5 orders of magnitude) till the end of experiments. In pilot-scale system (Fig. 4b), the *E. coli* levels were reduced to non-detectable levels in Run 1 in 10 hours. In Run 2, however, *E. coli* survived beyond 10 hours, despite the certain similarities of both the Runs.

In pilot-scale experiment (PFA, Run 1), *E. coli* was reduced from 7 orders of magnitude to non-detectable level in 8 hrs. In Run 2 PFA, however, *E. coli* was reduced from 10 orders of magnitude to 5 orders of magnitude in the same digester period (8 hrs.). While in PFNA Run 1, *E. coli* levels changed from 7.4 orders of magnitude to non-detectable levels in 9 hours. In PFNA Run 2, *E. coli* reduced from 8 orders of magnitude to 4 orders of magnitude in the same time.

While reductions in *E. coli* levels were relatively consistent in pilot-scale and bench-scale experiments, the detection of *Salmonella* in the feedstock was sporadic (Fig. 4c & 4d). A greater level of inconsistence in *Salmonella* inactivation was observed in both bench-scale and pilot-scale experiments. As an example, *Salmonella* levels reached to the non-detectable levels within first 40 minutes of digestion; however, re-growth was noticeable after 60 minutes. In Run 1, both bench-scale and pilot-scale experiments did not show *Salmonella* survival within 10-15 minutes of digestion, however, in Run 2, *Salmonella* levels were detectable in both bench-scale and pilot-scale experiments.

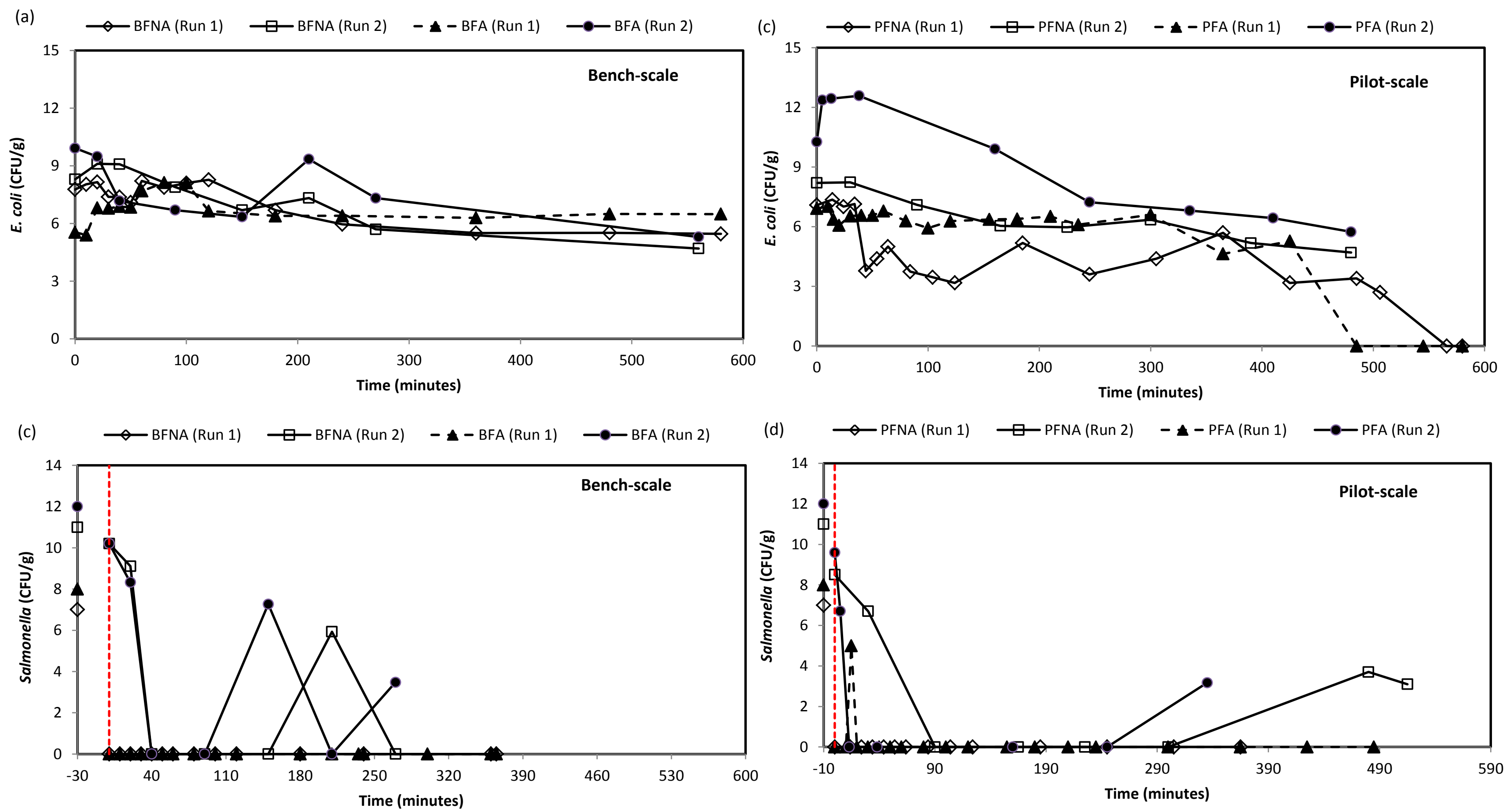

Figure 4. *E. coli* inactivation in pilot and bench scales experiments with and without additive conditions: a & b) change in *E. coli* and *Salmonella* levels in bench-scale reactors (with additive without additive); c & d) change in *E. coli* levels in pilot-scale digester.

Based on the results (of Run 1) of pilot-scale and bench-scale experiments, we anticipate that the low pH of feedstock played a major role in *Salmonella* inactivation because *Salmonella* level was reduced to non-detectable levels prior to reaching compost temperature (55-60 °C). Our anticipation was corroborated by the Run 2 of pilot-scale and bench-scale experiments. Despite the detection of *Salmonella* in a few initial samples, a large portion of the samples were negative to *Salmonella*. After a series of samples with non-detectable levels of *Salmonella*, a few samples were positive to *Salmonella* indicating the possibility of regrowth of *Salmonella.*

3.3. Changes in pH and C:N in bench-scale and pilot-scale experiments

The changes in pH of feedstock in bench-scale (Fig. 5a) and pilot-scale (Fig. 5c) indicate that both *E. coli* and *Salmonella* were subjected to acid challenge (pH 3.5 – 5.0). In the bench-scale experiment, pH varied from 3.5 to 4.1 and 4.5-6.6 in Run 1 and Run 2, respectively. In pilot-scale experiment, pH varied from 3.3 to 4.6 and 3.8 to 4.3, respectively. As shown in Figure 5a, pH of Run 2 (bench-scale experiments) was relatively higher than pH of Run 1. While the average pH of bench-scale in Run 1 was 3.8 (BFNA) and 3.9 (BFA), in Run 2 average pH was 5.6 and 6.1, respectively. In pilot-scale experiment, however, the average pH was identical in both Run 1 and Run 2 (Fig. 5c). The average pH in Run 1 was 3.8, while in Run 2 it was 4.0. Previous studies reported the decrease in pH (< 4.5) during foodwaste anaerobic digestion (Zhang et al., 2011) and composting processes (Yu & Huang, 2009) due to the production of organic acids. In an in-vessel foodwaste composting experiment, Yu and Huang (2009) reported a pH drop from 6 to 4.5 in less than 5 days of composting, and an increase in temperature from 20 to 60 °C. Their study also reported the survival of thermophilic bacteria (6-8 orders of magnitude) at temperature greater than 50 °C. Other study (Adhikari et al., 2008) was focused on

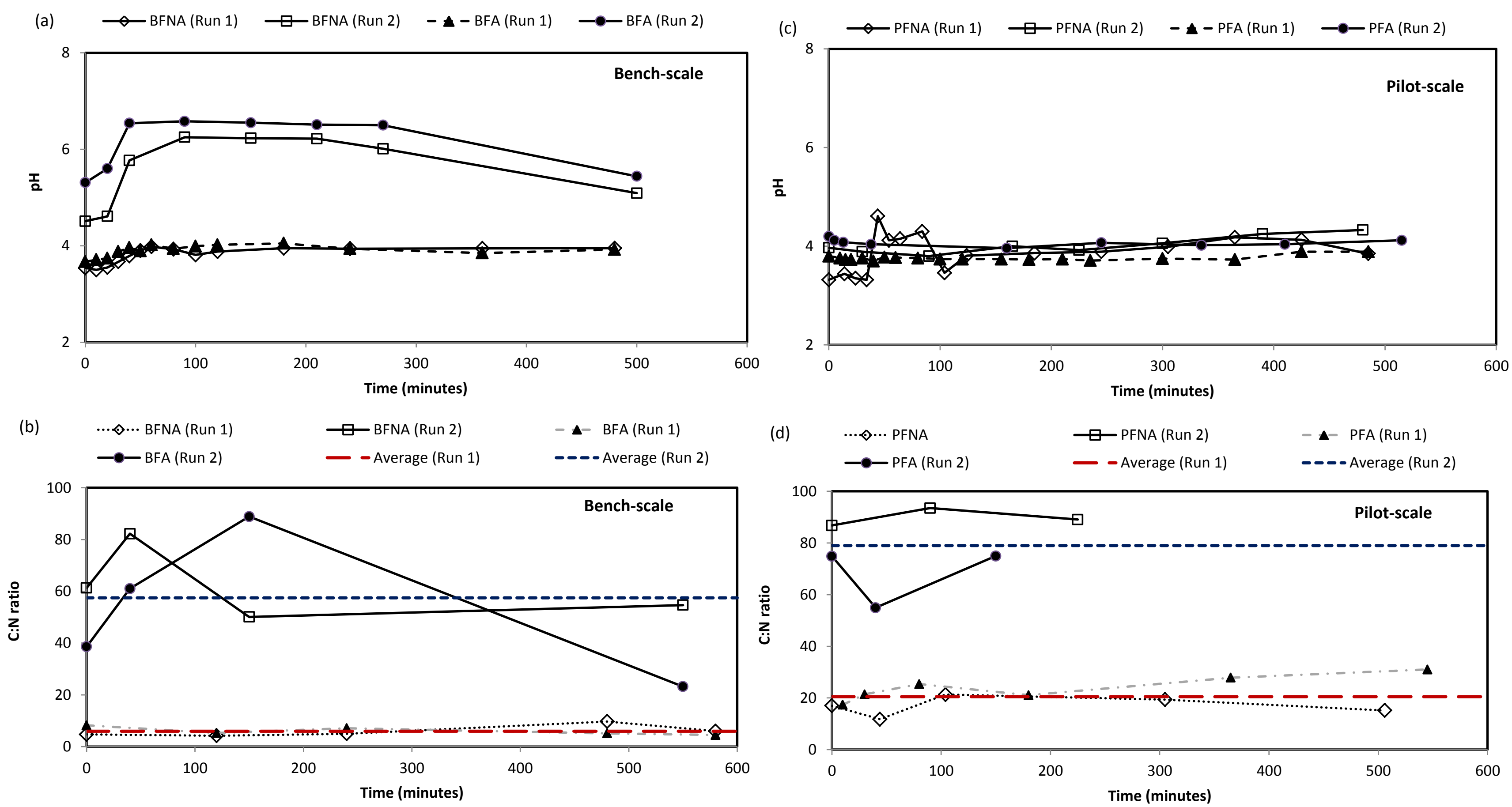

Figure 5. Change in pH, carbon, and C:N ratio in bench and pilot-scale experiments with and without additive conditions: a & b) pH and C:N ratio change in bench-scale reactors; c & d) pH and C:N ratio change in pilot-scale digester.

characterizing the foodwaste for composting and reported the pH of foodwaste between 3.9 to 4.5

In addition to pH, C and N ratio of Run 2 were considerably higher than the Run 1, which can be attributed to the independence of the experiment. The feedstock ingredients (foodwaste, grass waste, palm tree waste) were collected on two different times for these two Runs which resulted in different C: N ratio for the two Runs. In real situations, inconsistencies in foodwaste characteristics would be expected. The C: N ratio in the feedstock of Run 1 (bench-scale) varied from 4.2 to 9.7, while in Run 2 it varied from 23.2 to 88.9. In pilot-scale experiment, C:N ratio changed from 11.8 to 25.4 in Run 1, while in Run 2 it changed from 23.2 to 93.5. A descriptive statistics of pH, C: N ratio, moisture content, and carbon content are shown in Table 1.

3.4. Pathogen inactivation predictions

To predict pathogen inactivation in the process, we used observations of bench-scale and pilot-scale experiments to develop linear models. The linear fits of *E. coli* reductions for bench-scale are shown in Figure 6a and 6c, while Figures 6b and 6d showed linear fits of pilot-scale experiments. As shown in the Figures, the linear fits were relatively better for the process without any additive compared to the process with additive. The similar phenomenon was observed in both pilot-scale and bench-scale experiments. To derive the temperature and time dependent *E. coli* inactivation models valid for both type of processes (i.e., with and without enzyme), we used Run 1 (BFNA) data to develop the models. Subsequently the model predictions were used to compare the observations of Run 2 (BFNA), Run 2 (BFA), and Run 1 (BFA). A similar approach, we used for pilot-scale experiments. The developed model based on bench-scale data showed that *E. coli* inactivation likely to occur in 1,500

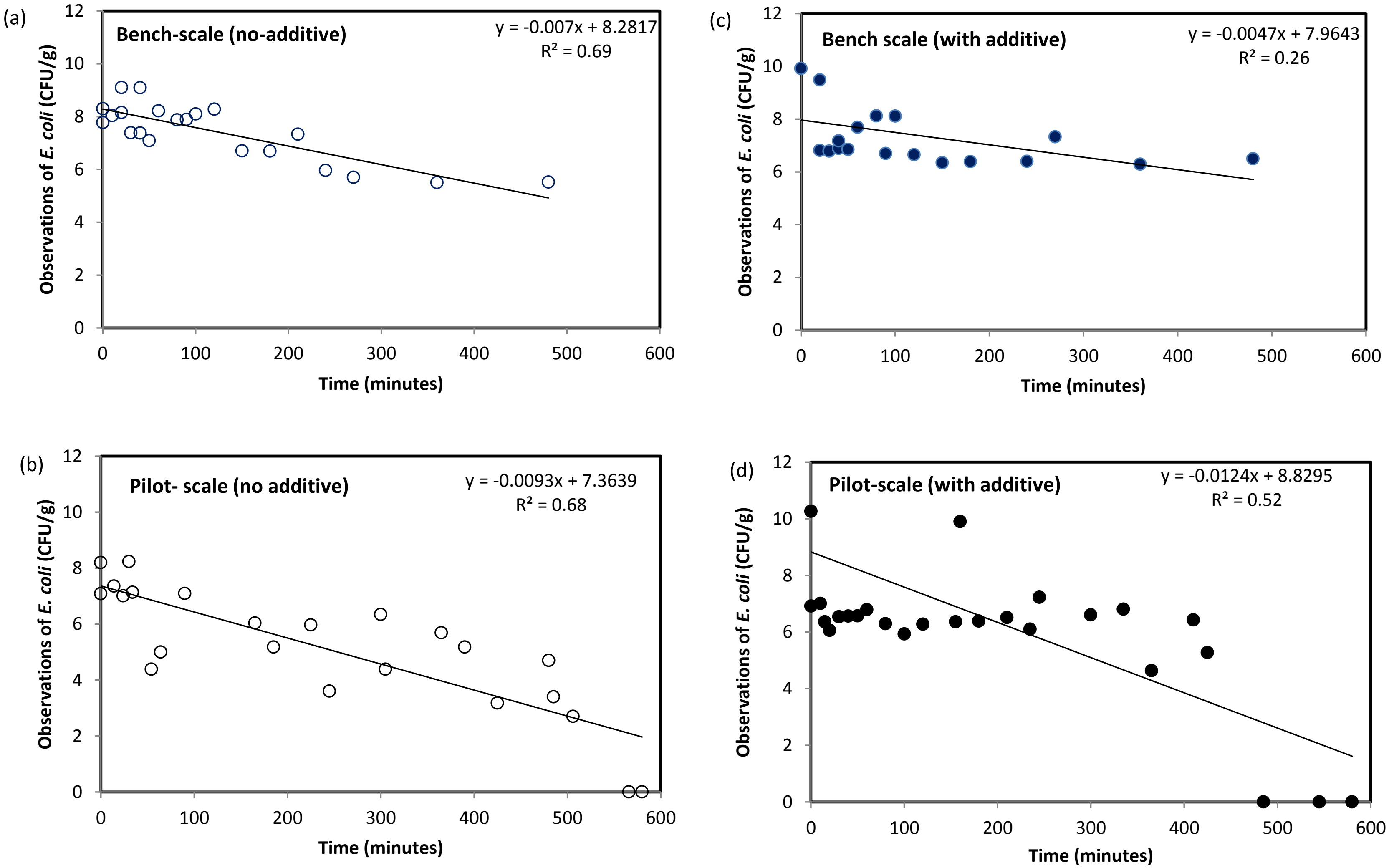

Figure 6. Linear regression curves of *E. coli* inactivation: a & c) bench scale experiment; b & d) pilot-scale experiment.

Table 1: Descriptive statistics of the parameters in bench-scale and pilot-scale experiments

Parameter	Bench-scale				Pilot-scale			
	Run 1		Run 2		Run 1		Run 2	
	BFNA	BFA	BFNA	BFA	PFNA	PFA	PFNA	PFA
Moisture (%)								
Range	86.0-92.0	86.1-91.0	91.5-94.7	90.6-93.13	64.0-80.0	58.0-65.0	37.7-76.2	35.8-76.1
Average	89.3	88.9	93.4	91.6	67.9	60.6	63.8	64.7
Carbon (%)								
Range	3.8-6.7	3.9-6.6	2.5-4.0	3.4-4.7	8.8-17.6	17.4-21.2	10.9-30.2	11.2-31.7
Average	5.2	5.3	3.2	4.0	15.8	19.8	17.2	16.9
pH								
Range	3.5-3.9	3.6-4.0	4.5-6.2	5.3-6.5	3.3-4.6	3.7-3.9	3.8-4.3	3.9-4.2
Average	3.8	3.8	5.5	6.1	3.9	3.8	4.0	4.0
C:N ratio								
Range	4.2-9.7	4.5-8.2	50.1-82.3	23.2-88.9	11.8-21.3	15.9-25.4	86.8-93.5	54.9-75.0
Average	5.9	6.0	62.1	52.9	16.9	20.2	89.8	68.3
***E. coli* (log)**								
Range	5.4-8.2	5.3-8.1	4.6-9.1	5.3-9.9	0-7.4	0-7.0	4.7-8.2	5.7-12.6
Average	7.1	6.7	7.3	7.6	4.5	6.3	6.5	9.3
***Salmonella* (log)**								
Range	0.0-0.0	0.0-0.0	0.0-10.2	0-10.2	0.0-0.0	0.0-5.0	0.0-8.5	0.0-9.6
Average	0.0	0.0	3.6	4.1	0.0	0.3	2.8	2.8

minutes, while model based on pilot-scale data showed that inactivation likely to occur in 1,000 minutes. Comparison between observations and predictions are shown in Figure 7a and 7b for bench-scale and pilot scale experiments, respectively. One plausible reason for this difference in

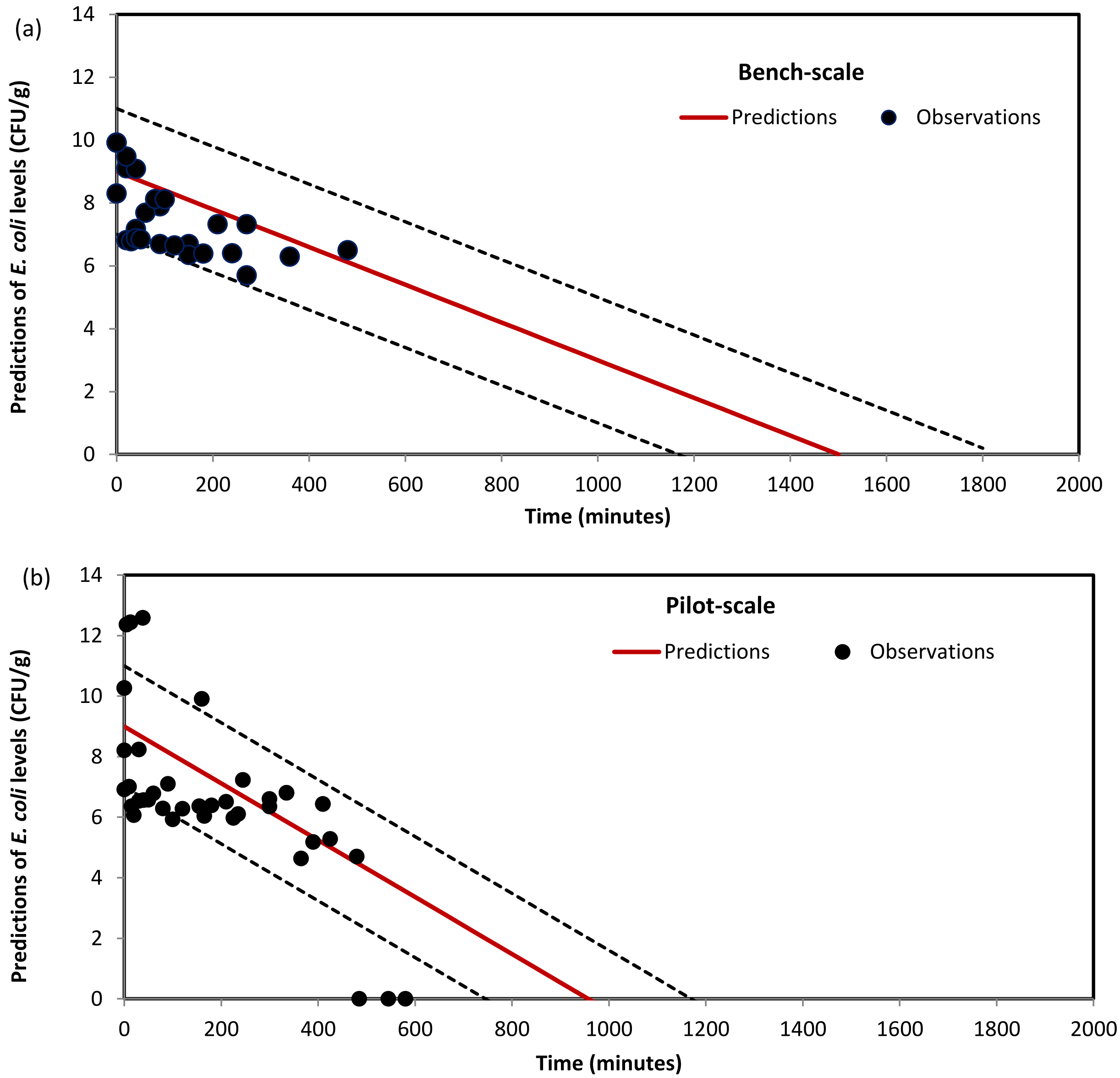

Figure 7. Comparison between *E. coli* predictions and comparison at bench and pilot-scale experiments

predictions (bench-scale and pilot-scale) could be the moisture content. At bench-scale experiment, moisture content (90.8%) was considerably higher than the pilot-scale experiment moisture content (64.2%) (Figs 3 a & 3 c).

The *Salmonella* inactivation was similar in both pilot-scale and bench-scale experiments. Majority of the samples were negative to *Salmonella*. To develop *Salmonella* inactivation model, we combined the data of bench-scale and pilot-scale experiments due to the fact that only few samples were positive to *Salmonella*. The 18% of the 28 data points were used for model development, and remaining points were used to validate the predictions. The model predictions showed that *Salmonella* inactivation likely to take 80-100 minutes. While comparing predictions and observations, we found that majority of the *Salmonella* inactivation took place within the predicted time (Figs 8a & 8b).

The survival of *E. coli* at low pH and at high temperature for extended period of time is of interest because many of foodborne infection were found to be related with acidic foods (Vivijs et al., 2014). The results of this study showed that the characteristics of waste streams (i.e., pH, moisture content, and C content) may influence pathogen survival in the treatment processes substantially. As an example, while studying a generic *E. coli* and *Salmonella* inactivation in four different bovine manure piles (straw with manure), Millner et al. (2014) reported *E. coli* and *Salmonella* reduction from 8-9 orders of magnitude to non-detectable level in 7 days. The pile temperatures varied from 20-65 °C. In our study, *Salmonella* inactivation was substantially faster indicating that the recipe used in this study was able to inactivate the *Salmonella* relatively in much shorter time at composting temperature, which was apparent from the results of both lab and bench-scale experiments. Previous study (Vinnerås, 2007) tested *Salmonella* and *Enterococcus* survival in foodwaste and reported the survival of both organisms beyond 5 days

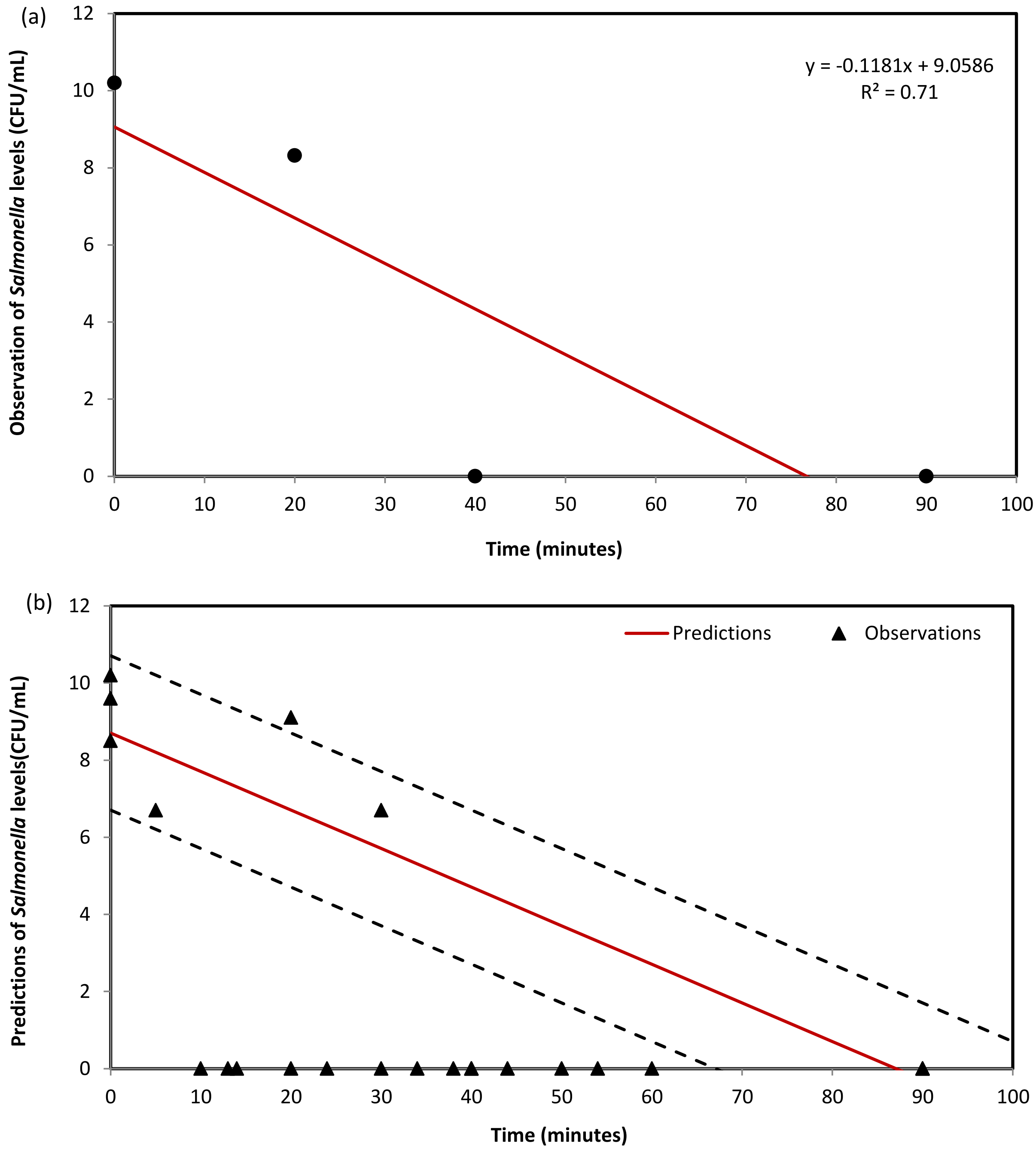

Figure 8. *Salmonella* inactivation predictions during in-vessel composting.

during the composting. The temperature of compost varied from 20 to 45 °C during the first 10 days of composting.

Similarly, Droffner and Brinton (Droffner & Brinton, 1995) reported *E. coli* survival in foodwaste composting for more than 9 days in bench-scale experiments at composting temperature (optimum temperature of the pile was 60-70 °C). Contrary to our findings, the study by Droffner and Brinton, 1995 reported that *Salmonella* in foodwaste composting can survive for more than 9 days at temperature greater than 60 °C. However, Sunar et al. (2014) reported that composting of kitchen waste for 8 days resulted in *Salmonella* reductions from 8 orders of magnitude to non-detectable level. To reduce pathogenic microorganisms, Cekmecelioglu et al. (2005) used a force-aerated in-vessel system (55 L) for optimizing the composting recipe. The authors reported that the use of 50% foodwaste, 40% cow manure, and 10% bulking agent helped to achieve the maximum temperature (> 55 °C) in 3.3 days, and *Salmonella* and *E. coli* were reduced by more than 90% in 12 days of composting. However, the reductions in fecal coliforms and fecal streptococci were 59 and 27%, respectively.

The results of this study clearly showed that the in-vessel system proposed here will be more effective in both *Salmonella* and *E. coli* elimination for producing pathogen free soil amendments compared to traditional composting system. As discussed above, majority of the previous studies indicated pathogen survival for more than a week in conventional composting system. The system proposed here can eliminate *E. coli* levels in less than 24 hours if feedstock moisture content is 90-95% and in less than 16 hours if moisture content is less than 60-70%. *Salmonella* level was reduced to non-detectable level in less than 1.6 hours irrespective of moisture content.

4. Conclusions

In this study, an accelerated method for converting foodwaste into a pathogen free soil amendment (compost) was developed. The foodwaste combined with horse manure, green waste, and palm tree waste was digested at the conventional composting temperature (60 °C). The inactivation of *E. coli* and *Salmonella* was tested at both bench-scale and pilot-scale experiments. The results showed that the *E. coli* survived for a longer period than *Salmonella*. The proposed method produced a composted material in 8-10 hours at pilot-scale setting compared to conventional composting which requires 60-90 days of composting. In contrast, the advanced composting proposed here produced pathogen free soil amendment (compost) in relatively shorter time. The authors assume that the proposed method has a greater potential to convert food and green wastes into valuable end products such as soil amendment to enhance agriculture sustainability.

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CHAPTER 2: Assessing foodborne pathogen inactivation and changes in nutrient levels of food and green waste under aerated, static, and plowed composting systems

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Abstract

More than 35 - 45% of the global food production is turned into waste. Most of the food waste goes into landfills, which causes environmental problems including global warming. Controlling excessive amount of food wastes reaching to landfills requires identifying improved methods capable of converting foodwaste into useful products. Composting is considered as a sustainable solution for converting foodwaste into organic fertilizers. While composting is used extensively for degrading various waste streams including food waste, grass clipping, and pruning waste, considerable challenges exist in using the composting process for controlling foodborne pathogens and obtaining a matured compost. In order to improve the understating of pathogen inactivation and changes in nutrient levels during the composting of green and food wastes and horse manure, we tested the effectiveness of three different composting methods: 1) aerated, 2) static, and 3) plowed. Three different composting units with provision for controlling temperature and aeration were designed, and the experiments were extended for more than two months. The inactivation of two foodborne pathogens (*Salmonella* and *Escherichia coli*) was studied along with the changes of C: N ratio, moisture content, pH, and temperature. Results showed no *Salmonella* positive sample after day 30, 10 and 40 days of composing in aerated, static, and plowed piles, respectively. The slightly greater number of *Salmonella* positive samples were observed in plowed composting compared to the static and aerated composting units. The inactivation of *E. coli* was different than that of *Salmonella.* The initial C:N ratio was 49.5 and it reduced to 19.2, 14.5 and 14.9 after 70 days of composting in aerated, static, and plowed composting units, respectively. We anticipate that the results of this study will help in improving the existing understanding of pathogen inactivation and composting of urban wastes including horse manure, green, and food wastes.

Keywords: green and food wastes; composting; pathogens; E. coli; Salmonella.

1. Introduction

Enhancement in agricultural technology resulted in the improvement of food productions; however, a considerable portion of food is discarded, leading to wastage of precious water and energy used in global food production. Food waste accounts as a significant portion of municipal/urban solid waste. Managing excessive food waste requires identifying a sustainable method to convert the food waste into useful products.

In addition to the food waste, excessive amount of green waste such as grass clipping, tree branches, domestic animal waste produced in urban environment is another issue, which requires improved disposal methods. Green wastes accounts for around 13.5% of total municipal solid waste in the USA (EPA, 2014). Currently, landfill disposal is one of the common methods for waste management, and approximately 54% of the municipal solid waste produced in the USA is buried in landfills (EPA, 2008). Increasing waste production and limited available spaces for designing new landfills in the vicinity of major cities are challenge for most modern cities (Adhikari, et al., 2008). Further, organic and inorganic leachates produced from landfill can be the source of groundwater contamination (Shin, et al., 2001).

Composting can be an alternative to landfill as it is advantageous in producing natural fertilizer and soil conditioner for crop land (Kumar, et al., 2011). Compared with other solid wastes, food waste contains greater levels of organic contents, higher organic to ash ratios, relatively greater amount of nitrogen, and lower carbon to nitrogen ratio (Chang and Hsu, 2008, Kumar, et al., 2010, Li, et al., 2013), which makes it as a suitable feedstock for producing compost. The organic substances in the food waste are easily degradable and makes it appropriate for composting process (Li, et al., 2013). Previous studies have shown the benefits of composting for converting food waste into organic fertilizer and its application as soil amendment for enhancing the fertility of soil instead of chemical fertilizers (Chefetz, et al., 1996, Wolkowski, 2003) has been reported. In contrast to food waste, green waste such as grass clippings and tree branches are not easily degradable and make the composting process relatively slower. Further, pathogen inactivation in the composting of green waste mixed with food waste is uncertain. With increased attention on the public and animal health risks, and the safety of environment, it is important to use the effective controlling mechanism for reducing pathogens in compositing process. Very few, if any, studies described the effects of composting on treating the mixed green waste (i.e., food waste, grass clipping, and horse manure) and the inactivation of food-borne pathogens.

Due to increased interest in adopting the sustainable methods, composting process has received particular interests recently (Adhikari, et al., 2008, Chang and Chen, 2010, Kumar, et al., 2010, Mills and Pearson, 2015, Zhou, et al., 2014). During the composting process, various chemical and biological changes occur depending on the extent and type of waste (Chang and Hsu, 2008). Consequently, the pathogen inactivation during composting process may change depending on the type of waste (i.e., green or food waste). The factors such as pH, moisture content, temperature, and aeration are reported to be crucial in composting process. An appropriate temperature and thermophilic phase is necessary for efficient composting process (Li, et al., 2013). It has been reported that aeration is crucial for microbial growth and gas exhaustion (Chang, et al., 2005, Jiang, et al., 2011). The injection air also influences the growth and metabolism of microorganism, and degradation rate of organic matters (Li, et al., 2013). In the past, multiple aeration strategies have been applied to optimize the composting process (Ekinci, et al., 2004, Guo, et al., 2012, Lau, et al., 1992). A study by (Lau, et al., 1992) recommended an aeration rate of 0.04-0.08 L/min kg volatile solid matter for optimal performance. Lin (2008) found that the concentration of coliforms dropped quickly at about 65^{o}C (Lin, 2008). The composting temperature between 55^{o}C and 65^{o}C is reported to inactivate pathogens (Stentiford, 1996).

While converting waste into organic fertilizer, one common concern is the survival of food-borne pathogens during the composting process. Although in theory, the heat generated (greater than 50 °C) during the composting process likely to kill the pathogens of the wastes, previous studies have shown pathogen presence in compost. Varieties of pathogens including bacteria and fungus can survive the composting process (Hassen, et al., 2001). Survivability of pathogens in a compost pile has been linked with the non-uniformity of heat distribution in the pile which might hinder the elimination of the pathogens (Elving, et al., 2010). The regrowth and dispersion of pathogens during the composting process are other issues, which poses risk to the public and animal health. Controlling *E.coli* and *Salmonella* are important for improving the hygienic quality of compost (Strauch, 1996). Therefore, the goal of this study is to understand the effects of various composting processes on degradation of green and food wastes and pathogen survival on compost material. The objectives of the study were to: 1) assess the pathogen (*E. coli* and *Salmonella*) inactivation in aerated, static and plowed composting process; and 2) evaluate the changes in carbon and nitrogen levels during the composting process.

2. Material and methods

2.1. Experiment setup

The study was conducted in the Extension Laboratory of the department of Population Health and Reproduction in the School of Veterinary Medicine at the University of California-Davis (UC Davis). Three commercially available bins (75cm×45cm×20cm) were used for three types of composting chambers namely static (control), aerated, and plowed (Fig 1). The first bin was the static (control) compost chamber without plowing and aeration. The second bin was named as plowed compost chamber because plowing of the pile using a hand held shovel (dimensions: 0.27 × 0.21 × 0.50, HDX 2531300) was involved. The pile was shoveled twice in a week for 15 minutes to pulverize/mix the composting pile. The third bin was named as an aerated compost chamber because air was injected for 15 minutes with 12 hour interval. A programmable timer (Prime, Cutnstk624) was used to control on/off of the aerator. To inject the air to aerated composting chamber, a piston pump, ¼ HP, 115 VAC(Welch 2546B-01 A) was used with the experimental unit (shown in Fig. 1). An air flow control meter with 127 mm scale (Cole Parmer, 100-700LPM, UX-32462-30) and a plenum coarse bubble diffuser (Cole Parmer, 304SS, 0.30 mL) were used to control the airflow injection (≈ 80 L/min) and diffuse the air uniformly inside the pile.

Since the temperature of composting in laboratory experiment often does not reach the composing temperature (>50 °C), external heat was provided uniformly to all three composting chambers. A heating unit shown in Figure 1 was designed to create the circulation of heat. A circulating bath (Haake DC50-K35, heating 1200 Watt) with capability to control temperature from -35 °C to 200 °C was integrated with the composting chambers. The circulation bath was used to circulate heated ethylene glycol (56 °C) into copper tubing (dia: 12.7 mm) fitted inside the composting bins (Fig 1).

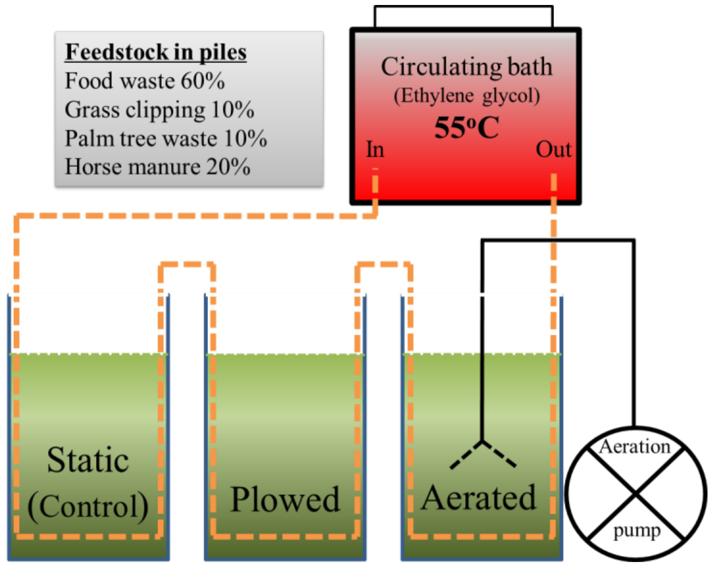

Figure 1. Schematics of composting experiment

2.2. Feedstock* p*reparation

A total 30 kg of wastes including food waste (mainly vegetable and bakery), horse manure, grass clipping, and branches of palm tree were used to create piles inside the three composting chambers. Food waste (green vegetables and fruits) was collected from a food bank located in Woodland, Yolo County, CA, and from a cafeteria (bakery leftover) situated near the School of Veterinary Medicine of University of California Davis (UC Davis). Horse manure was collected from the Center for Equine Health situated in the UC Davis. Grass clipping was obtained from an experimental farm, UC Davis. Palm tree pruning was collected from UC Davis Arboretum. The weight ratio of the food waste, horse manure, grass, and palm tree waste was 6:2:1:1. Each composting chamber received 10 kg of waste mixture consisted of food waste, horse manure, grass clipping, and branches of palm tree. The 10 kg waste mixture was then inoculated manually with 330 mL of *Salmonella typhimurium* (*Salmonella*) before placing to the composting chambers. The initial feed sample was collected to determining the initial concentrations of *Salmonella* and *Escherichia coli (E. coli)*. The source of *E. coli* in the waste mixture was not external but naturally present in the wastes. Moisture content was measured consistently over the period of experiment and additional water was added during the interval of sampling when the moisture content was below 50%.

2.3. Sample collection and measurements

In the first week of study, samples were collected daily. Subsequently the samples were collected twice a week over a month. In the second month of experiment, samples were collected once in a week. The total duration of experiment was 70 days. Temperature profile was recorded from the three chambers over the period of experiment using a handheld thermometer (Fisher Scientific, Digital Thermometers with stainless-steel probe). Solid samples were used to determine the moisture content (MC), total solid (TS), volatile solid (VS), nitrogen content, and carbon content (CC) in compost. To determine the other parameters (*E. coli*, *Salmonella,* and total nitrogen (TN)) of compost, 5 gm of sample was dissolved in 45 mL of Phosphate Buffer Solution (PBS) and then the mixer was homogenized using a blender (Magic bullet, MB1001B) for 3 minutes. Blended slurry was used for counting *E. coli*, *Salmonella* cells, and measuring pH and TN. For identification and enumeration of *E. coli* and *Salmonella* in compost, the US FDA suggested Bacteriological Analytical Manual (BAM) procedure was followed. MacConckey II agar with sorbitol (BBL, Becton, Dickinson and Company, Sparks, MD, USA) was used for *E. coli* enumeration and Xylose Lysine Desoxycholate (XLD) agar (Difco, Becton, Dickinson and Company, Sparks, MD, USA) was used to enumerate *Salmonella* levels. All the samples were plated in duplicate. The TN concentration was determined using HACH kit (Simplified TKN TNT plus, TNT880, method 10242).

3. Results and discussion

3.1. Changes in Salmonella levels in aerated, static and plowed composting

The change in *Salmonella* level is shown in Figure 2. Initial *Salmonella* level was in 7 orders of magnitude. In the aerated composting (AC), out of 20 collected samples, only 4 samples were *Salmonella* positive during the 70 days of experiment with a concentration ranging

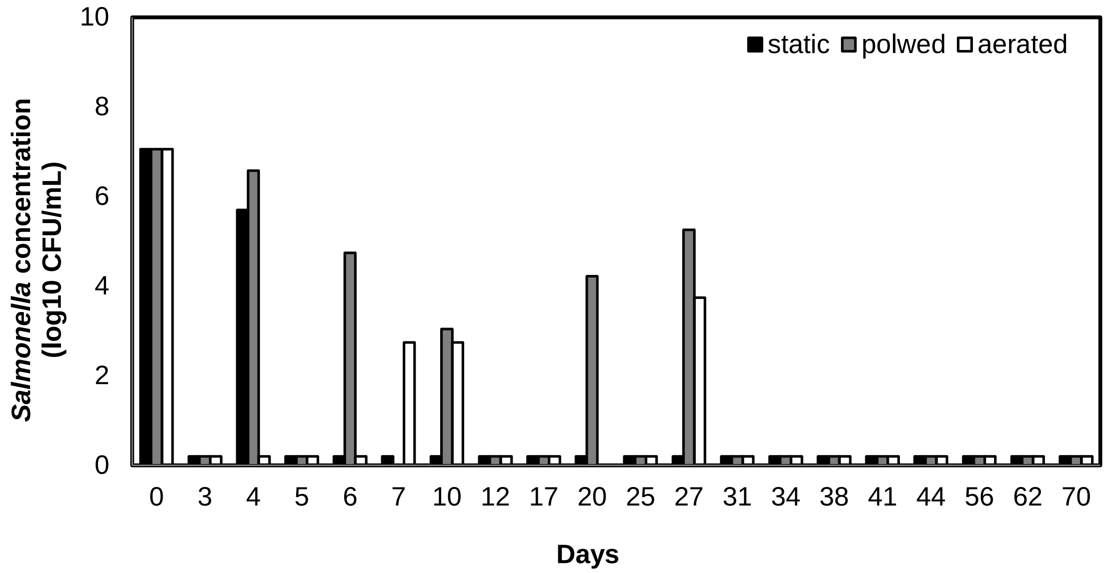

Figure 2. *Salmonella* concentration in the static (SC), plowed (PC), and aerated (AC) piles. Non-detection of *Salmonella* in samples is shown by 0.2 levels in the figure.

from 2.7 to 3.7 log_{10}CFU/ gm. After day 30, none of the samples were *Salmonella* positive in any compost system. In plowed composting (PC), six (including initial) samples were *Salmonella* positive (out of 20 collected samples). The range of concentration was 3.0 to 6.6 log_{10}CFU/ gm. In static composting (SC) process, only 2 samples were found to be *Salmonella* positive (7.1 log_{10}CFU/ gm and 5.7 log_{10}CFU/ gm) (out of 20 tested samples). After 10 days of composting, none of the samples were *Salmonella* positive. Compared with AC and PC, fewer *Salmonella* positive samples were observed in SC.

As shown in Figure 1, there were no obvious patterns of *Salmonella* reduction. While in SC, there were no *Salmonella* positive samples after day 10, in AC system *Salmonella* was non-detectable beyond 30 days of composting. Lower temperature extends the survival of pathogens in composting system (Li, et al., 2013). Previous studies (Gao, et al., 2010, Tateda, et al., 2002) showed that aeration affects the temperature of piles, which influences the bacterial survivability. Maintaining temperature 55-60 ^{o}C consistently for minimum three days is known to kill all the pathogens in compost piles (Déportes, et al., 1995), however, in real world studies, achieving this range of temperature (without applying external heat source) consistently were found to be challenging. Further, regrowth of pathogens in composted material is another issue. As an example, *Salmonella* regrowth is reported even after the finished compost products were stored in desiccator for one year (Russ and Yanko, 1981). The results of this study showed that regrowth and re-detection of *Salmonella* is highly possible in all composting methods, however, composting the material for greater than 40 days will likely to reduce the possibility of *Salmonella* presence in compost material.

3.2. Changes in E. coli levels in aerated, static and plowed composting

The changes in *E. coli* levels are shown in Figure 3. Eight samples (collected over regular interval) of each composting system were processed for enumerating *E. coli* levels. While *Salmonella* levels were found to be non-detectable beyond 40 days of composting, greater than 5 orders of magnitude of *E. coli* was found beyond 60 days of composting in all the system (AC, SC, and PC). This indicates that the survivability of *E. coli* is considerably different than *Salmonella*. Out of eight samples, six samples of SC system showed *E.coli* presence with a concentration varying from 5.5 to 9.3 log_{10} CFU/ gm. The presence of large numbers of *E.coli* (8 log_{10}CFU/ gm) in the final composting products indicates that the reduction of *E. coli* can be slower than *Salmonella* in composting environment.

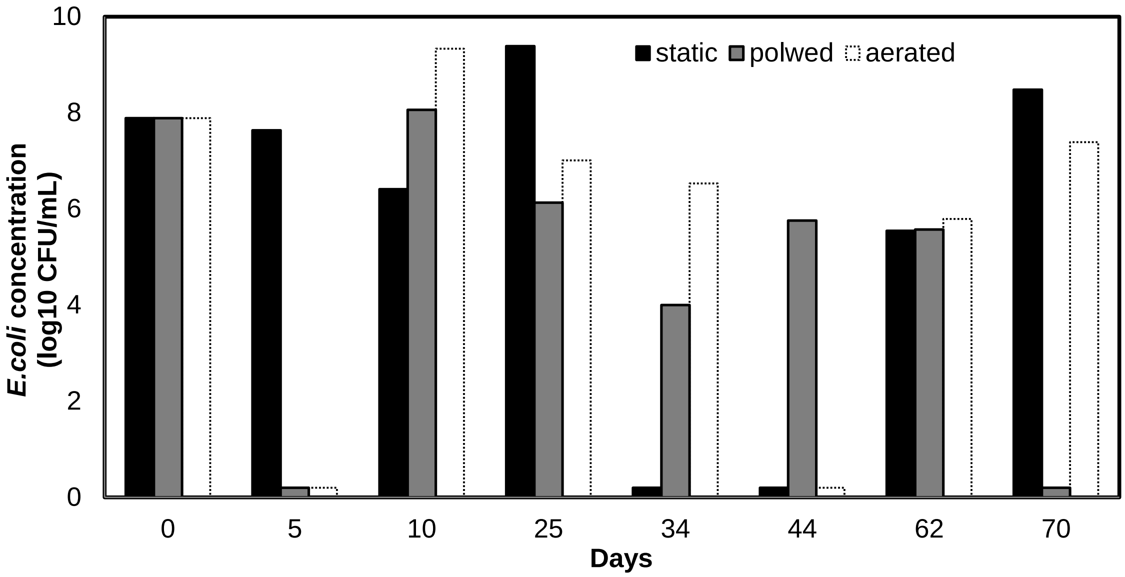

Figure 3. *E.coli* concentration in the static (SC), plowed (PC), and aerated (AC) piles. Non-detection of *E. coli* in samples is shown by 0.2 levels in the figure.

Similar to the SC pile, five samples of the PC pile were detected with *E.coli* at varying concentration from 5 to 8 log_{10} CFU/gm. In AC pile, six out of eight samples were *E.coli* positive. The concentration varied from 5 to 9 orders of magnitude. On day 70, both SC and AC piles showed *E. coli* presence in 8 and 7 orders of magnitude, indicating that the *E. coli* likely to survive composting system beyond 70 days. All composting system i.e., PC, AC, and SC showed periodic rise and fall of *E. coli* levels over the time. Although the last sample of PC system (at day 70) showed no *E.coli*, re-detection of *E. coli* is likely to possible as on day 62, *E. coli* level was in 5 orders of magnitude in the same composing unit.

Considering the presence of a large number of *E.coli* in the last phase (beyond 50 days) of composting in all three systems, the uncertainties of pathogen inactivation in composting systems is clearly apparent. This also emphasize the pathogen safety of soil amendment as well as crop issue if composting material is used as a fertilizer especially on vegetables. *E.coli* inactivation in waste subjected to composting was explored in previous studies by several researchers. As an example, Wichuk and McCartney (2007) conducted composting on sterilized materials with different moisture content and composition (Wichuk and McCartney, 2007). The authors found that *E.coli* was consistently reduced to undetected level in 2 hours when incubation was conducted at 55^{o}C. Hess's study observed *E.coli* inactivation to below the detection level when temperature exceeded 55^{o}C for 3.3 days (Hess, et al., 2004). The results of many other studies indicate that *E. coli* survival likely to extend beyond 60 days. For example, a study by Cekmecelioglu et al. showed that *E. coli* was detectable in windrow composting even the average temperature exceeded 55^{o}C for at least 24 days (Cekmecelioglu, et al., 2005), which is consistent with our results.

3.3. Changes in temperature and moisture content in aerated, static, and plowed piles

The changes in temperature and moisture content in AC, SC, and PC piles are shown in Figure 4a and 4b, respectively. The temperature profile of all three compost piles showed a decreasing trend of temperature over the experiment duration (Fig. 4a). It was found that the temperature of the pile at initial stage was higher (> 50 °C) but gradually decreased over the time. At the last phase of the experiment, temperature reached to mesophilic range (30-38 °C). In the initial phase of the experiment, the establishment of the thermophilic condition (i.e., elevated temperature) is reportedly caused by the breakdown of organic matter due to microbial respiration (Said-Pullicino, et al., 2007). The decrease in temperature, which was consistent with many previous studies, was mainly because of the slower bacterial activity of microorganisms and ageing of the compost material (Chang and Hsu, 2008, Chang, et al., 2006). In PC pile, the highest temperature was 55 °C which appeared at the first day and the lowest temperature was 28 °C, which appeared at the last day. The temperature of PC piles was higher than 55^{o}C for 3 days. The majority of the temperature data were between 40 and 50 °C indicating that the temperature of compost piles can vary considerably between mesophilic and thermophilic piles (Table 1).

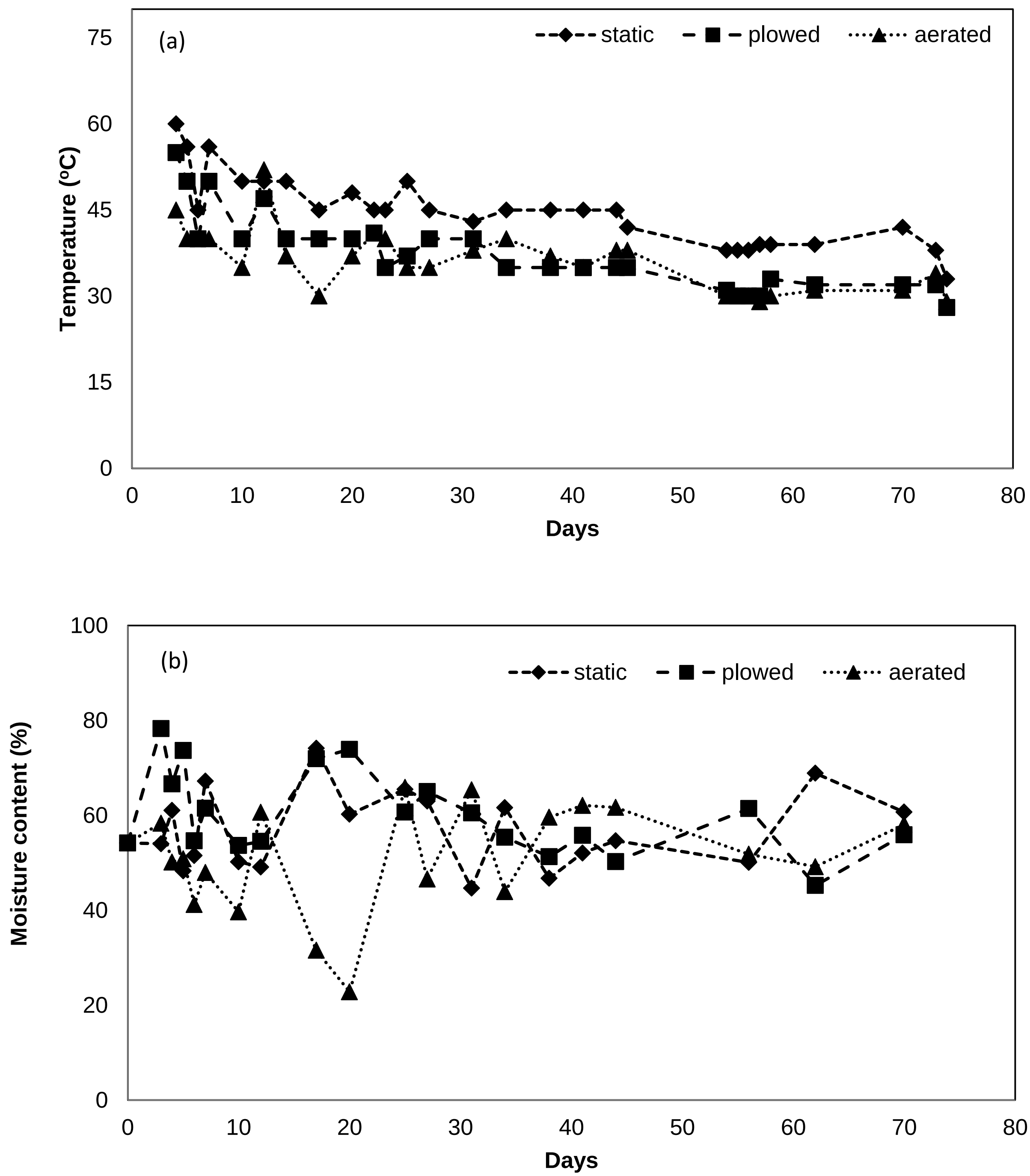

Figure 4a(top), 4b(bottom). Temperature and moisture content change in aerated (SC), plowed (PC) and static (SC) piles: a) temperature variation; and b) moisture content variation

Table 1. Summary of parameter changes in aerated (AC), plowed (PC), and Static (SC) piles.

Parameters	AC			PC			SC		
	Initial	Final	% change	Initial	Final	% change	Initial	Final	% change
MC%	54	58	+7.4	54	56	+3.7	54	61	+12.9
Temp (°C)	45	29	-35.6	55	28	-49.1	60	33	-45.0
pH	3.6	6.9	+91.6	3.5	7.2	+105.7	3.6	7.0	+94.4
CC (%)	22.3	16.7	-25.1	22.3	17.0	-23.8	22.3	13.6	-39.0
TN (%)	0.45	0.87	+93.3	0.45	1.14	+153.3	0.45	0.94	+108.9
C:N	49.5	19.2	-61.2	49.5	14.9	-69.9	49.5	14.5	-70.7

The initial temperature in SC pile was 60°C, which was relatively higher than the temperature of other piles indicating the heat loss in aerated and plowed piles. The temperature of this pile was also reduced over the time. Overall, the temperature in SC pile was higher than the AC and PC piles. In general, the trend of temperature changes was similar in all three composting system. The average temperatures for AC, PC, and SC were 36°C, 37°C, and 45°C, respectively. In composting process, temperature is often considered as a major parameter, which influences the compost quality (Tang, et al., 2011). The favorable temperature range for composting is reported to be 55 to 60^{o}C (Li, et al., 2013), which supports growth and metabolisms of mesophilic and thermophilic microorganisms, however, in field condition the temperature of compost pile lower than the recommended optimal temperature is common. While aeration of composting pile is a recommended procedure (Ahn, et al., 2007), it may lead to the cooling of the piles as observed in aerated piles of this study.

The variations in moisture content (MC) of three piles are shown in Figure 4b. In the AC pile, the initial MC was 54% at the start of experiment and the final MC was 58% (after 70 days of composting). Description of moisture content is shown in Table 1. Over the time, a total of 10 L water was added in AC pile to increase the moisture content. In the PC and SC piles, 6 – 7 L of water was supplemented to maintain the moisture content of the feedstock. The moisture content in AC, PC, and SC piles varied 78-23%, 78-45%, and 74-38%, respectively. The average moisture content in AC, PC, and SC was 51, 60, and 57%, respectably.

In addition to temperature, MC is another important factor controlling composting process as well as the temperature of the piles (Liang, et al., 2003). In our all three composting experiments, supplementation of water was needed to enhance the moisture level. Previous studies reported the importance of suitable MC for improved composting process and 50% – 70% of MC has been identified as a suitable range for composting process (Iqbal, et al., 2010, Liang, et al., 2003). During co-composting of food waste and green waste, 60% moisture level was found to be optimal (Kumar, et al., 2010). In our study, the moisture content was within the recommended moisture level for composting. In aerated condition, the addition of greater amount of water was needed because of waster losses caused by aeration.

3.4. Changes in pH and carbon content of aerated, plowed, and static piles

The changes in pH of three (AC, PC, and SC) compost piles are shown in Figure 5a.

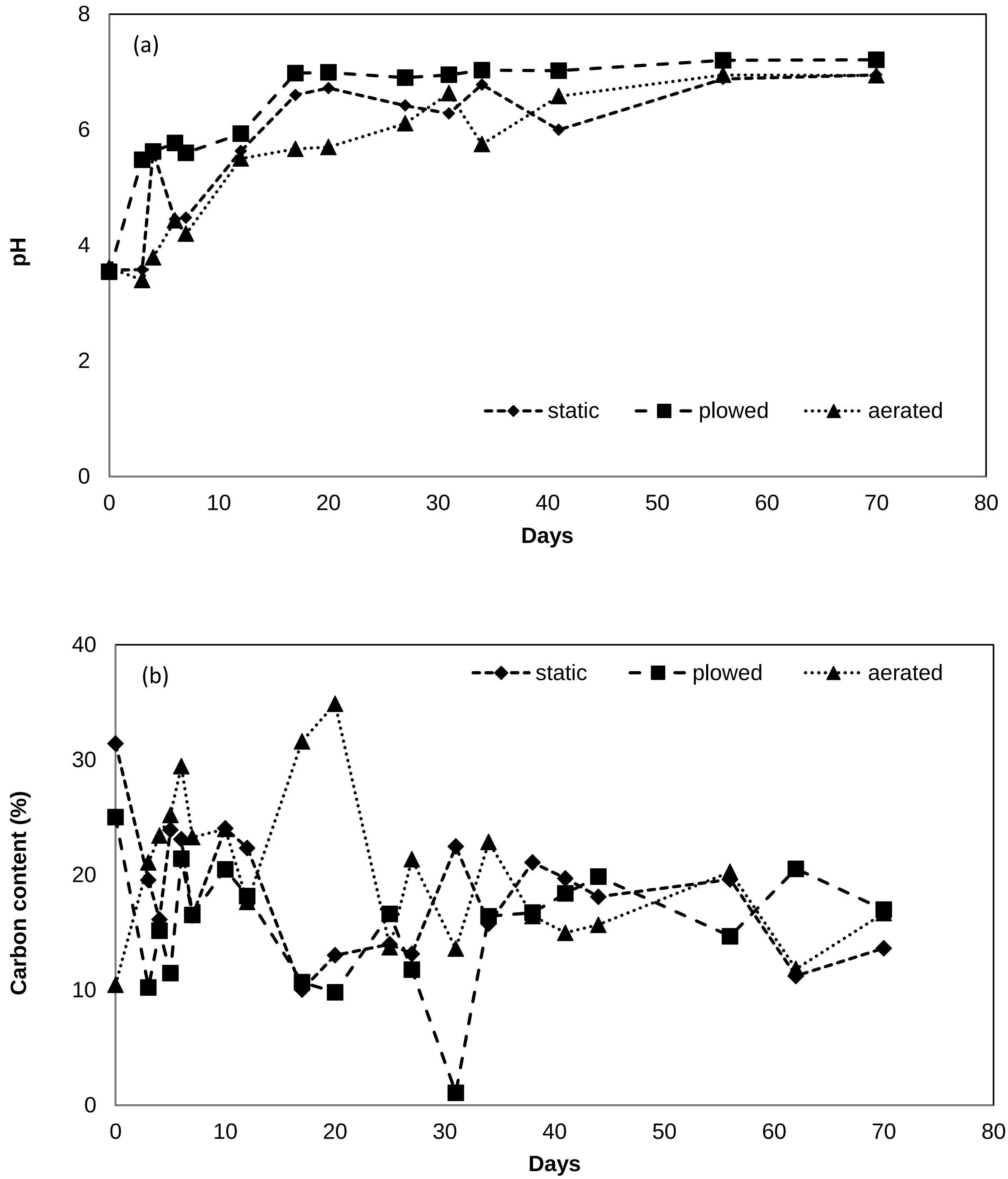

Figure 5a(top), 5b(bottom). Change in pH (a) and carbon content (CC) (b) over time in the aerated composting (AC), plowed composting (PC), and static composting (SC) piles

The mix of food waste, horse manure, and grass clips produced acidic compost piles. In AC pile, the initial pH of the feedstock was 3.6. Over the time, the pH was increased gradually to 7.0 (after 30 days). The pH of 7-8.0 is considered to be the optimal pH for food waste composting (Nakasaki, et al., 1993). The lower pH in food waste composting is reportedly caused by the presence of short chain organic acid in food waste (Yu and Huang, 2009). It is considered that both high and low pH might inhibit the growth of microorganisms and reduce the degradation in composting system (Smårs, et al., 2002, Sundberg, et al., 2004).

In PC pile, an increase in pH from 3.5 to 7.0 in first 20 days of experiment was observed. Subsequently, the pH remained stable ≈ 7.0. In SC pile, the pH was increased from 3.6 to 7.0, and in AC pile it was increased from 3.6 to 6.9. There was fluctuation in pH in the first five days, subsequently a consistence increase in pH was observed. The rise of the pile pH can be explained by the decomposition organic matters to the accumulation of NH_3 that forms alkaline NH_4^+ after reaction with water (Wong, et al., 2001). The volatilization of ammonia nitrogen and hydrogen ion release from microbial nitrification also contributes to the increased pH (Eklind and Kirchmann, 2000).

The inactivation of *Salmonella* is reported to be highly linked with pH changes. The sensitively of *Salmonella* to low pH is greater than *E.coli* (de W Blackburn, et al., 1997). Tiganitas et al. (2009) observed that *Salmonella* showed about 7 log reduction in concentration after about 100 hours of exposure to pH 4.0,while 4 log reduction in concentration after 719 hours of exposure to pH 4.5 at 10^oC (Tiganitas, et al., 2009). In our studies, *Salmonella* level was reduced to non-detectable level even in the initial phase of the experiment, while *E. coli* level was still relatively greater. Both higher temperature and lower pH may have resulted in *Salmonella* reductions. The increase in pH over the time, which we observed, was consistent with previous study (Conghos, et al., 2003, Michel Jr and Reddy, 1998). Conghos suggested that the increased pH is caused by the release of ammonia during the composting process (Conghos, et al., 2003).

The changes in carbon content inside the three compost piles are shown in Figure 5b. In AC pile, the initial CC was 22.3% and the final CC of the composted material was 16.7% (Table 1). In this pile, the carbon content was lost by 25.1%. In PC pile, the carbon content decreased from 22.3% to 17.0%. In SC pile, the carbon content was decreased by 39%. The carbon content of this pile varied from 10 to 24%. The reduction of carbon in compost pile is mainly attributed to microbial respiration and metabolism (Guo, et al., 2012).

3.5. Changes in total nitrogen (TN) and C:N ratio in aerated, plowed, and static piles

The changes in total nitrogen content and C:N ratio is shown in Figure 6a.

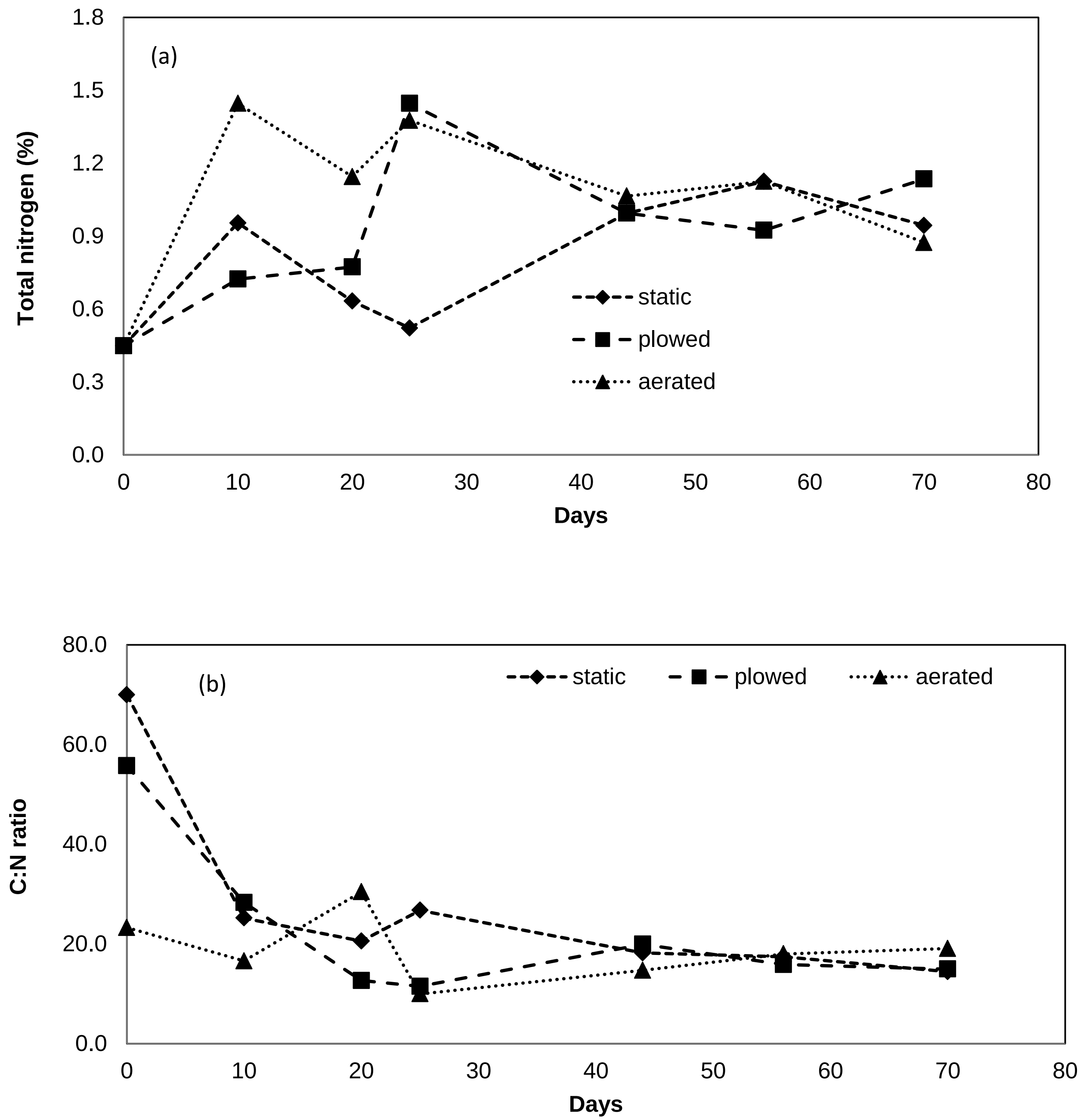

Figure 6a(top), 6b(bottom). Change in total nitrogen (TN) content and C:N ratio in the aerated composting (AC), plowed composting (PC), and static composting (SC) piles.

In AC pile, the TN content increased from 0.45% to 0.87%. The increase in TN concentration over the days may be caused by nitrogen immobilization in composting process (Huang, et al., 2004). The trend of TN change was similar for AC, PC and SC piles i.e., TN concentration increased over the time. In AC pile, TN was increased from 0.45% to 1.14%, while in PC and SC piles it was increased from 0.45 to 1.14 and 0.45 to 0.94, respectively.

The change in carbon and total nitrogen content in aerated, static, and plowed piles caused the changes in carbon to nitrogen ratio (C:N) (Figure 6b), which is an important parameter to determine the maturity of the compost product (Guo, et al., 2012). In AC pile, the C:N ratio (total carbon/total nitrogen) varied from 49.5 to 19.2, a decrease of 61.2%. In PC pile, the C:N ratio was decreased from 49.5 to 14.9 indicating a decrease by 69.9%. The C:N change in SC pile was similar to PC piles i.e., C:N was reduced by 70.7% (Table 1). The results of this study (higher C:N ratio in aerated pile) is similar to a previous study by (Guo, et al., 2012), who reported that the increased aeration rate in thermophilic phase elevates C:N ratio.

Both high and low C:N ratio have negative effects on the composting efficiency (Bernal, et al., 2009). The C:N ratio of feedstock depends on the types of wastes used in the feedstock, and feedstock C:N ratio influences the efficiency of composting process (Adhikari, et al., 2008). It has been demonstrated that most food waste has low C:N ratio ranged from 10 to 25 by (Adhikari, et al., 2008, Chang and Chen, 2010). The initial feedstock of this study showed elevated C:N ratio, which was due to the fact that palm tree waste was added in the feedstock, which has a relatively higher carbon content. The C:N ratio of wood chips, which are similar to palm tree waste, is reported to be 653 (Martinez, et al., 1999), and mixing of such waste in compost pile generate increased C:N ratio. The C:N ratio of matured compost is reported to be less than 20 (Hirai, et al., 1983), and the results of this study showed the C:N ratio lower than 20 in all three systems indicating final compost as a matured compost.

4. Conclusions

Uncertain pathogen inactivation during the composting process is a serious issue. To understand the effects of aeration, static, and plowing on pathogen inactivation of green and food waste during the composting, here we have conducted a series of experiments resembling aerated (AC), plowed (PC), and static (SC) composting conditions. The inactivation of *Salmonella* and *E. coli* was assessed in AC, PC, and SC piles for more than two months. In addition, the changes in physiochemical parameters including pH, TN, carbon, moisture, and C:N ratio were estimated. Results showed that all three tested composing systems resulted in matured compost with C:N ratio less than 20 (in 70 days of composting). The SC pile has the highest C:N ratio reduction (70.7%) followed by PC (69.9%), and AC (61.2%). While *Salmonella* levels was non-detectable in the initial phase of the experiments, *E. coli* persist till the end of the experiment indicating slow response of composting for reducing *E. coli* of food and green wastes. Beyond 40 day of composting none of the samples showed the presence of *Salmonella*, while *E. coli* was present in the sample collected at the end of the experiment (on day 70). All three tested composting methods resulted in elevated pH. The initial pH of the feedstock was between 3.5 and 3.6. The increase in pH in AC pile was 91.6%, while in PC and SC it increased by 105.7 and 94.4%. Authors anticipate that the results of this study will help improving food and green wastes composting processes, and will enhance the understanding of pathogen inactivation in the composting process.

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CHAPTER 3: Assessing the changes in *E.coli* levels and nutrient dynamics during vermicomposting of food waste under lab and field scale conditions

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Abstract

Vermicomposting has proven to be a promising method for treating garden, household, and municipal wastes. Though vermicomposting has been used extensively for converting wastes into fertilizers, pathogen such as *E. coli* survival during this process is not well understood. In this study we conducted both lab and field scale experiments to understand the dynamics of *E. coli* during vermicomposting of food waste and the impacts of temperature on the mortality of *Eisenia fetida* earthworms. In addition, other pertinent parameters such as carbon and nitrogen contents, moisture, pH, volatile solids, micronutrients, and macrominerals were monitored during the study. The experiments were conducted for more than 100 days. Results showed that vermicomposting was not effective in reducing *E. coli* levels, in food waste, in both lab and field scale experiments. The carbon to nitrogen ratio (C/N) decreased by 54% in the lab scale study and by 36% in the field study. While there was no observable mortality of *E. fetida* at 20 – 25 °C, increased mortality was observed at elevated temperatures of 30 °C, 35°C, and 39 °C.

Keywords: Food waste; vermicomposting; C/N ratio; E. coli; Eisenia fetida, mortality

1. Introduction

Vermicomposting has been recognized as an effective method for converting different types of solid wastes into soil additives (Aalok, et al., 2008) and is widely adopted in many parts of the world including Asian, African, European, and North and South American continents (Edwards and Arancon, 2005). Considerable attention has been given to the vermicomposting in the US because of its many benefits including sustainability (Edwards and Arancon, 2006, Ndegwa and Thompson, 2001, Ndegwa and Thompson, 2000). Numerous studies have shown that the vermicompost (mature vermicomposting product) is rich in many nutrients including nitrogen (N), phosphorous (P), potassium (K), and calcium (Ca) (Edwards, 1998, Orozco, et al., 1996, Parkin and Berry, 1994). Previous studies have also demonstrated that vermicompost enhances plants nutrient uptake (Nagavallemma, et al., 2004), provides humic acids which promote plant growth (Atiyeh, et al., 2002), while conditioning soil to improve water retention (Appelhof, et al., 1996).

Both the conventional composting processes (such as aerated windrow, aerated static pile, in-vessel, etc.) and vermicomposting are practiced in the USA (USEPA, 2015). While conventional composting methods are typically driven by microorganisms, vermicomposting is a combined effort of earthworms and microorganisms (Aira, et al., 2002). Composting worms (under favorable temperature conditions) actively ingest and digest feedstock (Sim and Wu, 2010, Tognetti, et al., 2007) to produce vermicompost or castings, which was used as a fertilizer. Both conventional composting and vermicomposting processes, however, have their inherent advantages and limitations. Vermicomposting process, in general, is a low-temperature process, which does not favor destruction or reductions of pathogenic bacteria present in the feedstock (Edwards and Arancon, 2006). Vermicomposting process is normally carried out at 10 – 32°C (Adhikary, 2012) because of earthworms high mortality above 35°C (Ndegwa and Thompson, 2001). Vermicompost or castings, therefore, do not meet EPA standard for pathogen destruction to be considered class-A compost (Edwards and Arancon, 2006, Ndegwa and Thompson, 2001, Williams, et al., 2006).

While vermicomposting certainly produces good quality soil amendments [15, 21], pathogens surviving the process may pose a potential risk to foods and environment via crops. In previous studies, Eastman, et al. (2001) reported reduction of faecal coliforms number during vermicomposting. Another study by Nair, et al. (2006) on investigating inactivation of *E. coli* and *E. faecalis* during vermicomposting of kitchen waste indicated reduction of the pathogens in three months. A couple of other studies, however, showed survival of gram-negative pathogens during the vermicomposting process (Hendriksen, 1995, Thorpe, et al., 1993). The goal of this study was to investigate the dynamics of *E. coli* and nutrients during vermicomposting of food waste. The specific objectives were to: 1) evaluate the changes in *E.coli* concentration during vermicomposting of food waste under lab and field conditions, 2) determine the changes in C/N ratio of food waste during the process; and 3) assess the effects of temperature on the mortality of earthworms.

2. Materials and methods

2.1 Laboratory scale experiment

The lab scale study was conducted at University of California, Davis, CA at a temperature of 22±2°C. Approximately, 250 g of compost worms (*Eisenia fetida*) purchased from a commercial vendor (Marlé Worm Growers in WA, USA) were added into a dark colored 20-L bin (sterile). Holes were drilled on the lid of the Sterlite bin to facilitate the aeration of the vermicomposting process. Details of the experimental setup are presented in Figure 1.

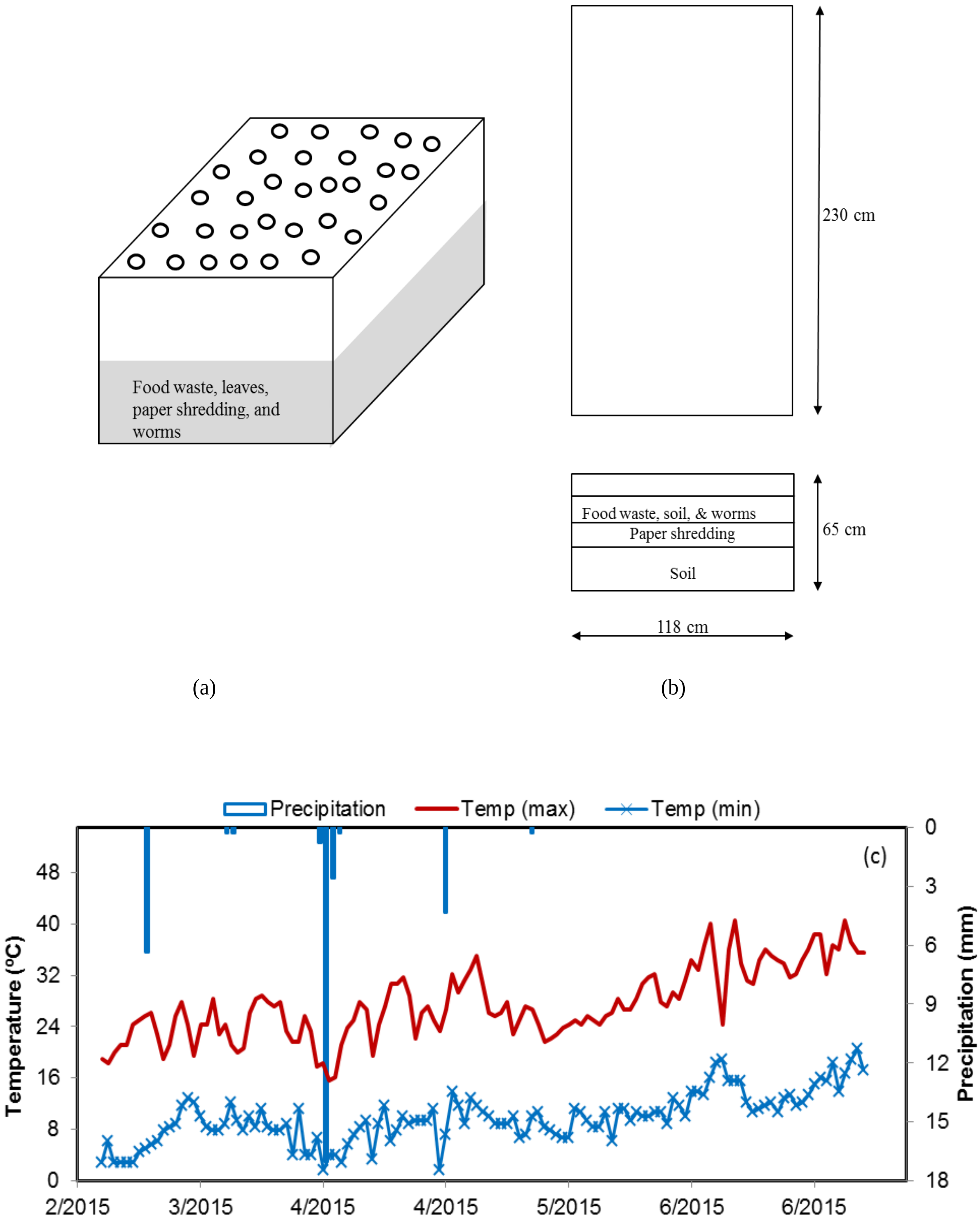

Figure 1. Schematic of vermicomposting experimental set-up at a lab scale (Fig 1a) and a field scale (Fig 1b) and temperature and precipitation of field study area (Fig 1c)

The average length and weight of the compost worms were 6 cm and 3.2 g, respectively. Approximately 500g of chopped vegetables (collected from a local grocery store) was added as feedstock, at the start of the experiment, while shredded paper was provided as bedding material. Water was added to maintain the moisture in the vermicomposting bin (shown in result and discussion section). After two weeks from the start of the experiment, an additional 500 g of chopped vegetables was added. The temperature of the substrate was recorded on a regular basis during the experiment.

2.2 Field scale experiment

The field scale studies were conducted at the community of Tri-Cooperative of University of California, Davis, mainly by the community residents themselves. The dimensions of the rectangular vermicomposting plot were 2.3 m × 0.65 m × 1.18 m (length × width × depth) as shown in Figure 1(b). Nearly, 54 pounds of mixed of food waste and two pounds of paper shredding (bedding) produced from the daily life of the community of Tri-Cooperative were added to the vermicomposting pile. About, three pounds of compost worms (*Eisenia fetida*) were also added to the feedstock. The order of materials layering from top was: soil; food waste, soil, and worms; paper shredding; soil; and plastic lining (silicon-coated nylon (sinlnylon)), respectively (shown in Figure 1b). The experimental plot (brick raised vermicompost bed) was covered with a tarp to avoid the direct sunlight and high temperature on the soil surface. Water was sprayed frequently on the soil surface to lower the pile temperature and enhance the moisture level (results are shown in section 3). The temperature of the compost pile was recorded frequently. The average maximum and minimum daily air temperature between March and June (during the experiment) in Davis, CA varied 15.6 °C - 40.6 °C and 1.7 °C – 18.9 °C, respectively (shown in Fig. 1C). The cumulative precipitation during this period was 31.98 mm.

2.3 Earthworm mortality test

Approximately 4.5 kg of earthworms (*E. fetida*) were randomly assigned to six bins (20 L bins) at an average of 0.7 kg to each bin. About 1 kg of food waste was also added to the bins. All the six bins were placed in three different incubators maintained at 30, 35, and 39°C, respectively. At each temperature, two bins were used. The bins were taken out from incubators after 3, 5, 24, and 45 h, respectively to evaluate the mortality of *E. fetida* under these temperature conditions.

2.4 Sampling and laboratory analyses

For both lab and field scale experiments, samples of compost material were collected every day during the first week, two times a week for the first month, and once a week for the rest of the experimental duration. The lab scale experiment was carried out for 107 d, while the field scale experiment was conducted for 103 d. Samples were transported to the laboratory and all necessary analyses were carried out immediately. Each time, a portion (5 g) of the sample was dissolved in phosphate buffered saline (PBS) for *E. coli* enumeration. Bacteriological Analytical Manual (BAM) method was followed for enumeration of *E. coli* in vermicompost using MacConckey II agar with sorbitol (BBL, Becton, Dickinson and Company, Sparks, MD, USA). Another portion of the sample was used for moisture content (MC), pH, volatile solids (VS), total carbon (TC), and total N (TN) concentration analyses. The latter parameters (MC, pH, VS, TC, and TN) were assumed to vary slowly during the experiment and, therefore, were performed less frequently than the *E. coli* analyses. The MC was determined using the standard over drying at 105°C, while VS content was analyzed in a muffle furnace (550°C). Total organic carbon (TOC) content was determined using the high range Test 'N Tube™ (Hach kit) method (Method 10128). The TN concentration was determined using Hach kit (Simplified TKN TNT plus). Dry physio-chemical analyses (beginning and end samples) such as total phosphorus (TP), total potassium (TK), total calcium (T-Ca), total magnesium (T-Mg), total zinc (T-Zn), total manganese (T-Mn), total sulphur (T-S), total ferrous (T-Fe), and total copper (T-Cu) content were performed by the UC Davis Analytical Lab using Ther Thermo-Finnigan Flash EA 1112.

3. Results and discussion

3.1 Effect of vermicomposting on E. coli at lab and field scales

The variations of *E. coli* concentration during the vermicomposting process at both lab and filed scale studies are shown in Figure 2.

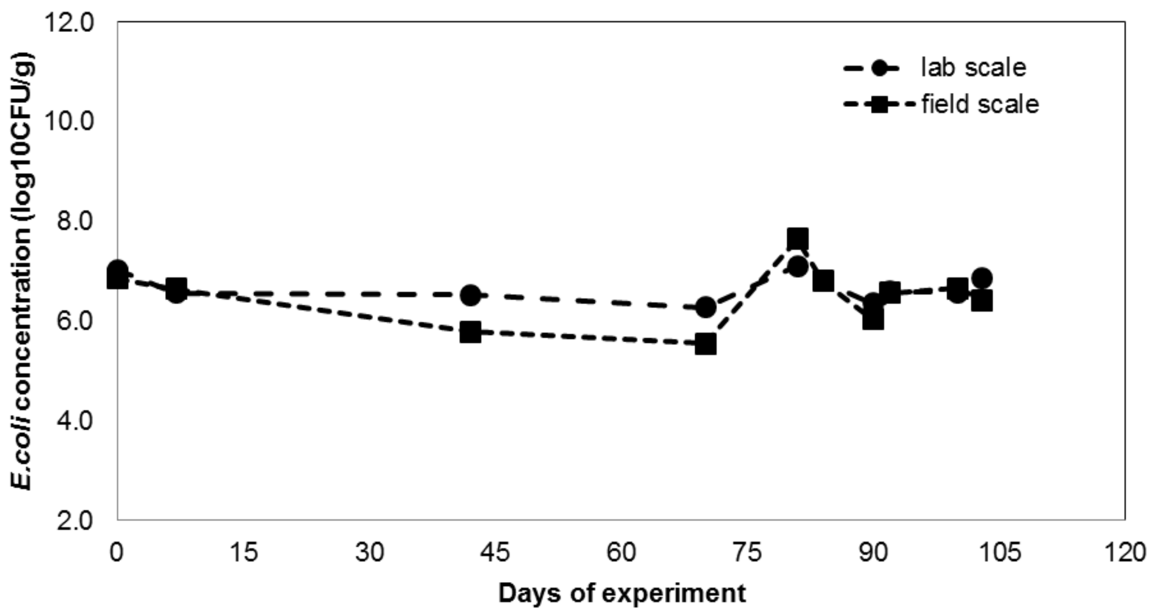

Figure 2. Variation of *E. coli* concentration during the vermicomposting at field and lab scales

Both lab and field studies showed similar trends from the start to the end of the experiment, which lasted more than 100 d. The *E. coli* concentration in both the treatments varied between six and eight logs CFU/g. The *E. coli* levels decreased slightly during the first 75 d, while increased levels were observed after 90 d of the experiment. At the end of the experiment, however, *E. coli* levels were in the same orders of magnitude as in the initial samples.

A pairwise t-test indicated no significant differences (p-value = 0.24) between *E. coli* levels in both lab and field experiments during the entire study period. The results of these studies, therefore, suggest that vermicomposting has no significant effect on *E. coli.* In contrast, previous studies reported that the pathogens can be reduced in vermicomposting processes (Eastman, et al., 2001, Edwards and Subler, 2010). Dominguez and Edwards (2004) showed that the antibacterial fluids secreted by worms were able to kill human pathogens.

3.2 The variation of C/N ratios during the vermicomposting

The particulars of C/N ratio for both at lab scale and field scale are presented in Figure 3.

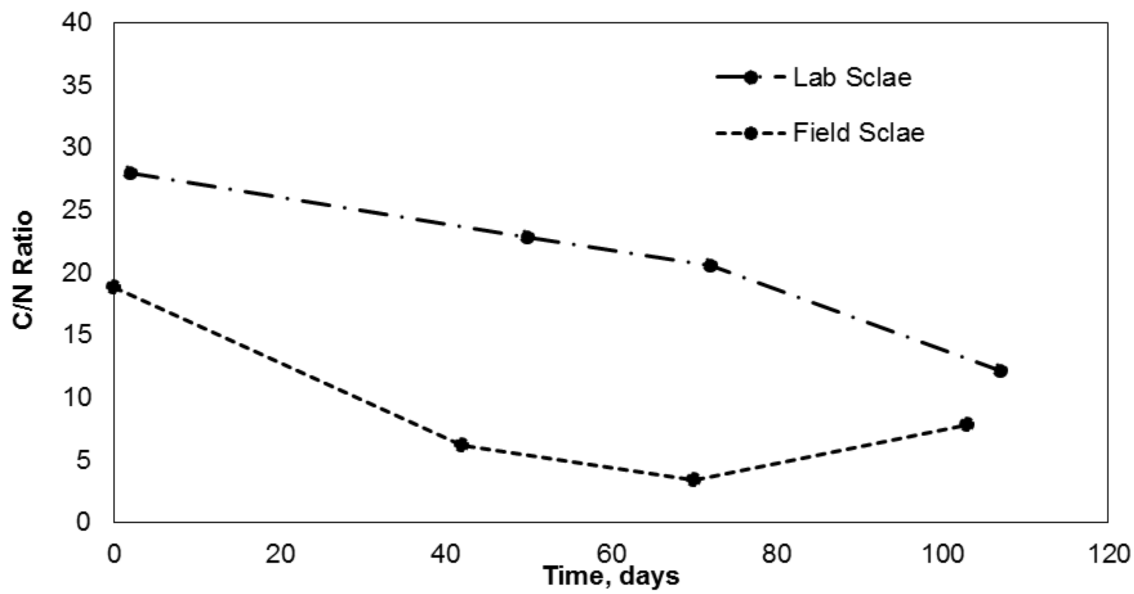

Figure 3. Change in C/N ratio at field and lab scales

The C/N ratio at both lab and field scales showed a good correlation. The C/N ratios of lab scale at the beginning and end of the study were 27.9, and 12.1, respectively while at the field scale they were 18.8, and 7.8, respectively. (Nair et al., 2006) reported that a C/N ratio of 25 or less (considered as matured vermicompost) was achieved in vermicomposting of mixture of paper, grass, and kitchen waste in 21 d. Our results were thus consistent with these studies and showed significant decrease in C/N ratios (54% in lab and 36% in field studies) during the vermicomposting process. The C/N ratio decreased steadily during first 2.5 months in the field studies but an increase in C/N ratio was observed between day 75 day and day 103.

3.3 Change in the moisture content during vermicomposting

The profiles of MC of the vermicomposting substrates during the processes at lab and field scale are presented in Figure 4.

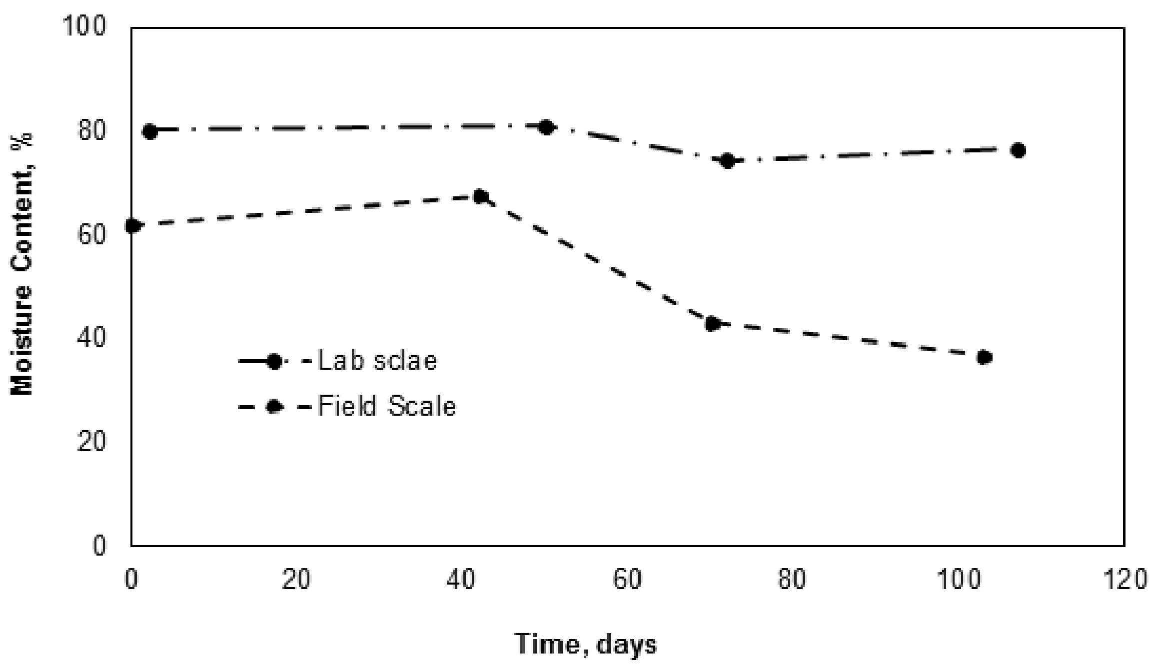

Figure 4. Variation of moisture content at field and lab scales

The MC of the material in lab studies averaged 78.3% during the 107 d and fairly consistent for the entire process due to the controlled laboratory conditions. In contrast, however, the MC of the substrate in field scale studies varied substantially between 37% and 62% most probably because of variations in environmental conditions especially during daytime and nighttime. The daytime and nighttime temperatures of the compost pile during the vermicomposting process averaged 20°C and 18°C, respectively. The reported optimal MC for *E. fetida* are between 60%

and 90% (Rodríguez-Canché, et al., 2010). Optimal MC (> 70%), for vermicomposting, was thus maintained in our lab scale study. Conversely, the MC of the substrate in the field studies on some occasions was lower than the optimal range, which triggered the earthworms to move from drier zones to wet zones of the piles.

3.4 Variation of pH during the vermicomposting

The pH values of the vermicompost and their variation during the process are illustrated in Figure 5.

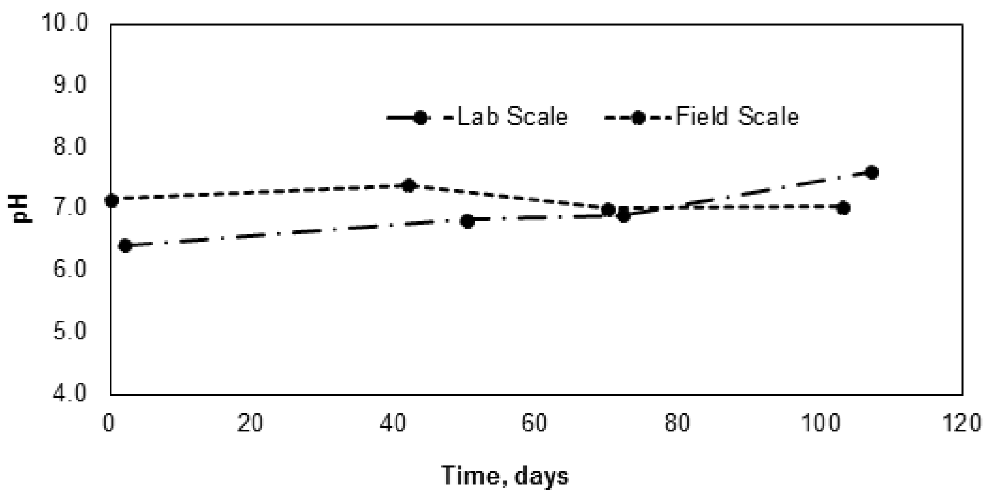

Figure 5. Change in pH of the vermicompost during field and lab scales

The pH of the vermicompost at lab scale experiment increased from 6.4 to 7.3 during the vermicomposting process (from a slightly acidic to a slightly alkaline). In the field experiments, however, the pH of the vermicompost remained almost constant within neutral pH range (7.17 – 7.05). By the end of the vermicomposting processes both the vermicomposting piles indicated similar and neutral pH-environments. A previous study, which compared vermicomposting of different substrates with initial acidic and alkali environment reported that the pH, for all, shifted towards neutral zone by the end of vermicomposting (Pramanik, et al., 2007). In another study, Nair also arrived at a similar conclusion and noted that neutral pH is the optimal pH-environment for the vermicomposting process (Nair, et al., 2006)

3.5 Survival of compost worms at three different temperatures

The information pertaining to the compost worms subjected to endurance test at three different temperatures (30, 35 and 39°C) is presented in Figure 6.

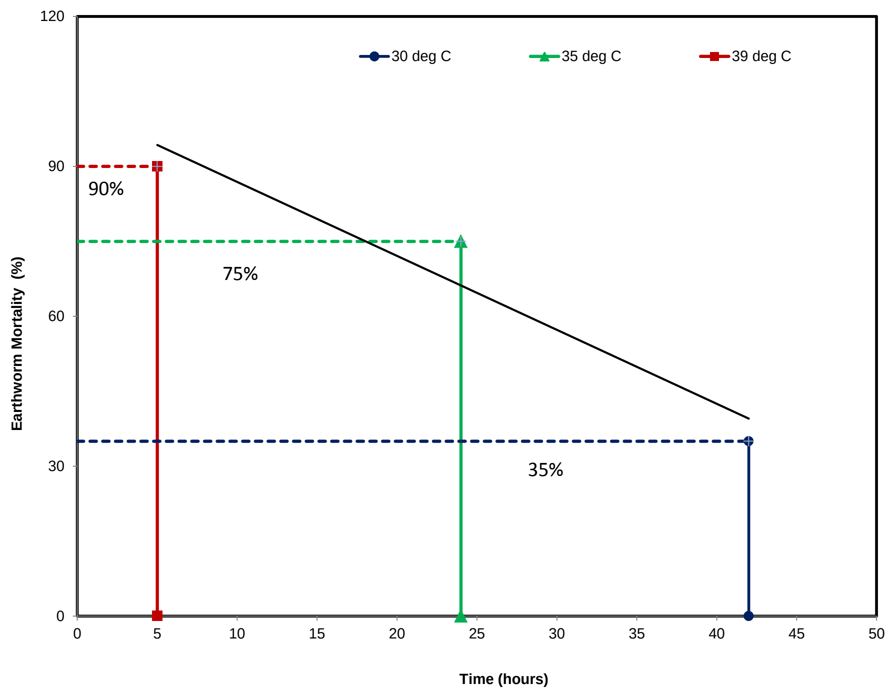

Figure 6. Survival of compost worms at three temperatures.

About 35% of the worms died during the first 45 h at 30°C temperature. The mortality of the compost worms was 75% in 24 h at 35°C, while the mortality rate was 90% after 5 h at 39°C. Conversely, under room temperature conditions (22°C), no mortality of compost worms was observed during the endurance study. It is evident from these results, that the temperature over 30°C was not suitable for the survival of *E. fetida*. These results agree with previous studies. A study by Ndegwa & Thompson indicated that temperatures above 35°C is detrimental to *E. fetida* and portends their imminent mortality (Ndegwa and Thompson, 2000).

3.6 Physio-chemical and elemental analysis of the lab and filed scale vermicomposting samples

The TP content decreased marginally from 0.29 to 0.28% at lab scale and increased from 0.14 to 0.16% at field scale, indicating no significant variation during the vermicomposting process. These results, however, disagree with results from vermicomposting of sewage waste and cow dung where P content nearly doubled during 45 d of vermicomposting of these substrates(Subramanian, et al., 2010). Total K content increased from 0.86% to 1.2% in lab scale studies and slightly increased from 0.52% to 0.58% in the field scale studies. Similar results were reported by Kaushik & Garg from their studies on vermicomposting of mill sludge mixed with cow dung (Kaushik and Garg, 2004). The authors reported that the increase in K content was observed in all 9 sets of experiments with different feedstock composition.

The T-Ca content in the both lab and field vermicomposting studies indicated marginal increase. Results showed that T-Ca increased from 0.54 to 1.0% and 0.96 to 1.13% for lab scale and field scales, respectively. Subramanian reported an increase in Ca content from their vermicomposting studies. The authors also indicted that the presence of Ca might promote vermicomposting with the improved feeding behavior of earthworms (Subramanian, et al., 2010).

In our study, by the end of the experiment, about 64% of initial T-Mg concentration remained in the vermicompost for lab scale studies while there was a slight decrease for field scale studies. Our results are in agreement with Chaudhuri who reported similar reduction in Mg concentration from 0.54 to 0.40% during the vermicomposting of kitchen waste(Chaudhuri, et al., 2000). The initial sulfur concentration, in the vermicompost, was 3430 and 720 ppm, while the final concentrations were 4370 and 950 ppm for lab and field studies, respectively.

Heavy metal (Zn, Mn, Fe, and Cu) concentrations, in the substrates, before and after vermicomposting for both lab and field scales were also determined. As shown in Table 1, for both lab and field studies, vermicomposting increased concentrations of T-Zn, T-Mn, and T-Cu and decreased T-Fe concentration.

Table 1. Physio-chemical and elemental analyses of the vermicomposting samples on dry basis (lab and filed scales)

Lab Scale	Days	VS, %	TP, %	TK, %	T-Ca, %	Mg, %	Zn, ppm	Mn, ppm	T-S, ppm	T-Fe, ppm	T-Cu, ppm
	0	16.4	0.29	0.86	0.54	0.67	84.9	139.7	3430	4927	71.4
	50	14.3	-	-	-	-	-	-	-	-	-
	72	17.9	-	-	-	-	-	-	-	-	-
	107	16.6	0.28	1.2	1.0	0.43	137.5	81.6	4370	2719	303.5
Field Scale											
	0	14.3	0.14	0.52	0.96	2.0	147.8	648.7	720	34,415	59.6
	42	20.3	-	-	-	-	-	-	-	-	-
	70	10.5	-	-	-	-	-	-	-	-	-
	103	15	0.16	0.58	1.13	1.9	158.2	610.3	950	32,732	68.4

Previous research on dynamics of heavy metal during vermicomposting has produced mixed results. Hayawin observed an increased in heavy metal concentration (Zn, Mn, Fe, and Cu) in the final vermicomposting product compared to the feedstock (Hayawin, et al., 2010). In contrast, Suthar reported that the heavy metal concentrations during the vermicomposting of sewage sludge decreased significantly compared to that of the initial feedstock (Suthar, 2009). Deolalikar attributed the increase of heavy metal in the final product to the weight and volume reductions during the vermicomposting process (Deolalikar, et al., 2005). In general, however, heavy concentrations of heavy metals, in the soil, may produce negative influence on plant growth and earthworm reproduction (Hayawin, et al., 2010). It is, therefore, necessary to determine heavy metal concentration prior to the land application of vermicompost.

4. Conclusions

Both field and lab scale studies were conducted to assess the fate of *E. coli* in food waste during vermicomposting of waste using *E. fetida*. The experiment was conducted for more than 100 d. In addition, endurance of *Eisenia fetida* earthworms to temperature was evaluated at four temperatures (22°C, 30°C, 35°C, and 39°C) conditions in the lab. Based on the results from these studies, the following conclusions were drawn:

1. The vermicomposting process, during 100 d of the process, was not effective in reducing *E.coli* levels, in food waste, in both lab and field scale experiments. In the first 75 d, *E. coli* levels decreased slightly, however, later regrowth resulted in increased *E. coli* levels. By the end of the experiments, *E. coli* levels were in range of 7 orders of magnitude in both lab and field experiments.
2. The average moisture levels of the vermicomposting feedstock in lab and field studies were 78.5 and 52%, respectively. The moisture content of the feedstock remained above 70% in the lab studies due to controlled conditions; however, at field scale the variation in moisture content was relatively larger. Nonetheless, based on the C/N ratio, both lab and field scale experiments produced reasonably good vermicompost, and earthworms were able to tolerate low moisture content.
3. The pH of the vermicomposting feedstock in lab studies shifted from slightly acidic zone (≈ 6.4) to a low alkaline zone (≈7.6). However, the pH of the feedstock in field scale study remained in the neutral zone (varied from 7.1 to 7.0).

4. The temperature endurance experiments on the *Eisenia fetida* earthworms showed elevated mortality of earthworms at higher temperatures, particularly at 35°C and 39°C. Approximately 70% of earthworms were able to survive for 45 h at 30°C compared to more than 75% of earthworm mortality at 35°C and 39°C within 24 h.

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CHAPTER 4: Urban waste and compost estimation model

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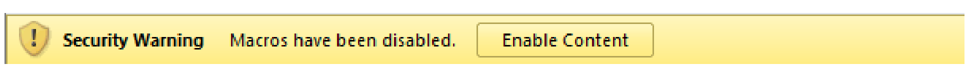
1. Purpose

There are 5 spreadsheets in the model: "**Waste Estimations**" (Figure 1), "**Waste Calculations**" (Figure 2), "**Composting Verification; Days**" (Figure 3), "**Composting Verification; Parameters**" (Figure 4) and "**References**" (Figure 5).

There are two main purposes for this model:

1) To calculate the waste production from the sustainable city annually, monthly, and weekly. The spreadsheets that address this are "**Waste Estimations**" and "**Waste Calculations**".
2) To verify the quality of compost material by various parameters such as temperature, pH, carbon content, carbon-to-nitrogen ratio reduction, macronutrients, micronutrients, E. coli concentration, and PAS limits. The spreadsheets that address this are "**Composting Verification; Days**" and "**Composting Verification; Parameters**".

2. General Note



If you see this warning when you open the spreadsheet, make sure to press "Enable Content" to enable the use of "RESET CALIBRATION VALUES" button.

3. Waste Estimations

URBAN WASTE ESTIMATIONS

This sheet provides the overall calculated wastes produced from each source. Adjusting the values in red (on the right) will automatically adjust the overall waste values (on the left).
Calibration values can be reset if desired by clicking the "RESET CALIBRATION VALUE" corresponding to the source.

	Type of Wastes	Yearly (tons)	Weekly (tons)	Monthly (tons)
1	Food waste	843.88	16.23	70.32
2	Grass clipping	1.18	0.02	0.10
3	Horse manure	307.77	5.92	25.65
4	Palm tree dry leaves	80.00	1.54	6.67
	Total	1232.83	23.71	102.74

	Source of Grass Clippings	Yearly (tons)	Weekly (tons)	Monthly (tons)
1	Parks	0.27	0.01	0.02
2	Back yard	0.91	0.02	0.08
	Total	1.18	0.02	0.10

	Source of Food Waste	Yearly (tons)	Weekly (tons)	Monthly (tons)
1	County club, planetarium, museum, & observation deck	58.26	1.12	4.86
2	Masjid	3.86	0.07	0.32
3	Resort	287.65	5.53	23.97
4	Restaurant	287.65	5.53	23.97
5	Retail	67.95	1.31	5.66
6	School	47.12	0.91	3.93
7	Sustainable Excellence Center	67.74	1.30	5.65
8	Townhouse	23.65	0.45	1.97
	Total	843.88	16.23	70.32

Calibration variables (eg. "Average dry leaves produced per year (kg)") are default values. They may vary depending on geographic location.
*Any text in red color indicates possible self-input.

Tree waste Palm	Descriptions	# of Palm Trees	Average dry leaves produced per year (kg)
RESET CALIBRATION VALUE	Palm tree	1000	20
	Other trees	1000	20
	# of resorts	2	
Grass waste Park	Descriptions	Total Area (sq ft)	Average grass clippings produced per sq ft per year (kg)
RESET CALIBRATION VALUE	Park	1500	0.182
	Backyard	5000	0.182
	# of towns	5	
	Backyard area in each townhouse (sq ft)	1000	
	# of resorts	1	
Foodwaste_venue_club_museum	Descriptions	# of Seats	Average food waste produced per year (kg)
RESET CALIBRATION VALUE	Venues and events in Club	500	100
	Planetarium, Museum & Observation Deck	100	82.6
	# of resorts	1	
Foodwaste_resort_restaurant	Descriptions	# of Guests	Average food waste produced per year (kg)
RESET CALIBRATION VALUE	Lodging/hotels	286	500
	Restaurant	10	82.6
	# of resorts	2	
Foodwaste_retail_grocery stores	Descriptions	# of Employees	Average food waste produced per year (kg)
RESET CALIBRATION VALUE	Supermarket	15	1359
	Grocery stores	10	1359
	# of resorts	2	
Waste_equestrian center	Descriptions	Associated numbers	Average food waste produced per year (kg)
RESET CALIBRATION VALUE	Adult horse	30	8432
	Baby horse	10	5480.8
	# of equestrians	1	
Foodwaste townhouses	Descriptions	Associated Numbers	Average food waste produced per year (kg)
RESET CALIBRATION VALUE	Adults	3	110
	Children	2	71.5
	# of townhouses / households	50	
Foodwaste Madiid	Descriptions	Associated Numbers	Average food waste produced per year (kg)
RESET CALIBRATION VALUE	Imam or leader	2	64.31
	Visitor to Masjid	105	17.15
	# of Masjid	2	
Foodwaste_Research_ctr_univ	Descriptions	# of Students	Average annual food waste disposed (kg/person/year)
RESET CALIBRATION VALUE	Residential	1000	64.31
	Non-residential	200	17.15
	# of colleges / universities	1	
Foodwaste_school	Descriptions	# of Students	Average annual food waste disposed (kg/person/year)
RESET CALIBRATION VALUE	Elementary school	1000	11.78
	Secondary school	1000	11.78
	# of schools	2	

Figure 1. Visualization of the "*Waste Estimation*" spreadsheet.

This spreadsheet displays all the calculated wastes produced **yearly**, **weekly** and **monthly** from **sources of food waste**, **grass clippings**, **horse manure** and **trees**. In order to take into account of changes in numbers over time, each source has specified cells where its parameters can be changed. Any changes will be automatically calculated in the overall waste calculation.

3.1. Table Description

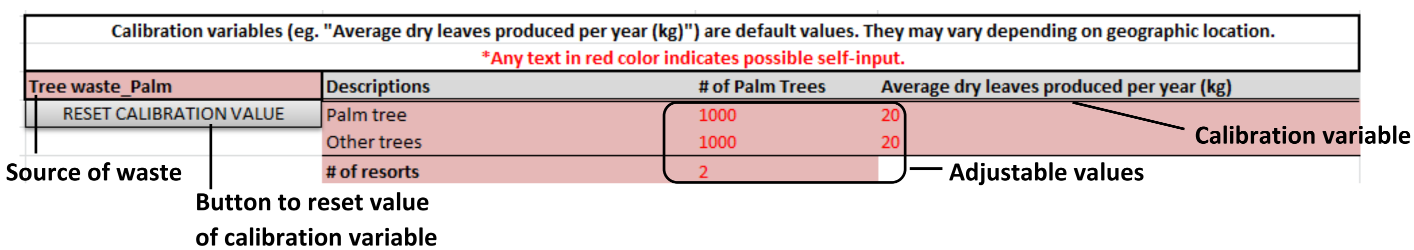
Type of Wastes	Yearly (tons)	Weekly (tons)	Monthly (tons)
Food waste	843.88	16.23	70.32
Grass clipping	1.18	0.02	0.10
Horse manure	307.77	5.92	25.65
Palm tree dry leaves	80.00	1.54	6.67
Total	1232.83	23.71	102.74

This table presents the **total amount of waste from all sources**. The total values from the two tables below it (*Source of Grass Clippings*, *Source of Food Waste*) are linked to this table.

The "*Source of Grass Clippings"* and "*Source of Food Waste"* tables display calculated output originating from the values inputted on the right. See "*How to Adjust the Numbers*" below for more detail.

3.2. How to Adjust the Numbers

This section refers to the right-hand side of the "*Waste Estimations*" spreadsheet. This area is provided for each parameter from each source to be changed to the actual or estimated values from the urban environment. Adjustment of the values in red text in this spreadsheet will automatically adjust the overall waste values. Values that are not meant to be changed are in black and are locked (eg. *Grass_waste_Park; Description: Backyard*).



The **number of resorts** refers to the number of areas of that source. For example, if there are 5 parks, then "5" can be inputted into the number of resorts.

The **calibration variable** is an estimated value obtained from literature and other resources. Because of the differences in geographic locations, the calibration value may not fully represent the actual value. Thus these values may be changed accordingly. If the user prefers to return to the values originally set, then clicking "RESET CALIBRATION VALUE" will do so.

4. Waste Calculations

CALCULATIONS

This sheet displays all of the calculations made based on the values inputted on the first page. The results also link to the first page.

The entire sheet is locked to preserve the formulas.

Tree waste_Palm	Tree waste_Palm					
	Descriptions	# of Palm Trees	Average dry leaves produced per year (kg)	Total estimated tree waste disposed annually (kg)	weekly (kg)	monthly (kg)
	Palm tree	1000	20	20000.00	384.62	1666.67
	Other trees	1000	20	20000.00	384.62	1666.67
			Total per resort (kg)	40000.00	769.23	3333.33
			Total per resort (tons)	40.00	0.77	3.33
			Total all resort(kg)	80000.00	1538.46	6666.67
	# of resorts	2	Total all resort (tons)	80.00	1.54	6.67

Grass_waste_Park	Grass_waste_Park					
	Descriptions	Total area (sq ft)	Average grass clippings produced per sq ft per year (kg)	Total estimated grass waste disposed annually (kg)	weekly (kg)	monthly (kg)
	Park	1500	0.182	273.00	5.25	22.75
	Backyard	5000	0.182	910.00	17.50	75.83
				1183.00	22.75	98.58
	# of towns	5	Total per resort (tons)	1.18	0.02	0.10
	Backyard area in each	1000	Total all resort (kg)	1183.00	22.75	98.58
	townhouse (sq ft)		Total all resort (tons)	1.18	0.02	0.10
	Total area	5000				
	# of resorts	1				

Foodwaste_venue_club_museum	Foodwaste_venue_club_museum					
	Descriptions	# of Seats	Average food waste produced per year (kg)	Total estimated food waste disposed annually (kg)	weekly (kg)	monthly (kg)
	Venues and events in Club	500	100	50000.00	961.54	4166.67
	Planetarium, Museum &	100	82.6	8260.00	158.85	688.33
	Observation Deck			58260.00	1120.38	4855.00
			Total per resort (tons)	58.26	1.12	4.86
			Total all resort (kg)	58260	1120.38	4855.00
	# of resorts	1	Total all resort (tons)	58.26	1.12	4.86

Foodwaste_resort_restaurant	Foodwaste_resort_restaurant					
	Descriptions	# of Guests	Average food waste produced per year (kg)	Total estimated food waste disposed annually (kg)	weekly (kg)	monthly (kg)
	Lodging/hotels	286	500	143000.00	2750.00	11916.67
	Restaurant	10	82.6	826.00	15.88	68.83
			Total per resort (kg)	143826.00	2765.88	11985.50
			Total resort (tons)	143.83	2.77	11.99
			Total all resort (kg)	287652	5531.77	23971.00
	# of resorts	2	Total all resort (tons)	287.65	5.53	23.97

Figure 2. Visualization of the "*Waste Calculations*" spreadsheet. Only a fraction of the sheet is shown.

This spreadsheet displays all of the calculations linked to the "*Waste Estimations*" spreadsheet. Total waste in both tons and kilograms can be viewed here. The entire sheet is locked to preserve the formulas.

5. Composting Verification; Days

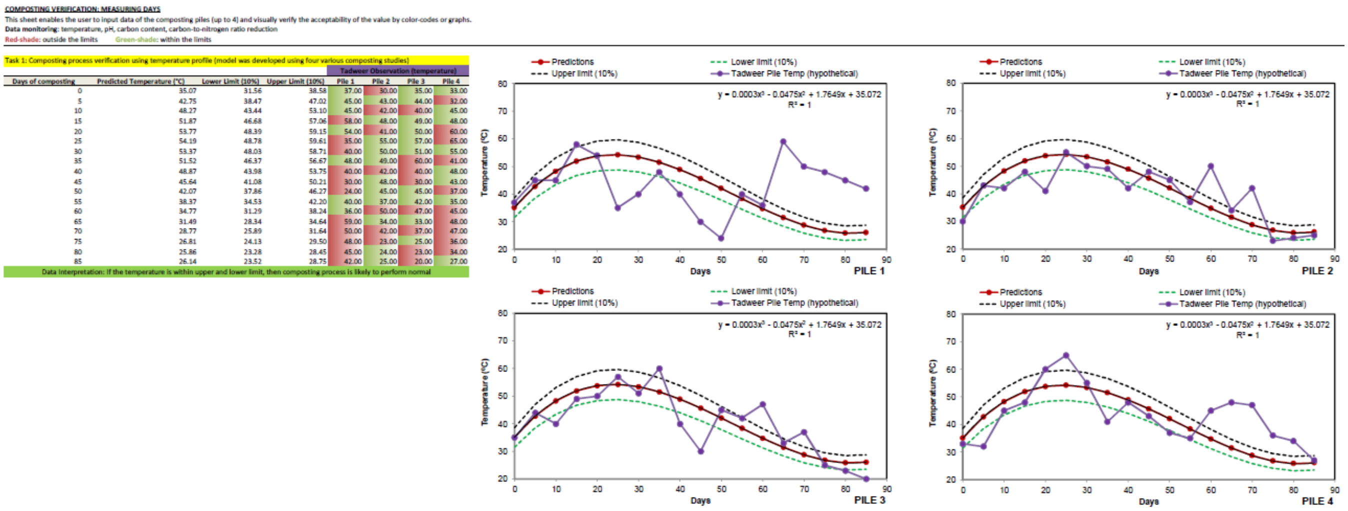


Figure 3. Visualization of "*Composting Verification; Days*" spreadsheet. Only Task 1 on temperature profile is shown. The user-inputted values (colored in green and red) directly transform the graph corresponding to the chosen pile (up to 4) for a dynamic interface.

This spreadsheet, along with the "*Composting Verification; Parameters*" spreadsheet, observes the quality of the composting on several parameters. This sheet contains the **models for parameters** (**temperature**, **pH**, **carbon content**, **carbon-to-nitrogen ratio**) that are checked *during* the composting process.

5.1 Table Description: Temperature verification

Task 1: Composting process verification using temperature profile (model was developed using four various composting studies)							
				Tadweer Observation (temperature)			
Days of composting	Predicted Temperature (°C)	Lower Limit (10%)	Upper Limit (10%)	Pile 1	Pile 2	Pile 3	Pile 4
0	35.07	31.56	38.58	37.00	30.00	35.00	33.00
5	42.75	38.47	47.02	45.00	43.00	44.00	32.00
10	48.27	43.44	53.10	45.00	42.00	40.00	45.00

Figure 3.1. Close-up of the temperature verification table.

The **predicted temperature** values were calculated using the model, which was developed in this study. The observations of multiple studies were used to develop this model. This represents the ideal temperature during the composting process. Any values equal to or within the **upper** and **lower limits** are considered acceptable. **Tadweer** is a sample of the company name. The user may input actual values of the measured temperature under the column for the pile number (up to 4).

Once inputted, values will be shaded either **green** (within the limits) or **red** (outside the limits) on the table.

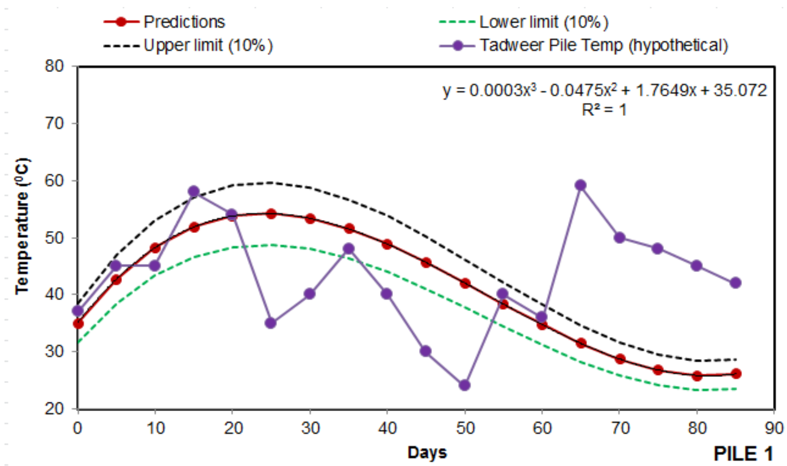


Figure 3.1.2. Close-up of the graph corresponding to Pile 1 of the user-inputted values on the temperature verification table.

Each pile has a corresponding **graph** to visually inspect the quality of the composting process. The graphs automatically adjust when the corresponding pile values are inputted. This graph is an example of how it may appear by the end of the composting process. The **equation** on the graph is the mathematical basis of the model.

5.2 Table Description: pH verification

Task 2: Composting process verification using pH profile (model was developed using four various composting studies)							
				Tadweer Observation (pH)			
Days of composting	Predicted pH	Lower Limit (10%)	Upper Limit (10%)	Pile 1	Pile 2	Pile 3	Pile 4
0	6.81	6.13	7.49	8.00	7.00	7.50	7.50
5	6.98	6.28	7.68	4.00	8.00	6.00	6.00
10	7.12	6.41	7.84	5.00	9.00	6.50	5.50
15	7.25	6.52	7.97	7.00	5.00	8.00	6.00
20	7.35	6.62	8.09	6.50	6.00	8.50	6.50
25	7.44	6.70	8.19	8.50	7.00	9.00	7.00
30	7.51	6.76	8.26	8.00	7.50	7.00	7.50
35	7.57	6.81	8.32	6.40	5.00	7.50	8.00
40	7.60	6.84	8.37	7.20	4.00	7.50	9.00
45	7.63	6.87	8.39	7.10	5.00	7.00	7.10
50	7.64	6.88	8.41	7.40	6.00	6.00	7.40
55	7.65	6.88	8.41	7.80	7.50	6.50	7.80
60	7.64	6.87	8.40	8.00	8.00	7.00	8.00
65	7.62	6.86	8.38	7.50	8.50	7.50	7.50
70	7.60	6.84	8.36	8.20	9.00	8.00	8.20
75	7.57	6.81	8.33	7.00	7.50	9.00	7.00
80	7.53	6.78	8.29	8.00	7.00	8.50	8.00
85	7.50	6.75	8.25	7.50	7.50	8.00	7.50
Data Interpretation: If the pH is within upper and lower limit, then composting process is likely to perform normal							

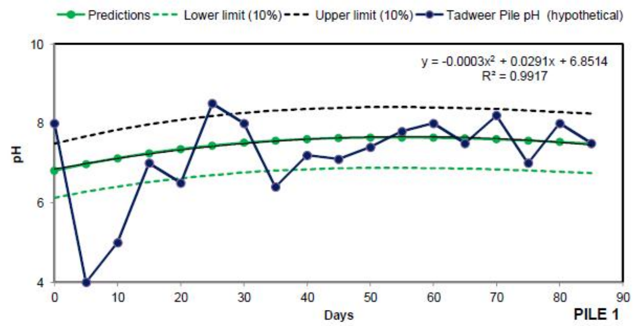


Figure 3.2. Close-up of the pH verification table with a graph corresponding to Pile 1.

The predicted pH values were calculated using the model, which was developed from the observation of several studies. The functionality of the pH verification parameter is analogous to the temperature verification described above.

5.3 Table Description: Carbon content

Task 3: Composting process verification using carbon content profile (model was developed using four various composting studies)							
Initial carbon value	55			Tadweer Observation (carbon content)			
Days of composting	Predicted carbon content	Lower Limit (10%)	Upper Limit (10%)	Pile 1	Pile 2	Pile 3	Pile 4
0	53.46	45.44	61.48	52.00	50.00	47.00	53.00
5	52.97	45.02	60.91	56.00	55.00	42.00	45.00
10	52.47	44.60	60.34	54.00	50.00	49.00	57.00
15	51.98	44.18	59.77	48.00	60.00	48.00	60.00
20	51.48	43.76	59.20	46.00	65.00	55.00	48.00
25	50.99	43.34	58.63	47.00	45.00	57.00	42.00
30	50.49	42.92	58.06	45.00	49.00	59.00	45.00
35	50.00	42.50	57.49	55.00	51.00	60.10	47.00
40	49.50	42.08	56.93	50.00	53.00	61.00	55.00
45	49.01	41.65	56.36	51.00	54.00	57.00	68.00
50	48.51	41.23	55.79	56.00	57.00	56.00	63.00
55	48.02	40.81	55.22	42.00	59.00	52.00	51.00
60	47.52	40.39	54.65	48.00	48.00	47.00	57.00
65	47.03	39.97	54.08	46.00	47.00	57.00	60.00
70	46.53	39.55	53.51	55.00	42.00	52.00	57.00
75	46.04	39.13	52.94	54.00	49.00	46.00	54.00
80	45.54	38.71	52.37	42.00	57.00	58.00	49.00
85	45.05	38.29	51.80	42.00	51.00	51.00	47.00
Data Interpretation: If the carbon is within upper and lower limit, then composting process is likely to perform normal							

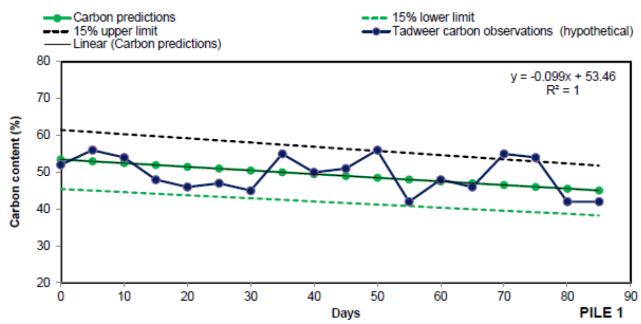


Figure 3.3. Close-up of the carbon content verification table with a graph corresponding to Pile 1.

The predicted carbon content was calculated using the observations from various studies. The estimated initial carbon content value is 55%, which is used to calculate the predicted carbon content that reduces over time (shown in the graph). The function of the table and graph is same as described for temperature verification.

5.4 Table Description: Carbon-to-nitrogen ratio reduction

Task 4: Composting process verification using carbon-to-nitrogen ratio reduction (model was developed using four various composting studies)

Initial C/N value: 48

Days of composting	Predicted carbon nitrogen ratio	Lower Limit (10%)	Upper Limit (10%)	Tadweer Observation (carbon nitrogen ratio) Pile 1	Pile 2	Pile 3	Pile 4
0	47.22	37.77	56.66	55.00	40.00	57.00	47.00
8	46.00	36.80	55.20	48.00	45.00	54.00	48.00
16	44.67	35.73	53.60	54.00	43.00	53.00	54.00
24	43.21	34.57	51.85	55.00	50.00	58.00	55.00
32	41.63	33.30	49.95	60.00	58.00	47.00	50.00
40	39.92	31.94	47.91	25.00	54.00	43.00	47.40
48	38.09	30.48	45.71	35.00	40.00	42.00	44.00
56	36.14	28.91	43.37	45.00	48.00	35.00	42.00
64	34.07	27.26	40.88	52.00	42.00	31.00	43.00
72	31.87	25.50	38.25	25.00	50.00	34.00	38.00
80	29.55	23.64	35.46	20.00	42.00	28.00	37.10
88	27.11	21.69	32.53	32.00	35.00	22.00	31.90
96	24.55	19.64	29.46	25.00	25.00	23.00	30.50
104	21.86	17.49	26.23	24.00	24.00	18.00	25.40
112	19.05	15.24	22.86	21.00	20.00	16.00	22.50
120	16.11	12.89	19.34	22.00	18.00	17.00	19.00
128	13.06	10.45	15.67	18.00	14.00	12.00	17.00
136	9.88	7.90	11.85	20.00	13.00	10.00	8.00

Data Interpretation: If the carbon nitrogen ratio within upper and lower limit, then composting process is likely to perform normal

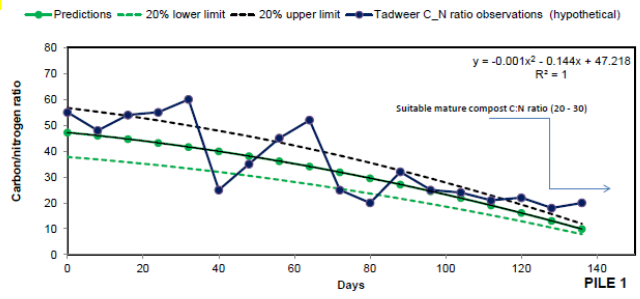


Figure 3.4. Carbon-nitrogen reduction verification table with a graph corresponding to Pile 1.

The predicted carbon-nitrogen reduction values were calculated with a model based on observations from multiple studies. The estimated initial C/N ratio is 48%, which is used to calculated the predicted C/N ratio reduction over time (shown in the graph). The function of the table and graph is same as described for temperature verification.

6. Composting Verification; Parameters

COMPOSTING VERIFICATION: MEASURING OTHER PARAMETERS

This sheet enables the user to input data of the composting piles (up to 4) and visually verify the acceptability of the value by color-codes or graphs.

Data monitoring: macronutrients, micronutrients, E. coli concentration (example), PAS limits

Red-shade: outside the limits Green-shade: within the limits

Compost characteristics will vary with factors including raw materials, pre-treatment (source separation), and the composting methods (He et al, 1992; Ward et al., 2005).

Task 5: Compost macronutrients (model was developed using biodegradable municipal waste compost study in UK)

Elements (Macronutrients)	Average levels (mg/kg dry matter)	20% lower limit	20% upper limit	Tadweer Observations (mg/kg dry matter) Pile 1	Pile 2	Pile 3	Pile 4
N	468	374	561	420	350	355	420
K	133	107	160	170	150	140	130
P	3767	3014	4521	1000	800	1100	1000
S	668	535	802	660	790	620	660
Mg	175	140	210	150	328	324	150
Ca	1398	1119	1678	1200	1000	1600	1115
Na	1021	817	1225	1500	1369	1800	1200

Total nitrogen (N) = Nitrage and ammonium nitrogen

Expected Macronutrient levels were estimated using the characteristics of 12 different matured compost obtained from biodegradable municipal waste compost

Reference: Dimambro et al., 2006

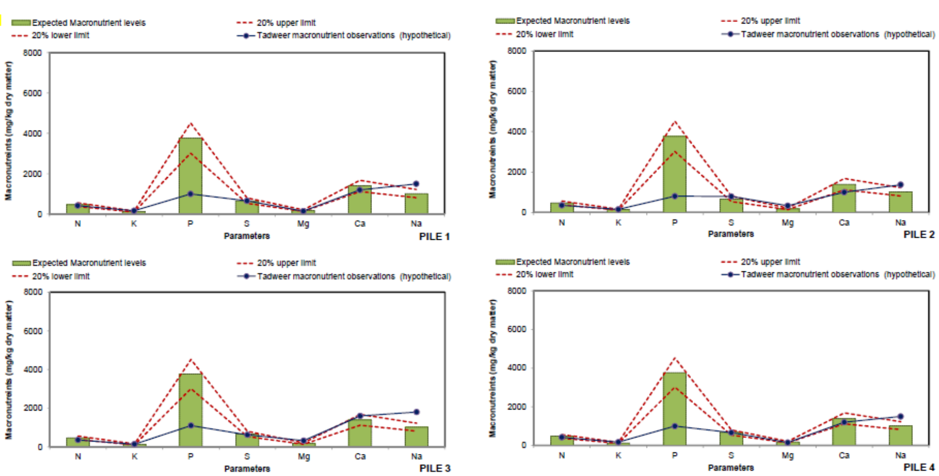


Figure 4. Visualization of "*Composting Verification; Parameters*" spreadsheet. Only Task 5 on compost macronutrients profile is shown.

This sheet contains the **verifications for parameters** (**macronutrients**, **micronutrients**, **compost pathogen level**, **PAS limits**) that are checked at the end of the composting process. The

PAS is a publicly available specification/recommended threshold value for a parameter (Dimambro et al., 2006). Note that compost characteristics vary depending on several factors, including raw materials, pre-treatment (source separation), and composting methods (He et al, 1992; Ward et al., 2005). Figure 3.1 and 3.1.2 describes functionality of data input for each parameter in the spreadsheet.

6.1 Table Description: Compost macronutrients

Task 5: Compost macronutrients (model was developed using biodegradable municipal waste compost study in UK)

				Tadweer Observations (mg/kg dry matter)			
Elements (Macronutrients)	Average levels (mg/kg dry matter)	20% lower limit	20% upper limit	Pile 1	Pile 2	Pile 3	Pile 4
N	468	374	561	420	350	355	420
K	133	107	160	170	150	140	130
P	3767	3014	4521	1000	800	1100	1000
S	668	535	802	660	790	620	660
Mg	175	140	210	150	328	324	150
Ca	1398	1119	1678	1200	1000	1600	1115
Na	1021	817	1225	1500	1369	1800	1200

Total nitrogen (N) = Nitrage and ammonium nitrogen
Expected Macronutrient levels were estimated using the characteristics of 12 different matured compost obtained from biodegradable municipal waste compost
Reference: Dimambro et al., 2006

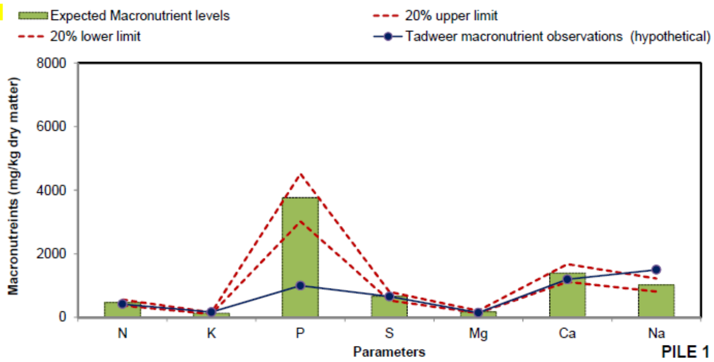


Figure 4.1. View of the compost macronutrient table with a corresponding graph of Pile 1. The average levels of macronutrients (N, K, P, S, Mg, Ca and Na) in the table were estimated using the characteristics of 12 different matured compost obtained from biodegradable municipal waste compost (Dimambro et al., 2006).

6.2 Table Description: Compost micronutrients

Task 6: Compost micronutrients (model was developed using biodegradable municipal waste compost study in UK)

Elements (Micronutrients)	Average levels (mg/kg dry matter)	20% lower limit	20% upper limit	Tadweer Observations (mg/kg dry matter): Pile 1	Pile 2	Pile 3	Pile 4
B	3.38	3	4	2	3	2.5	3.1
Cl	2319.75	1856	2784	1500	1450	2000	2711
Cu	2.87	2	3	2.2	2.6	3	2.9
Fe	154.89	124	186	130	140	175	155
Mn	7.48	6	9	6	7	10	8
Pb	123.14	99	148	120	154	140	142
Ni	30.70	25	37	30	35	26	24.5
Zn	6.20	5	7	2	8	6	7

Expected Macronutrient levels were estimated using the characteristics of 12 different matured compost obtained from biodegradable municipal waste compost
Reference: Dimambro et al., 2006

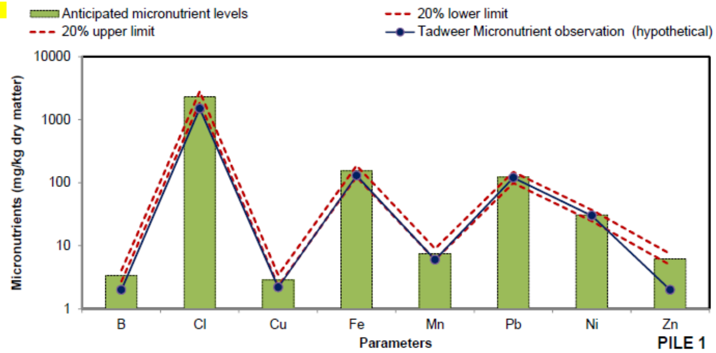


Figure 4.2. Display of the compost micronutrient table, along with the graph corresponding to Pile 1.

Similar to the compost macronutrients, the micronutrients (B, Cl, Cu, Fe, Mn, Pb, Ni, Zn) were estimated using the characteristics of 12 different matured compost obtained from biodegradable municipal waste compost (Dimambro et al., 2006).

6.3 Table Description: Compost pathogen levels

Task 7: Compost pathogen levels (model was developed using biodegradable municipal waste compost study in UK)

Various compost material (C)	Recommended E. coli levels (cfu/g)	40% lower limit	40% upper limit	Tadweer Observations (cfu/g): Pile 1	Pile 2	Pile 3	Pile 4
C1	1,340	600	1400	822	800	700	841
C2	10	600	1400	1500	1600	1455	1577
C3	673	600	1400	600	800	874	769
C4	38,333	600	1400	700	500	677	1347
C5	140	600	1400	500	600	580	813
C6	67	600	1400	700	800	1934	879
C7	27	600	1400	800	677	2496	1340
C8	1,347,333	600	1400	200	677	844	1570
C9	43,567	600	1400	500	700	673	863
C10	22,000	600	1400	600	1666	1879	1279
C11	10	600	1400	4000	4800	1400	2700
C12	10	600	1400	1000	1200	957	1244
PAS 100	1000	800	1200				

Expected Macronutrient levels were estimated using the characteristics of 12 different matured compost obtained from biodegradable municipal waste compost

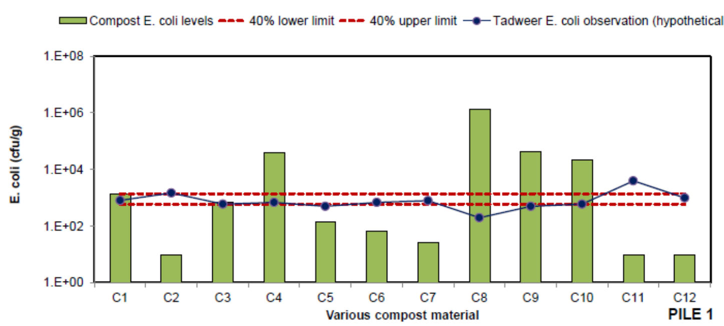


Figure 4.3. Compost pathogen level table with a corresponding graph to Pile 1.

For Task 7: Compost pathogen levels, the example pathogen used is E. coli concentration. Recommended E. coli levels were obtained from the data of mature compost, gathered from 12 different commercial compost-producing companies in UK. The upper and lower limits were developed from the average level.

6.4 Table Description: PAS limits

Note: PAS = publicly available specification

Product verification

		Tadweer compost observations (hypothetical)			
Elements	PAS limit (less than or equal) (mg/kg dry weight)	Pile 1	Pile 2	Pile 3	Pile 4
Cd	1.5	2	5	14	0.4
Cr	100	25	70	80	102
Hg	1	25	17	0.5	0.2
Cu	200	150	166	199	143
Ni	50	40	70	33	43
Pb	200	50	143	201	189
Zn	400	800	391	366	241

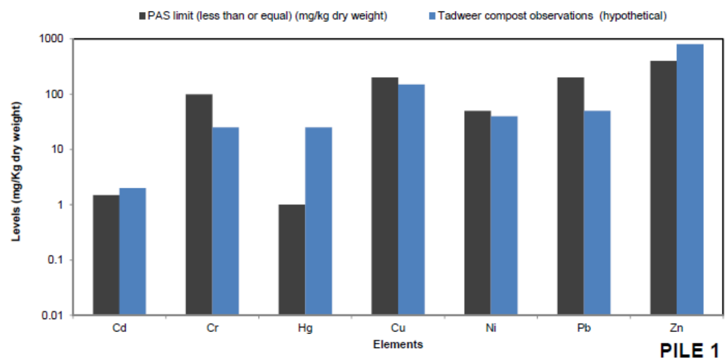


Figure 4.4. View of PAS limit table and a corresponding bar graph comparing acceptable PAS limits with user-inputted values from Pile 1.

Elements Cd, Cr, Hg, Cu, Ni, Pb, and Zn are particularly observed. For PAS levels, values below or equal to the limits are acceptable.

7. References

REFERENCES

Dimambro, M. E., Lillywhite, R. D., & Rahn, C. R. (2006). Biodegradable municipal waste composts: analysis and application to agriculture. *Warwick HRI, University of Warwick* .
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http://www.endfoodwastenow.org/index.php/resources/facts
http://www.worldfooddayusa.org/food_waste_the_facts
http://waste360.com/mag/waste_food_waste_3
http://www.epa.gov/osw/nonhaz/municipal/pubs/MSWcharacterization_508_053113_fs.pdf
http://www.epa.gov/osw/facts-text.htm
http://www.epa.gov/reg3wcmd/solidwasterecyclingfacts.htm
https://center.sustainability.duke.edu/resources/green-facts-consumers/how-much-do-we-waste-daily
https://center.sustainability.duke.edu/resources/green-facts-consumers/how-much-do-we-waste-daily
http://www.epa.gov/osw/nonhaz/municipal/msw99.htm
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Kitchen waste estimation

1.8 kg of food scraps / house hold
97% of food waste generated ends up in the land fills
33 million tons of food makes its way to landfills
A restaurant in US produce approx. 25,000 to 75,000 pounds of food waste in a year
Each American goes through 1.3 pounds of food a day
In 2011, Americans generated about 250 millons tons of trash and composted almost 87 millons tons of this material.

4.40 pounds (MSW) per person per day

106 pounds per person per year

45-60% recovery in source separation
60-70% of solid waste stream (mixed)

Figure 5. Visualization of the "References" spreadsheet.

This spreadsheet lists all of the references used to determine calibration values in the waste and composting model.

PART 2

1. Nada Radwan Ghanem’s MS Thesis

Vermicomposting Research at American University of Beirut (AUB), Beirut, Lebanon

TITLE: ASSESSING THE VIABILITY OF VERMICOMPOSTING IN LEBANON ON COMMUNITY LEVEL: WARHANIEH CASE STUDY

AMERICAN UNIVERSITY OF BEIRUT

ASSESSING THE VIABILITY OF VERMICOMPOSTING IN LEBANON ON COMMUNITY LEVEL: WARHANIEH CASE STUDY

by

NADA RADWAN GHANEM

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Science in Environmental Sciences Program
of the Interfaculty Graduate Environmental Sciences
(Ecosystem Management)
of the Faculty of Agricultural and Food Sciences
at the American University of Beirut

Beirut, Lebanon
April 2015

AMERICAN UNIVERSITY OF BEIRUT

ASSESSING THE VIABILITY OF VERMICOMPOSTING IN LEBANON AT COMMUNITY LEVEL: WARHANIEH CASE STUDY

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Signature Date

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My profound appreciation goes to my brother Mr. Wissam Abou Dargham for supporting me spiritually throughout the years. You have constantly gave me the motivation to perform to my maximum potential and taught me to never give up. I am eternally grateful for your presence in our life. This thesis is just the beginning of my journey.

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AN ABSTRACT OF THE THESIS OF

Nada Radwan Ghanem for Master of Science in Environmental Sciences
Major: Ecosystem Management

Title: Assessing the Viability of vermicomposting in Lebanon on Community Level: Warhanieh Case Study

This study is a case study that aims to assess people's perception and attitudes towards vermicomposting in Lebanon. For this purpose a direct field application of vermicomposting at household level was carried out in Warhanieh, a rural community in the Chouf region.

Two vegetable crate boxes tied to each other were used to develop a small vermicomposting unit which allows for the lateral movement of worms from one container to the other. The unit is made of readily available and cheap material and it is practical in that it reduces the direct handling of worms. Briefly the first container is filled with bedding material (soil), worms, and kitchen waste and it is covered with cotton material. Once the waste is fully digested by the worms, bedding and kitchen waste are added to the second container causing the worms to migrate towards fresh food source.

Thirty six households volunteered to test the experimental vermicomposting unit. In addition, a contingent valuation study was conducted involving 200 households to assess the attitude of village residents towards vermicomposting and towards home sorting of waste. Furthermore, the study assessed people's willingness to pay additional tax to fund the construction and operation of a large scale vermicomposting facility at the municipality level.

These findings revealed that participating residents were enthusiastic about their involvement but they preferred that vermicomposting of organic waste be managed at the municipality level. The setup of large scale vermicomposting systems did not prove financially feasible while small scale household units established in home gardens are beneficial.

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DEDICATION

I dedicate this work to my family and to Dr. Sami Makarem whose presence in my life and teachings have touched my heart and changed me, May your soul rest in peace.

I will always keep in mind your famous quote “The scourge of knowledge is vanity”.

CHAPTER I

INTRODUCTION

Vermiculture is defined as the process of composting organic waste using earthworms to produce vermicast, also known as worm casting or worm manure (Sinha et al, 2010). Earthworms used in vermiculture are red wigglers or Eisenia foetida. Earthworms are hermaphroditic, meaning that they both impregnate each other at the same time, and they have both male and female sex organs. Yet, it still takes two worms to reproduce (Ndegwa & Thompson, 2001). Vermicompost serves as a humus rich soil amendment (Nagavallemma 2004, Blouin et al 2013). Unlike conventional composting, vermiculture composts organic materials more quickly and does not generate offensive odor, which makes it convenient for indoor home composting. Compared to other organic fertilizers, vermicompost was shown to have better fertilization potential (Kumar Srivastava et al., 2011). This was established at the 20% ratio of vermicompost in potting mix, and gave significant results which varied from increased number of branches and leaves, to increased root and shoot length, and number of flowers and pods. vermicompost also improves soil quality in terms of water holding capacity, disease suppression, porosity, microbial composition and abundance, and porosity (Adorada, 2007, Blouina 2013).

Vermicomposting has been successfully produced and used in many developed countries and is considered an important technology to be applied on a household level, and on larger municipality level scale (Purkayastha 2012). Vermicomposting is appealing because it is faster than the traditional composting methods, requires less space, and is odorless. It helps in getting rid of municipal organic waste (Sim and Wu 2010).

Vermicomposting is still new to Lebanon and the chances for it to prosper are directly linked to whether people would accept to work with earthworms or not. A previous study by S. Moledor (2014) concluded that one obstacle for the progression of vermicomposting in Lebanon is the negative perceptions towards earthworms and waste collection.

This study addresses social issues surrounding vermicomposting, it looks into people's perceptions towards the technology. Chapter II of this thesis introduces the study area; Chapter III addresses the direct field application of vermicomposting at the community, and the change in attitudes. Chapter IV discusses the contingent valuation study made at the community to assess the people's willingness to pay to construct and operate a municipal scale vermicomposting facility that treats the community's organic waste; Chapter V is a feasibility study that compares small-scale home vermicomposting to large-scale municipality level vermicomposting. Conclusions and recommendations are presented in chapter VI.

CHAPTER II
DESCRIPTION OF THE STUDY AREA

A. Warhanieh: a rural Lebanese village in Mount Lebanon

Lebanon is an Arab country that lies on the Eastern shores of the Mediterranean. It has an area of 10,452 km^2 with only 2730 Km^2 dedicated to agriculture. It has a population estimated at 4.4 million people out of which 9.2% work in agriculture (Ministry of Agriculture, website source accessed on 25/02/2015). In addition to its narrow coast, the country's landscape is roughly divided into three main units, the Mount Lebanon Range, the Bekaa valley, and the Anti-Lebanon Mountains running parallel to the Mediterranean Sea (Wally, 1998).

Warhanieh is a rural village in the Chouf region that has a land area of approximately 6.0 km^2 and is situated at higher elevations of Mount Lebanon ranging from 1000 m to 1150 m. Although Warhanieh is only 52 km away from Beirut, the village's geographic location away from main roads, lends itself towards isolation; like many villages in Lebanon, the infrastructure of Warhanieh has yet to be completely developed. Roads were first built in the 1950s. The first car followed in the 1960s, incidentally owned by a foreigner. Construction of a water network commenced in 1960 to 1962; prior, villages depended on two springs for household use. A sewer network was constructed in 1988 (Ghassan Ghanem, head of municipality). The municipality of Warhanieh estimates that the current population at 2,000 residents. With 350 households in the village, an average of 5.7 people resides in each household. Of these, an estimated 65 households live in cities and are part-time residents of the village and reside there during weekends and summer break (Ghassan Ghanem, head of municipality). With respect to level of education in Warhanieh, local authorities indicate that illiteracy has been eradicated since 1990. The village has one public elementary school which has experienced a decline in enrollment; as income levels in the village have increased, a growing number of families chose to enroll children in private schools located outside Warhanieh. Beyond elementary schools, students must attend elsewhere, usually in larger villages 15 km away from Warhanieh (Kamel Ghanem, village Moukhtar).

In 2007, Batal et al. (2007) estimated that the average income level for Warhanieh and two other nearby communities at 943,379 LL or 629 USD (exchange rate 1,500 LL for 1 USD) per month and unemployment rate of 25 to 35 percent.

Like most mountain villages in Lebanon, the landscape of Warhanieh is steep and has the capacity to harbor diverse natural resources suitable for agricultural land use (Rachid, 2007). Terrain ranges from 800 to 1300 meters, where the lowermost elevations run along the Nahr al-Safa (Safa River), a primary agricultural water source. The Nabaa al-Safa (Safa River) located to the northeastern side forms a natural village boundary. The primary source of income and employment in Warhanieh is the agricultural sector (Kamel Ghanem, village Mokhtar). Warhanieh has two basic agricultural areas, an upper area and a lower area. Primary crops grown in Warhanieh include apples, apricots, olives, and vegetables, listed in order of importance and these have been grown continuously in the lower agricultural area since the 1950's. Other crops are also grown in Warhanieh, including peaches, cherries, persimmons (kaki fruits), prickly pears, nuts, and others (Osmat

Ghanem, large landowner, farmer). To help enhance livelihoods, vegetables were introduced in Warhanieh in conjunction with apple orchards, in the 1950s. This practice is not done for biodiversity or income diversification. Rather, these farmers elect to plant vegetables in their home gardens for their own household use. Primary crops include cucumbers, tomatoes, mint, and beans.

Local farmers indicated that lands were once fertilized solely using animal manure. Today, this manure continues to be used to a limited extent; fertilizers are generally preferred.

Cultivated areas in Warhanieh primarily rely on Nabaa al-Safa (Safa River) for irrigation. Water is diverted from Nabaa al-Safa a short distance downstream (see Appendix 12) from its spring source, where outflows are estimated to range from 0.3 m^3/sec in November to 2 m^3/sec in April (Dia & Jach, 1992). From the diversion canal, water is then pumped via a pumping station, to reach an extensive concrete canal network which then flows via gravity. From this canal network every farmer redirects water to flow to his/her land. Water then flows via furrows that pass through the terraced landscape (see Appendix 12). Farmers report that lands are watered every 15 to 20 days from May through September each year.

Similar to many villages in Lebanon, Warhanyeh residents no longer practice agro pastoralism which is declining in Lebanon, partly due to recent conflicts and government focus on the industrial sector versus the agricultural sector (Abou Zeid, 2007; Chalak & Sabra, 2007; Zurayk, 2000);

In contrast, few farmers still practice beekeeping as part of the holistic agriculural practices to maintain crop sustainability through pollination. Honey and other products are normally for household use only. At present, four beekeepers maintain hives in selected areas in and around the village, collecting and selling bee products as part of their livelihoods. According to local accounts bee keeping was at its highest in the 1960s when there were 15 beekeepers and each reportedly had up to 40 hives. This number was significantly reduced to four due to bee disease, and subsequent losses to bees and their hives.

B. Selecting Warhanieh as a prototype village

Considering that farmers are primary beneficiaries of vermicompost production and use, the target community for this study was one that was rural with an active agricultural profile (Ninawe, 2008). However, these characteristics could apply to many rural village communities in Lebanon. Another priority during the selection process was the ability to document 'real' attitudes and perception change in the community (Duncan and Ridley Duff, 2014). Vermiculture may be regarded as bizarre for the Lebanese and similar to other environmental projects that face resistance, the results were not guaranteed to be positive (Devine-Wright, 2007). In addition to all the above mentioned reasons, the nature of the participatory work to be carried out required continuous follow up. So, the decision was made to conduct the study in the community of the researcher as it fulfilled most requirements. Letiecq and Schmalbauer (2012) indicated that being an insider is important when attempting to engage with communities to facilitate communication, and develop meaningful university community partnership. Furthermore, the location of Warhanieh in close proximity to Nabaa al-Safa (Safa River) makes it ideal for ensuring a continuous supply of local earthworms near river banks to the participants throughout the entire study period.

Figure 1 Agricultural land in Warhanieh

CHAPTER III

APPLICATION OF VERMICULTURE AT COMMUNITY LEVEL AND PERCEPTION CHANGE TOWARDS EARTHWORMS

Vermiculture is widely used across the globe with wide range of benefits (Sim and Wu 2010, Ansari 2007, Adorada 2007, Purkayastha 2012). India is the main producer and largest exporter of vermicompost in the world. In addition, the Unites states is also known for producing and using vermicompost products at several states such as Oregon, California, New South Wales, Washington, North Carolina, and others. The U.S is considered the largest importer of vermicompost from India. Other countries that produce vermicompost at a large scale are France, Canada, Italy, Japan, Malaysia, Cuba, Australia, Ukraine, Indonesia, Estonia and several others. In addition to selling the fertilizer, firms sell worms for small scale applications. Iran has started investing in vermicompost production and now has more than fifteen industries. Also, academic institutions in Iran are dedicating special attention to the science behind this process and many studies and publications are available regarding this subject (Majlessi et al., 2012). In Turkey, there are at least five industries for vermicompost production one of them produces liquid vermicompost known as vermin-tea (Sherman, 2014).

Vermicompost and earthworms are used to remediate contaminated soil. For example, in India a major soil contamination with toxic heavy metals was amended by adding vermicompost and worms followed by planting maize to monitor the levels. After a short period, they recorded only traces of heavy metals (Sitton, 2010). India also has the single largest vermicompost company in the world “VermiCo” (Bogdanov, 2013). Vermicompost enterprise for rural women is popular in India, Philippine and others in which medium scale vermicomposting units are managed by women. Countries such as Philippine use vermiculture projects for community development, and social economic improvement (Adorada, 2007). Vermicomposting is also used for municipal solid waste management, and it was first established in Holland followed by England, and Canada. Later on, it was applied in USA, Italy, Philippines, Thailand, China, Korea, Japan, Brazil, France, Australia, Israel, and Russia (Sinha & Agrawal, 2010).

Lebanon is one of the 22 Arab countries located in the Middle East region. Despite the fact that many innovative projects are being implemented in the Arab world to promote sustainability and eco-friendly activities, vermiculture projects are still absent or not reported (renewables & User, 2013). There is only one company that produces vermicompost located in Dubai, UAE (Guardian of Earth), however there are no available information on its production rates, number of customers, and its location.

This study was carried in order to introduce vermiculture at the household level and examine the social dimension of vermiculture including people’s perceptions and attitudes towards it.

A. Methodology

1. Designing the Vermiculture unit

In a previous study by S. Moledor (2014), vermiculture units were developed out of readily available plastic vegetable crates. The advantages of these units are that they are cheap that are made of readily available materials. However, upon the completion of the study, two disadvantages were identified, mainly the lack of practicality especially at the harvesting stage, and the poor ergonomic potential. After waste was degraded by worms, these were harvested manually; the process was time consuming and not suitable for community intervention. These points were addressed in the current study, whereby modifications were made to the units before approaching the community. The resulting new units consisted of a two crate setup and minimized the need to handle worms.

The new setup consisted of two compartments made of two vegetable plastic crates, attached to each other with screws. A cut was made to the adjacent sides, removing the centers, and keeping only the frame to keep them attached as one unit. The opening between the two compartments was covered with a cotton cloth to keep the worms from moving from one compartment to the other. With this set up, the worms stay in the first compartment for a period of one month until the food waste is completely transformed into vermicast. Then the cotton sheet is removed to expose worms to light and encourage them to migrate to the other compartment, filled with food waste, and covered to keep the interior environment dark, contrary to the conditions in the compartment where the vermicast was produced. To maintain high humidity, the sides of the crates were lined with recycled lint material. This was supposed to ensure optimal humidity and absence of flies.

2. Public introductory seminar

The project team organized a public seminar at the village on May 27 and all villagers were invited to attend, whether farmers or not. During this presentation the team introduced vermiculture, relayed past experimental findings, and explained the planned participatory research (Appendix I). At this early stage the study objective and proposed methodology were presented to the residents, and they were asked to contact the resident researcher in case they were interested in taking part of the study. At the end of the presentation, some asked questions on technical aspects of vermiculture, while others indicated that they are accustomed to see lots of earthworms when they plow the land. Others said that they notice that chicken are a big fan of earthworms. Samples of vermicompost were distributed to all attendees to familiarize them with the texture of the product and highlight the fact that it is odorless. More than 70 men and women attended the public seminar and the participants included farmers, housewives, entrepreneurs, university students, and even teenagers (see Appendix 3). An information sheet was circulated amongst those interested in participating in the study; 29 registered their names during the seminar.

Each household that chose to participate in the study was given the prototype for free, and trained on the following:

- How the system works and what is the theory behind the set up.
- What to feed and not to feed the worms
- How to monitor and assess the progress of the process
- What are possible reasons for failure, and how to prevent and mitigate problems

Participants were asked to give their feedback and recommendations on the overall method, and they were encouraged to suggest ways to improve the system and trouble shoot problems. Most importantly, they were expected to collect the organic waste generated from their own household, conduct the vermiculture process by themselves, and consult on a regular basis with the resident researcher who was available, on site, during weekends and by phone on weekdays.

Following the seminar, 29 units were prepared at the American University of Beirut, in the Eco Unit of the Faculty of Agricultural and Food Sciences (check Appendix 2) and distributed to participants a week later. Written instructions about what to feed the worms and what not to feed them, was placed on each unit along with the resident researcher's contact information (Appendix 2)

3. Visit of Permaculture expert to the village

In September, the project team, in partnership with an international NGO supporting farmer to farmer exchange, organized another public seminar led by a permaculture and vermiculture expert consultant. Although the invitation was open to everyone the main attendees were the project participants. The permaculture expert shared his farming experience and highlighted the importance of vermicompost 'tea' which is known for its high nutrient content. The resident researcher contributed to the translation of the presentation session and the question and answer session (check Appendix 10 for presentation material and pictures). The expert showed images of the vermiculture system installed on his farm, discussed the size, the steps of installation, and the byproducts being vermicompost and vermin tea. Attendees were surprised to hear that the juice excreted from the process is also beneficial to the plants. The expert showed images of tomato plants and other trees that he grows with vermi-tea, in order to emphasize its real effects in terms of crop quantity and quality. Attendees were interested to meet a foreigner who applies vermicomposting as well. A nice interactive atmosphere dominated the seminar, where everyone was engaged in the discussion which took longer than planned (check Appendix 10 for pictures). Many questions were asked, people wanted to make sure that the technique was really giving positive results, and that's what the expert confirmed. In addition, we discussed the concept of a closed system in agriculture; its benefits were explained and discussed.

4. Setting up Vermiculture units in the households

a. Phase one (June 2014) – a failed attempt

Each participating household was asked to collect their organic kitchen waste for a period of 7 days. Red wigglers Eisenia fetida were provided for free from two sources, (1) American University of Beirut FAFS Eco Unit where worms were raised, and (2) the Nabaa al-Safa (Safa River) bank located near the village. The resident researcher scheduled an appointment with each household and together, they set up the units, placed the collected organic waste inside one of the compartments, and added around 400 grams of worms. The participants were then given one to one instructions on how to monitor and adjust humidity; if the bin was dry, they were asked to spray some water to keep it moist. Three weeks later the study was discontinued because the worms in all units died. Factors that may have contributed to the collapse of the set up included high temperature, high moisture, and lack of ventilation. Furthermore, it was also thought that the worms collected directly from the river may have experienced a shock, either during collection and transportation, or in the set up due to the rapid change in environment. The following changes were made; remove insulation material from the sides of the boxes, add bedding material (soil), and protect worms from stress during harvesting. Possible reasons for failure were presented, modifications to the methodology were explained, and the participants were informed that the experiment will be launched again in one month period.

b. Revising the methodology on campus and setting up trial units

During this phase, which lasted one month (July 2014), prototypes were set up at the resident researcher's house. Bedding was added, lining was removed from the sides and kept only at the bottom and on the top to keep flies away and maintain darkness inside. Worms were collected from the Nabaa al-Safa (Safa River), rinsed with fresh clean water, and added to three starter containers filled with organic material. At the same time, another group of earthworms was placed in clay pots containing bedding material. Clay pots provide a cool and convenient environment for the worms to live in. The number of pots was 36, the same as the number of participating households, so that the components of each single pot are later given to one household. After one month, worms in both the mother bins and in the clay pots increased in size and multiplied.

c. Setting up vermiculture units in the households using revised methodology (August-December, 2014)

In the third and last phase, in order to standardize the model, participants were asked to collect only 1Kg of kitchen organic waste. After one week, the resident researcher went to every household and set up the units. Lining material at the sides was removed, bedding material was added, and a clay pot filled with red wigglers was empties on top of of the organic waste and covered. The bin was monitored for a period of one month then the participants were asked to prepare the adjacent compartment to make it ready for worm migration; new bedding material was added, as well as 1Kg of organic material. The bin was also kept covered on top. When all the organic material in the first compartment degraded into Vermicast, the cotton sheet separating the units was removed, and the worms migrated within few hours to the compartment with fresh organic material. The cotton sheet was put back in between, in order to prevent worms from returning to the initial bin. At every house, the resident researcher performed all the phases of the process herself. After that, participants were asked to proceed on their own. This rotation occurred four times before completing the study.

B. Results

Following the failure of the first phase in June, 2 out of 29 participating households dropped out of the study. One the other hand, nine additional households joined at the beginning of the 3rd stage. The total number of participants in the study was 37; those who continued until the end period were 34 households.

1. Description of people's reactions and feedback

The residents of Warhanieh were open to the initiative and appreciated to the fact that a resident from their village was conducting the study and that they were part of the process. The interest in the material that was distributed during the initial public seminar can be shown in the following anecdote: A couple of weeks following the seminar, the resident researcher was stopped by a women and asked for the 'black fertilizer' that was distributed. The women explained: "I saw the basil that my neighbor grows have become healthy and their odor reached my house. So I asked her what had happened, what did she add to them that made them special? She said that she added from the fertilizer that you distributed in the seminar last week. Can you please give me a sample? I wasn't able to attend but I really want to try it!"

Other comments made by people were related to the fact that a 'university student' was actually working with 'dirt' and handling worms and she was neither afraid nor disgusted. This was interesting to the residents who commented that young people of the age of the resident researcher refuse to work with the land and consider it less prestigious than modern lifestyle. Many times, people commented to the resident researcher that it was the first time a university student from Warhanieh does something beneficial to her/his community, and that they wish others would do the same. Another comment that illustrates the adult community's interest was made by a woman as follows: "Look at you, how you hold the worms! I'm older than you and don't dare to do that! …" The oldest farmer (65 years old) among participants insisted that he will support the resident researcher's work until the end, and that he supports any individual who genuinely wants to help the villagers and develop the community of Warhanieh.

Participants communicated their feedback to their neighbors and relatives. By the time the project closure was due, all members of the community had gone through four vermiculture ‘cycles’, and they were happy to know something new others are not aware of yet, which can be shown in the following anecdote: During the final stages of the study, a woman told me that she is explaining to her visitors about the vermicomposting project and showing off that she is taking part in it. What she liked the most is that when she talks, no one can interrupt her, because it’s a new idea and they just sit and listen to her.

2. Perception and attitude change

Perception among women was different at the beginning. Some were anxious to deal with the worms, whereas others were suspicious, but tended to enjoy working with the worms at a later stage. During the trials and tests, participants became more engaged in the process when they saw the worms growing and multiplying in numbers. The worms became the subject of the morning and evening conversations in town. They discussed with how the worms move and how they hide and go to the bottom of the bin once the cover is opened and light strikes. Women were eager to use the vermicompost on their plants and vegetables, whereas men wanted a larger scale production to use it in their farms. Their final conclusions and recommendations were positive and encouraging; everyone enjoyed the experience and wanted to spread it to others. Below are some of the comments made by participants that reflect their perception and attitudes towards the project:

Dalal: “I was worried at first when I heard about the project, I wanted to help Nada but the idea was new. The worms that nada provided us with were small, but as I started adding food wastes and taking care of them, their numbers started to multiply fast and they grew bigger and became healthier. Once I was putting the lettuce as it is without chopping it, and Nada took it back from the bin and chopped it into smaller pieces. This caught my attention and since then I always chop the waste into smaller pieces before adding them to enhance their degradation. I’m happy with the results. I never imagined myself holding worms, but now I can easily do so. It is amazing how the worms use the food waste we generate to produce a valuable product to our garden. I really wish everyone tries it because the process is very easy and the product is beneficial. What I liked the most is that you shared with us an important technique that you know in the lab, but no one of the framers knows. It is very important to couple lab experiments with infield application, to share and disseminate the knowledge across communities.”

Jouhaina: “It is a weird idea! That’s why we were very excited about it. We were eager to try it and see what the results would be. Dealing with the worms is very easy for us, they are domestic creatures especially that we raise many animals such as chicken, ducks, birds, cats, dogs and turtles. Worms can be raised like any other animal; the process is simple, clean, and beneficial at the same time.”

Sheikha: “We have large agricultural land and we don’t use chemical fertilizers nor pesticides. We use goat manure and compost as fertilizers; for insects we spray a homemade solution that is a mixture of olive oil, garlic, and hot pepper. Your project is very successful. We are taking good care of the worms, adding food waste, and keeping them in optimal conditions. We will use the vermicompost for plants and herbs in our home garden. God bless you and be with you. We support you in whatever you want to do.”

Sohaila: “It was the first time we hear about the idea of vermiculture and we loved it! We started applying vermiculture and obtained great results from the first round. We produced vermicompost and used it on vegetables and garden plants. The results were amazing. As you can see, there is a difference of 6 cm in the leaf length of lettuce planted with vermicompost versus without vermicompost. I was surprised that after adding vermicompost to my garden plants in November, the spring blooming gardenia bloomed in November and gave nice glowing flowers with extraordinary fragrance. I recommend this technique to everyone and I hope every house in the village applies it.”

Wissam: “We are making use of the organic kitchen waste to produce healthy crops. I would like to produce it at a larger scale.”

Kamel: “It is good soil amendment. Studies proved it to be very effective and beneficial on many aspects as reduced irrigation, better crop yields, and better quality.

Being a rich soil amendment, producing it locally will reduce the farming cost of purchasing chemical fertilizers. We were born and raised in Warhanieh, our ancestors were farmers, we are farmers, and our children will continue to practice farming. vermiculture is a great tool. What else would a farmer want! vermiculture is a new idea and I believe it is going to flourish and with the help of the municipality, we want to produce it on a large scale."

Nashaat: "The project is very important. It helped us get rid of the kitchen food wastes. At the beginning I was disgusted from the worms. But this changed after I witnessed their high efficiency in transforming whatever I add to the bin into valuable vermicompost. It was a great experience! We found the idea very appealing since we own large agricultural land and it generates high amounts of organic waste (vegetables and fruits). Using earthworms to transform this waste into a useful product that can be applied back on our land implies maximizing our profit and minimizing our loss in the least expensive way. Even though sorting the waste requires additional time, but having to deal with living creatures makes the process enjoyable. I believe that the demand on this technique will increase tremendously in the future."

Nazih: "This project is international, it is very important. We are taking good care of the worms, keeping them in the shade during the hot summer days, and in warm places during cold winter. However, the 5 Kg of vermicompost I'm producing now won't help me because I'm a large land owner. I participated in the project to support you and try the new technique, but we need incentives to be able to continue and help researchers in further field trials. If they don't give us incentives, we won't participate later on."

The experience with children was more emotional and oriented towards exploring earthworms for the first time, by watching them as they move and trying to hold them with care in order not to harm them.

Amir, A 10 year old kid ran away screaming out of disgust the moment he saw me holding earthworms with bare hands. It took him less than a minute to come back running after me racing to the bin to watch me as I open it to add the worms. He kept screaming every time he saw a worm. But I kept talking to him all the way, telling him stories about the worm, explaining how it moves, how it eats, and how it changes color as it moves. He was staring at me and as I finished my words, he gazed at me and said: "Wow, you are a scientist!" I also told him that it won't bite him if he touches it. At that moment, he started mocking the idea and asked ironically: "Who would I touch the worms? Is anyone in the village touching them?" I said:" Yes, many children your age already held them". He was surprised and instantly requested to touch them. During the first trial, he started screaming even before his finger touched the worm. But during the second time, he held it with bare hands. I finished checking on the bin. I Left and he stayed playing with the worms. As I said goodbye to his grandparents, I saw him running back home and explaining to them what I told him about the worms. I heard him saying: I saw the most beautiful thing ever! A worm can change its color!"

Rami is a cute 6 year little boy and his younger brother were watching me while I was harvesting worms from the large bin to distribute to other households. They stared for some time before Rami requested confidently to hold the worm. I gave him some instructions on how to hold it, do not to squeeze, hold it softly, make sure you don't hold it for long or else it will dry and die, if it moves make sure to adjust your hand so it stays attached to it. He nodded and opened his hand to hold the worm, and he did, very gently. His smile grew wider as it moved all over his hand. His younger brother felt jealous and wanted to hold it as well (figure 20 in Appendix 3). And they started to fight over it; Rami wants to keep it while Rabih wants to try and hold it. I made sure not to give him another worm, to see how they will behave. As soon as Rabih grabbed the worm and felt proud of himself, their friend came and started to ask what is the creature that they were holding. Both explained for him that it is an earthworm. He wanted to hold it as well. But the surprise was that Rami and Rabih became very worried that their friend will harm the worm if he held it, so they refused to pass it to him. After insisting, Rabih gave it to him while Rami kept giving him instructions on how to hold it and made sure he returned it back to the bin before it dried.

One of the participants mentioned towards the end of the study that the first time she saw the resident researcher handling earthworms without wearing gloves; she got very disgusted and took a shower directly after the researcher left her home. This same woman now handles the worms with bare hands. She also indicated that it was an extraordinary experience for her, as she never imagined that one day she would hold an earthworm. She used to kill them if they appeared in the soil.

One of the participating women was able to save the worms in her bin during the first trial. She saw few earthworms in her garden while plowing, and wondered why the worms are active in her garden, whereas they are dying in the bin. Then she decided to add soil to the bin and collected some worms from her garden and added them to the bin. The few worms grew and multiplied in the presence of soil. In the third phase the resident researcher gave her a new bin to apply the new methodology. She ended up having two well-functioning bins.

C. Discussion

Although vermiculture was not known in the village of Warhanyeh the study showed that in the span of few months residents became receptive to the idea and some participants even supplied their neighbors, who recently became interested in vermiculture, with earthworms and helped them design their bins. The community was engaged in all phases of the study. Everyone wanted the project to succeed. Driven by their interest to see the "resident researcher" succeed in her research they were willing and proud to be the pioneers in applying this technology. Even in the beginning when the method failed, their reaction was very unique mainly because they owned the process; if it fails it means they failed, and they wanted to succeed (Rabinowitz, 2014). In addition, they trusted the resident researcher and believed that the knowledge that was disseminated is true and they were eager to experience the results by themselves.

The four main principles in community based participatory research, according to Potvin et al (2003), were met in this study. First, community members were integrated as equal partners. During the opening seminar, the ultimate goal of the study was clearly communicated which is to improve the health of community members, improve soil quality, which will be reflected in the quality and quantity of crop yields, and that Warhanieh will be the first village to apply this technique in Lebanon. These goals are direct benefits to the community, people supported them and chose to participate, which made them collaborates in this research. And the university was ready to help them apply a technique for their own benefit. Second, the study integrated intervention and evaluation. As observed in the failing stage, the participants came up with interventions and recommendations to overcome problems and proceed with the project. The third principle was organizational and programmatic flexibility through the continuous follow up on the study participants and results, in addition to organizing the workshops and seminars for making sure the community is well convinced with the technique. Fourth, the project was a learning experience for everyone, which was the best part of this study. Participants continued to practice vermicomposting after closing the study, which indicates that they are applying out of interest and awareness of its importance as soil amendment and solid waste management strategy. Most of the participants asked for bigger vermicomposting units that can tolerate larger volume of organic wastes.

D. Conclusions

This study as a whole met its objective and people's perception towards vermiculture was assessed as well as the practicality of the vermiculture set-up. The process has the potential to change how people deal with the environment. It made them notice the un-noticeable creature living under the soil, and appreciate its role in maintaining a healthy ecosystem. The approach to the community which was based mainly on respect, humbleness, love, and most importantly based on trust was accepted by all and these facilitated communication and help develop a rapid and meaningful university community partnership. Based on people's request it would be beneficial to design larger household vermicomposting units that can tolerate higher amounts of organic waste.

CHAPTER III

CONTINGENT VALUATION TO ASSESS THE PERCEPTION, ACCEPTABILITY AND WILLINGNESS TO PAY OF VERMICOMPOSTING

Vermicomposting is being promoted in many countries due to the wide range of benefits it possesses. Vermicomposting provides solutions in agriculture for poor soil quality (Munnoli et al, 2010; Singh et al, 2008; Atiyeh et al, 2000; Edwards et al, 2010; Aroncon et al, 2005). Moreover, it is an effective tool for community development (Shivakumar et al, 2009; Purkayastha, 2012; Roseland & Soots, 2007) besides being a strategy for solid waste management (Clarke, 2000; Singh et al, 2011; Tognetti et al, 2007). As a technology, vermicomposting has been successfully used in some developed countries for years (Karousakis & Birol, 2008). Vermicomposting is appealing because it is faster than traditional composting methods, requires less space, and creates unrecognized odor (Sinha, 2010; Shouchet, Bhatiz and Jain, 2014). Considering that solid waste management is a major concern in Lebanon, vermicomposting can contribute to the alleviation of this problem. Actually, the resulting nutrient-rich compost end product from vermicomposting is an environmentally sound amendment that enriches soil for plant growth which will directly be reflected on the health of the population. However, in Lebanon, there are no tangible estimates of the community acceptability of vermicomposting and there is no observable market data contrary to other European and North American countries (Doherty & McKissick, 2000; Sherman, 1997; Munroe, 2005). The following study adopts contingent valuation (CV), defined as a survey-based technology for non-market environmental valuation (Baarsma, 2000).

A. Objectives

The study's objective was to estimate the acceptability of vermicomposting in a village community with a farming background, and to gauge the community's willingness to pay (WTP) for setting up a municipal vermicomposting facility to manage part of the village organic waste and to assess whether there is variation across different socioeconomic and attitudinal profiles.

B. Methods and materials

1. Contingent valuation

In order to start an environmental project, public acceptance is a necessary step to be able to implement the theory in the field (Baarsma, 2000). Therefore, a contingent valuation survey was conducted in Warhanieh - Chouf to assess public's willingness to pay through payment card options ranging from $0 to $31. Payment card is a widely used elicitation format for CV (FAO, 2001). Many studies are available on the use of contingent valuation in waste management, for example in Malaysia; CV is used to estimate the WTP of households to improve waste collection systems (Afroz & Masud, 2011). Another study done in Ghana assessed the demand of farmers for compost (Danso, Drechsel, Fialor & Giordano, 2006).

a. Questionnaire development

The aim of this study was to investigate the attitudes and perceptions of Lebanese citizens towards vermicomposting and to test the viability of this method at a rural village where agriculture is widely practiced. All the benefits of vermicompost were explained to residents of Warhanieh village through a public seminar.

Willingness to pay (WTP) was elicited from respondents by means of an increase in municipal taxes in exchange for this new service. The face-to-face survey (Copies of the survey and the consent form in both Arabic and English are attached to appendices 4, 5, 6 and 7) provided information on whether the community in Warhanieh would accept the concept of vermicomposting and whether they are ready to apply it if the required resources were available.

The questionnaire was developed and adjusted to fit Warhanieh. Pilot-testing was done prior to the field survey; several focus group meetings were held at both the university and the village levels, with specialists and with local farmers, to test the survey. The survey was approved by the university's Institutional Review Board (IRB). The final version included a consent form followed by five sections tackling 1) major environmental concerns 2) contingent valuation exercise 3) further questions about current farming practices 4) demographics and 5) observation of the household situation. All questions were closed ended of two types, either multiple choices or ranking questions see Appendix 6 for the questionnaire.

C. Household interviews

The survey was conducted face-to-face in Warhanieh between November and December 2014 by means of a pen-and-paper questionnaire. A team of surveyors was trained to deliver the questionnaire in such a way to minimize interviewer bias. Only one individual from each available household was surveyed. The sample was selected by means of convenience sampling, if no response was received when knocking at the door, the household was skipped. The target group consisted of the males and females residents of Warhanieh, aged between 18 and 64 years old, and fully or partially responsible of the household budget and expenses. Interviews took approximately 30 minutes apiece. The number of households approached was 200 households, out of which 144 (72%) took part in our study while 51 (28%) refused to participate. The participants were informed of the purpose of the research following protocols agreed by the IRB university ethics committee. Consent was sought through both verbal and written communication see Appendix 4 and 6. It was made clear that participants could withdraw at any time. Those who completed and in recognition of their time and effort were given a souvenir which is a mug with the AUB logo and the name of the village printed on it (check Appendix 8).

D. Results and Discussion

1. Sample characteristics

In Warhanieh, the results show that 47% of villagers use chemical fertilizers while 34% use organic fertilizers. Goat manure is preferred over the other types of organic fertilizers. None of the farmers use compost. Relative to Lebanese agricultural villages, Warhanieh's level of education was considered high, with the absence of illiteracy and up to 33% of household heads with university degrees. The detailed sample characteristics are mentioned in the table 1 below.

Table 1 Characteristic of the sampled population in Warhanieh during the Survey

Variable	Level (%)
Males	57% (83)
Females	43% (61)
Respondents educated with university degrees	33%
Stay in the village regularly	76%
Income: ➢ of low income $800 and below ➢ of middle income $800-1500 ➢ of high income $1500 and above	 40.6% 34.03% 25.37%
Household size: Small Big	 43.75% (63) 55.56% (80)
Farming: ➢ use only organic fertilizers ➢ use goat manure ➢ use cow manure and less than 1% use poultry	 31% 32% 22%
Think that solid waste disposal and management problem is a priority	31%
Strongly disagreed with the statement that solid waste disposal was done safely and environmentally safe.	25%
Think that vermicomposting is very interesting	76%

The number of university educated people is 33% which is significantly high compared to other rural villages. In addition to that and as previously stated, illiteracy was completely eradicated in Warhanieh since 1990. It is remarkable that 31% of the people use organic fertilizers which imply that there is a great deal of environmentally good practices.

Meanwhile, 31% of people think that solid waste disposal and management is a priority and 25% believe that solid waste disposal is not done safely which gives urgency to proceed with vermicomposting. High level of interest in vermicomposting was recorded (76%) which is encouraging and further supports this study.

2. Warhanieh Face to Face Survey

It was hypothesized that the willingness to pay and acceptability of vermicomposting will be affected by age, gender, income, education, and the type of fertilizers used. Particularly, it was expected that i) an increase in income will increase people willingness to pay for vermicomposting, ii) as the level of education increases people's willingness to participate and pay for vermicomposting increases because they can better understand the benefits of the product, iii) younger people will be more willing to pay for vermicomposting, and iv) people that use organic fertilizers will be more willing and accepting to pay and participate.

3. Model Estimates

a. Willingness to pay responses

People were asked if they would accept to pay an additional tax to the municipality to install and run a vermicompost production facility. Also, people were shown a sample of vermicompost and asked whether they would accept to pay for vermicompost as a soil improver, in addition to other questions. For the analysis, we chose the multiple linear regression with square root transformation for the WTP. Multiple linear regression with square root transformation equations are as follows:

$$Yi = \alpha + \beta_1 X_{i1} + \cdots + \beta_p X_{i,p} + \varepsilon_i$$

$$\sqrt{cost} = \alpha + \beta_1 x_{i1} + \ldots + \varepsilon$$

Based on this mean function, expected willingness to pay is explained by educational level, income level, age and gender.

Variables	Coefficients	Std-Error	t-value	P-value
Income 800 – below	1.3767	0.2682	5.133	$1.27e^{-06}$ ***
Willing to do vermicompost at their house	0.4315	0.2430	1.776	0.07861 .
Income $ 800-1500	0.4612	0.2711	1.701	0.09181 .
Income above $1500	0.9954	0.3300	3.017	0.00319 **
People Educated with a university degree	0.8441	0.2811	3.003	0.00333 **
People who use organic fertilizers exclusively	0.4904	0.2353	2.084	0.03951 *

Table 2 Model estimates for WTP

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

N: 144, Multiple R-squared: 0.2506

p-value: $7.217e^{-06}$

Table 2 presents our model estimates which has an acceptable R-squared of 0.25. The variable income, education, and organic fertilizers practice exclusively were significant and positively correlated with WTP. This model explains 22% of the variables in the data.

The results confirm the factors that are commonly linked to WTP; these factors are income, education, and organic fertilizers practice. The other factors such as gender and age are not significant. In Warhanieh, people who are willing to do vermicompost at home are willing to pay $1.37/hh/month more than the average WTP, while people with university degree are willing to pay $3/hh/month more. Besides, people who use organic fertilizers exclusively have $1.5/hh/month higher willingness to pay. In addition, as the income increases above $1500 the willingness to pay will increase by $3.7/hh/month.

The average willingness to pay an additional tax for implementing a vermicomposting facility in the village is $7.4 per month. Few people said that they are ready to pay $35 as a tax in a month in case the project is well done and having beneficial outcomes. In general everyone was satisfied with services of the private company that is currently managing the solid waste collection management in the village, Chouf. While very few of those of higher income class didn't like the idea and sometimes refused to fill the survey from the very beginning as they believed that this issue has nothing to do with their living or work. People were glad to participate in filling the survey and they were really interested in the idea of vermicomposting and using earth worms. Many people used chemicals to sustain their income from farming though they believe it's not healthy.

Some of the visited houses said that they do not really grow crops, however, for them it is a good idea that others start using vermicomposting instead of chemical fertilizers. Others did not have any objections as long as there will be transparency in the municipality's work and there is continual monitoring. In general, all respondents were ready to be contacted for the next steps in case their assistance was needed.

The WTP in Warhanieh (US$7.4/hh/month) was half the WTP of people from the pilot testing survey that covered different regions (US$14/hh/month). This can be attributed to many factors; mainly the sample of the regional survey was mostly comprised of university students who are characterized with high education level and low income level. In addition the Cedar Environmental firm mentioned earlier that it is charging less ($4), meaning that even if the existing WTP ($7) for vermicomposting decreases, the aforementioned firm can still cover the expenses and gain profit.

b. WTP estimates for different profiles

Looking into other scenarios is helpful for giving a wider view of possible WTP with changing variables of income, willingness to do vermicomposting at home, education, and use of organic fertilizers exclusively. Table 3 shows how the willingness to pay changes with different profile characteristics.

Profiles of people of different characteristics	Average cost
Profile of a person of Income less than $800	
Income is less than 800, ▪ Abstains from vermicomposting at home, ▪ Did not go to university, ▪ Does not use organic fertilizers exclusively	WTP is $1.9/household/month more than the average WTP
Income level less than 800, ▪ Went to university, ▪ Willing to do vermicomposting at the household, ▪ Uses organic compost exclusively,	WTP is $9.8/household/month more than the average WTP
If this same person did not go to the university	WTP decreases $4.59/household/month.
For the person who is in the income is less than $800, ▪ Did not go to university, ▪ Not interested in doing vermicomposting at home	WTP decreases by $6.39/household/month
Profile of a person of Income above $ 1500	
Income level above $1500, ▪ Went touniversity, ▪ Willing to do vermicomposting at the household, ▪ Uses organic fertilizers exclusively	WTP is $17/household/month more than the average WTP.
For this same person if he was not interested in doing vermicomposting at the household	WTP decreases by $3.38/household/month.
If this same person is ▪ Not interested in vermicomposting, and ▪ Did not go to university.	WTP decreases $7.2/household/month.
If this same person is ▪ Did not go to school, ▪ Not interested in doing vermicomposting at his house, ▪ Does not use organic compost exclusively.	WTP decreases by $ 11.49/household/month.

Table 3. Estimated Willingness to pay (WTP) for different profiles

c. Estimating the Logit model

In order to compare the characteristics of the people who prefer the municipality to do the vermicomposting versus those who prefer doing it at the household level, the logit model was used.

Logit model log transformation equation:

$\eta i = \text{logit}(\pi i) = \log (\pi i /1 - \pi)$

Variable	Estimate	Std. Error	z value	Pr(>|z|)
Income $800 - below	0.8804	0.2885	3.052	0.00227 **
Income $800 - 1500	-0.7578	0.4064	-1.865	0.06224 .
Income $1500 - above	-1.4065	0.4534	-3.102	0.00192 **

Table 4 Participants who chose to do vermicomposting at their homes

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

Based on table 4, it was found that the probability to participate in vermicomposting at home for someone of high income more than $1500 is 37%. While the probability increases to 71% for a person of low income less than $800. For the people of middle income, 800 to 1500 the probability is 50%. It can be concluded that people who have higher income are less likely to do vermicomposting at home.

Variable	Estimate	Std. Error	z value	Pr(>|z|)
Income $800 - below	2.5649	0.5189	4.943	7.68e-07 ***
Income $800 - 1500	18.0011	2532.9101	0.007	0.994
Income $1500 - above	-0.1978	0.7961	-0.248	0.804

Table 5 Participants who prefer that the municipality handles all the process

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

However, almost 90% of the people prefer the municipality to handle the project (estimates from table 5). But when it comes to implementing the technology at the household level the percentage drops. On the other hand, people that have low income tend to have a higher acceptance to do it at home, and as the income increases their willingness drops. While people who want to do it at home tend to be of lesser economic means, and the people who are the least to do it are the people of high economic means. And what was found is that paying people money to do it does not change a lot their willingness to participate. As such it would be important if we were to increase the acceptability of the product, to invest in raising the level of education of farmers through workshops and certification programs. However, future programs targeting the spreading of this technology should bear in mind that even educated people, once their income increases to a certain level their willingness to do it at their household will decrease. People were highly interested in vermicomposting and eventually almost all wanted the municipality to handle the process.

E. Conclusions

This study revealed that residents of Warhanieh, even those of low economic classes, are willing to adopt vermicomposting at household level. This may be due to the fact that the majority are full time or part time farmers and they see the end product as beneficial to their activity. The results also show that the residents were aware of the importance of solid waste treatment and environmental initiatives with a considerable willingness to pay for these types of projects. Although this study focused on a farming community it would be interesting to expand it to a larger geographical area that will encompass the whole of Lebanon. Therefore, it would be interesting to investigate the WTP and perception of urban dwellers which allows us to compare rural versus urban settings. But the question remains whether a large scale facility is feasible and doable especially when talking about continuous daily flows of municipal organic waste.

CHAPTER IV

FEASIBILITY STUDY VERMICULTURE APPLICATION ON LARGE SCALE VERSUS SMALL SCALE

Many studies show that vermicomposting can be used as a tool for improving economic status in rural settings (Purkayastha 2012). However, it is not yet proven if this applies to Lebanon in the absence of an established market for vermicompost. To provide baseline information regarding the economic feasibility of vermicomposting in a rural community in Lebanon this study compares the value of small scale vs large scale vermicomposting.

Solid waste in Lebanon is managed by a private company that gets paid per ton of waste from the government. This company manages the waste in the capital Beirut and in Chouf – Mount Lebanon. Compared to other towns Warhanieh which is located in the Chouf region does not have a pressing waste management problem. However, based on a village wide survey the majority of residents agreed that solid waste was not disposed of safely and did not take into consideration the environment. For the city of Beirut, waste disposal is a pressing problem due to the fact that the only landfill to dump the waste is Naameh landfill which was put up to work in 1997. The landfill was intended to close after six years of establishment, however it has been functioning for 17 additional years and has received five times more waste than its designed capacity per day (Zaatari & Sidahmed, 2015). Naameh is a residential area and people are complaining and suffering from the negative effects of the landfill. Increased number of cancer cases and pulmonary problems are detected, in addition to high air pollution levels and noise pollution because of the site incoming and outgoing trucks. On top of that the unpleasantodors and flies generated from waste worsen the living conditions. Dwellers have been protesting for many years asking for the closure of the landfill (The Daily Star, 2015). However, not until this year the government has seriously dealt with the problem after a major crisis in this sector that lead to the accumulation of the waste in the streets for more than one week. Protestors from across Lebanon stood together claiming a fast and effective mitigation for the problem. The final suggestions presented by the minister of environment in the Lebanese government were 1) opening landfills in other towns 2) incinerators (Al Kantar, 2014). However the area of Lebanon doesn't tolerate opening other landfills, and incineration can be a real threat to health if air quality wasn't well monitored, especially that we lack a functioning air monitoring system although the plan, equipment and hotspots were defined in a study that was done in collaboration between the United Nations for Environmental Protection, the American University of Beirut and the University Saint Joseph.

In light of the above, many studies and public calls are made to adopt solid waste sorting and recycling at the source, vermicomposting can contribute to this strategy.

A. Cost

1. Large scale application

The project would involve some basic costs as the opportunity cost of the land for the installation of the facility, transportation and collection of the waste, employees and equipment to run the facility. Costs are dependent on the size of the facility which is determined based on the volume of waste it should handle (Bogdanov, 2004). Besides, if vermicomposting is to contribute significantly to waste management, then the process must be sustained throughout the year. Based on this, the internal environment should be optimized through installing air conditioning system to control the temperature, and humidity.

a. <u>Construction Costs</u>

In Lebanon the average organic waste production per household per week is estimated at 3Kg. According to a study done by Visvanthan in 2005, 20 tons of household waste is vermicomposted in France every day and this requires 1000 to 2000 million earthworms and produces 400 tons of vermicompost and 10 tons of earthworms (Visvanathan, et al., 2005). In the case study of Warhanieh, if we follow the same ratios, an estimated 300 households would produce an estimated 6 tons of organic waste per month. This amount of organic waste produced per month requires 12 tons of earthworms as they reportedly consume half their weight every day (Sinha, Herat, Valani & Chauhan, 2009). So on a scale of 6 tons, 12 tons of earthworms will produce 0.8 tons of vermicompost and 0.02 tons of earthworms. The area required to carry the process is 1.22 Km^2 or 1,228,898 m^2 which is costly to buy and difficult to find especially in rural areas because land is considered an important asset. Figure 1 summarizes the costs of operating a large scale vermicomposting facility.

Earthworms double in number every 60 days given optimal conditions of temperature, moisture, and feeding material. If earthworms don't get physically damaged they can live up to 220 days. They need 4 to 6 weeks to become sexually mature. On average worms produce 3 cocoons every week and produce 300 to 400 young worms during its lifecycle (NC State University, 2015), Eisenia foetida species have a maximum net reproduction rat of 10.4 worm per week (Dynes, 2003). They are sensitive to light and prefer to live in the dark (Sinha, Herat, Valani & Chauhan, 2009). Eisinea fetida, the earthworm found in Lebanon and used in this study is known of its ability to survive extreme conditions such as soil toxicity and heavy metal pollution (Satchell, E., 1983). However, treating organic waste on a municipal level high amounts are needed which becomes expensive where 6 tons of earthworms will cost $1,111,131. Although their numbers will multiply but this amount should be available to initiate the process and guarantee that the 6 tons of waste will be treated and converted to vermicompost on time since there will be a continuous flow of waste to the treatment facility.

Water should be available on site all time, for water is used in preparing the bedding and keeping the earthworms moist. The water sources available in villages are either spring water or the water supplied by the government. These are not enough and keeping the process going will require additional water sources which can be delivered to the site in cisterns. However water availability is decreasing in Lebanon and the government has already initiated several campaigns to direct the use of water. vermicomposting technique is important because it improves the environment and protects its resources. That's why it is not environmentally safe to have a large scale vermicomposting facility.

Other costs involve construction of the facility, which need to be indoors to make sure it functions throughout the year. Materials and equipment for building the facility: this involves cement blocks, wood, metal shelves and others. In addition to the cement and concrete building, the interior structures should be designed to hold the municipal waste and at the same time provide the adequate environment for the worms to live in. These costs will be invested once at the beginning before starting the process. This will include also installation of air conditioners to regulate the temperature.

The size of the facility will determine the cost. In other words the quantity of organic waste to be treated which varies based on the number of households in each village.

b. Operational costs

Monitoring equipment to control the environment inside the facility (ex: log, pH meter, and others) will be needed. Also tools to perform tasks and distribute the waste across the compartments such as shovels to mix and ensure aeration inside the beds are needed as well.

At least 6 workers should be present on site to aid in waste disposal and distribution across the worm beds. Moreover, there is the cost of collecting waste from households and transportation to the site. It is mainly the fuel and truck maintenance, in addition to the salary of 2 employees who are going to perform this job.

c. Maintenance Costs

The cost of maintenance is minimal, mainly the worm population should be kept in check, and any decrease should be compensated. Truck maintenance, tools and equipment is necessary.

d. Additional costs in case of major crisis

In case the worms died or disappeared for reasons such as increase or decrease in temperature, dryness or increased moisture, invasion of ants, harmful insects, or chicken which are known to be direct threats to earthworms, high costs will be incurred. The worms should be purchased and added immediately to control the process or else many additional problems will prevail some of which are offensive odors, attraction of flies, waste leachate, increase of harmful bacteria and microbes on site (Bogdanov, 1996). The waste will be piled and the facility will reach its full capacity in less than two weeks. For that reason usually facilities are designed to account for emergency situations for example an additional compartment for treating waste used only in case of cleaning or defects in the process (Galante, Aiello, Enea & Panascia, 2010). However, if such thing is to be applied, the area of the facility will have to double, which is not feasible and almost impossible in the Lebanese model.

Figure 6 Costs of large scale vermicomposting

2. Household level application

Carrying vermicomposting at the household level is considered cheap since the installation and operation costs are minimal. In my study we used plastic vegetable crates, bedding material (soil), cotton sheets to cover the top, and earthworms.

Since the size of the setup is relatively small, enough to manage organic waste of a single household, the needed amount of earthworms ranges between 400 to 500 grams as a starter. Knowing that worms multiply fast, the vermicomposting process will sustain itself by itself. Figure 3 shows the steps for preparing and installing the household bin which is easy and cheap. Therefore, household application is prefered over large scale because it involves less costs.

Figure 7 Stages of household vermicomposting

B. Benefits

1. Economic Benefits

a. <u>Large scale</u>

Profit from large scale facilities takes time and is not immediate especially with the absence of vermicompost market to sell the product it is not guaranteed. Moreover, the cost will be divided on the households and is considered high for rural communities. In addition, it is not safe to depend solely on vermicomposting to manage the waste of an entire community due to the high risk of failure because earthworms are sensitive creatures and are subject to many threats. Besides, even if the municipality was able to cut the organic waste out of the stream, it won't save the money charged by the government for waste management because the amounts are reduced automatically from the municipality balance before reaching its treasury. This prevents the municipality from saving the money to do developmental projects in the village that could benefit the community. This is the major drawback of the large scale application. This model was found not feasible because the money invested will not be returned neither through selling the product due to the absence of market, nor by the deducted municipality tax. People will have to pay additional tax for implementing the whole project from A to Z, while their municipality tax doesn't decrease and the municipality will not be able to offer them in return beneficial projects that address their needs.

b. Small scale household

Economic benefits in small scale vermicomposting are very low. The production rate is low and there is no market to sell whatever is produced. Thus Vermivcomposting will not be applied for its economic feasibility, but rather for its ecological, environmental, and health benefits which will be discussed below. So people and farmers are recommended and encouraged to produce and use vermicompost for its benefits on ecology, health, and local food security. These are the added values that distinguish vermicompost from the rest of the existing fertilizers.

2. Ecological Benefits and increased crop growth

Vermicomposting is an alternative method for improving soil fertility. It is highly recommended in home gardening practices. Vermicompost is stabilized and is the byproduct of the interaction between earthworms and organic material in the presence of soil or bedding material (Fernández-Gómez, Díaz-Raviña, Romero & Nogales, 2013). The worms excrete a powerful fertilizer called vermicompost. Known as the black gold, vermicompost has many benefits to the ecology. Many studies show that vermicompost provides high soil porosity and high water holding capacity which contribute to aeration, water drainage and resistance to erosion (Domínguez, 2004; Weber et al., 2007; Adhikary, 2012; Bachmann and Metzger, 2007). This prevents nutrient runoffs during storms and irrigation thus sustains the groundwater clean from contamination and eutrophication problems (Chaudhary, Bhandari and Shukla, 2004). Besides, vermicompost regulates the soil pH levels; if the soil is acidic mixing it with vermicompost will increase the pH towards 6 or 7 which is the optimal. It does the same when the soil is basic; vermicompost decreases the pH to the optimal level (Chaudhary et al, 2004; Bhandari and Shukla, 2004). Another important feature is that it suppresses plant diseases by providing certain nutrients that increase the plant's natural resistance to pests and fights plant microbial diseases, insects and parasites (Biradar et al., 1998; Rao, 2002; Ramesh, 2000; Noble and Coventry, 2005; Termorshuizen et al., 2006; Arancon et al., 2003)

In addition to all the ecological benefits, vermicompost is important for producing healthy fresh food. It is known that using vermicompost enhances the smell, color, taste, and keeps the quality of flowers, fruits, vegetables, and grains (Sinha, Agarwal, Chauhan, Chandran & Soni, 2010). It stimulates plant flowering and seed germination, thus increasing the flower number and biomass (Arancon et al., 2008). It is also rich in biochemical substances and organic carbon which play an important role in soil fertility. Worm casting has ten to twenty times higher microbial activity of beneficial microorganisms than that present in the soil and other organic matter which promote plant growth, stimulates shoot and root development (Edwards et al., 2004; Adhikary, 2012; Tomati and Galli, 1995; Nardi et al., 1988; Graf and Makeschin, 1980; Dell'Agnola and Nardi, 1987). Moreover, the humic material present in earthworm vermicompost, that is the form of completely mature compost that reaches the stable state and is used by horticulture specialists to regenerate soils, increases hormonal activity which in-turn induces root growth (Canellas et al., 2002, Zandonadi et al., 2006; Canellas et al.; 2002; Zandonadi et al., 2006). Many studies show that vermicompost have higher nutrient availability because it transforms the nutrients present in soil from insoluble to soluble which makes it available for plants (Scott, 1988, Adhikary, 2012; Edwards and Burrows, 1988). Thus it increases nutrient uptake by plants and also regulates the release of nutrients into the soil by chelation where it only releases the amounts required by the plant (Kabir et al. 1998; Cavani and Mimmo, 2007; Adhikary, 2012). A study done by Lazcanoa and Domínguez (2011) shows that adding a mixture of 25% vermicompost and 75% inorganic fertilizer to plants made significant greater increase in plant height and crop yields compared to 100% inorganic fertilizer. Many other studies are done prove that vermicompost increases crop yields which is a great incentive to users especially farmers as it will have a positive impact on their profit (Adhikary, 2012; Ansari, Ismail & others, 2008; George, Pillai & others, 2000; Jelin, Dhanarajan & Mariappan, 2011; Blouin et al., 2013). All these characteristics contribute to healthier plants, increased crop productivity and quality of food which is directly linked to better health and improved farming profit.

Figure 8 Lettuce planted by one of the volunteers during the study period at the same timing shows different growth results: without using vermicomposting (top) with vermicompost (bottom)

3. Environmental Benefits

The benefits of vermicompost extend beyond improving ecology, supplying nutritious foods, and promoting healthy lives, to environmental benefits. vermicompost is defined as the use of earthworms to transform organic waste into fertilizer of high quality. It recycles back the nutrients into the soil and treats waste at the source which is the most effective strategy to solid waste management. Reducing waste generation eventually reduces the community's ecological footprint. In addition it reduces ground and surface water pollution and eutrophication problems as a result of reduced use of chemical fertilizers (Fernández-Gómez, Díaz-Raviña, Romero & Nogales, 2013), because of its ability to control the release of nutrients into the soil based on the plant's need for it.

Not to mention the benefits that include increased landfills size because of reduced volume of waste dumped in it, reduction of the use of Fertilizers by at least 50% which saves money and protects the environment, and finally possible profits from selling Vermicompost.

C. Warhanieh interviews

1. Ecology and livelihood practices in Warhanieh

Soils in Warhanieh are porous which are distinguished by high infiltration rates, low moisture retention, and poor fertility due to limited organic matter and nitrogen (Aulakh & Bijay-Singh, 1997). To compound matters, when crops are harvested, nutrients are moved from the soil, leaving it depleted (Bijay-Singh et.al, 1995). Although fertilizers may help to increase crop yield, excessive usage may negatively impact the ecosystem, affecting other resources like water (Aulakh & Bijay-Singh, 1997; Bijay-Singh, et al., 1995).

Synthetic fertilizers were first introduced in Warhanieh fifty years ago. Most farmers rely on fertilizers to increase crop yield. Because of cost, applications may be restricted to every other year (Kamel Ghanem, Moukhtar). However, there is a general belief that fertilizer quality has declined, suggesting the nutrient composition has decreased. Studies have revealed that lack of confidence in these chemicals have resulted in farmers using 20 to 30 percent more than label recommendations despite cost (Farajalla & Khoury, 2007).

2. Home gardens

Family production systems whether called kitchen, home, or backyard gardens, are the oldest known production system (Marsh, 1998). Large or small in area, home gardens provide security to households by diversifying its sources of livelihood and by making them less vulnerable to external factors as food shortage. House gardening isn't necessary practiced by those of low income, but mainly by the households which have access to the needed resources such as water for irrigation, land, and labor (Marsh, 1998). Studies show that the successful household food security strategy would be to focus on the micro rather than macro level. In other words, it's to focus on the household not on the government, ministries, and municipalities. Home gardens are also important because they provide ecological niches for many insects, and function as conservation areas for beneficial organisms (Marsh, 1998).

Although people use chemical fertilizers and pesticides in their farms, yet at their home gardens they apply only animal manure and spray some plants with a mixture of water and ashes to fight insects and worms to reduce the use of pesticides. People believe that organic gardens are their only source for healthy and fresh food. The gardens have wide diversity of vegetables and fruits; especially the smallest gardens because they force people to group many different species in small numbers. While big gardens allow multipurpose use of the area and gives space to more diversity of plants, small gardens are managed in a way that allocate space for the plants which constitute the highest portion of their diet. Even landless families tend to cultivate in containers. Daily practices in Warhanieh during the summer season involve harvesting the vegetables directly from the garden to prepare the food for the family to eat them fresh and healthy. Outsource purchase is very low, home gardens provide almost all the needed food products.

Figure 9 Aerial view of Warhanieh

The image in figure 15 shows the old village clustered at the middle, the area around it was a community garden. The residential area in Warhanieh doubled in size between 1970 and 1978 and took over the community garden. However, the houses built around the old village portray the individualistic lifestyle where each household has its own garden (check Appendix 13). Home garden vegetation has two purposes, decorative and functional. Even in small gardens people manage to plant both types of plants. Land is always dedicated for planting vegetables and herbs, while ornamental plants in pots and placed outdoors and indoors, in narrow spots, on garden stairs, home stairs, and on balconies. Fragrant trees and plants are usually planted in the garden or in pots in close proximity to the house's main entrance. Larger gardens provide more space for wider range of plants. Processing fruit, vegetable, and dairy products is part of the village heritage practiced by almost all housewives where they prepare products in the summer for local consumption in winter season. Processed food constitutes a significant portion of the winter diet, some of the products include: jam, juice, salad dressings, tomato paste, grape molasses, mulberry and rose syrup, kushk, pickles, dried fig, apricots, grapes and others (see figure 6).

Figure 10 Home gardens in Warhanieh

a. Absence of gardens

Houses without kitchen gardens plant the food for local consumption in their large agricultural lands that are located away from the residential area. These houses represent 25% of the households which constitutes the old clustered village. Although if we look at the map in figure 5 they might seem more in number, but each home in the old village have burst into more than one household dispersed in the extended village area. Only the first generation of aged families inhibits them, or in some cases one of their children. People without access to land next to their home plant only ornamental evergreen plants, flowering plants, and fragrant herbs in pots and place them indoors or on their balcony as shown in figure 7 a and b, and figure 8.

Figure 11 a)Decorative plants on narrow balconies b)Vegetables planted in plastic pots

Figure 12 Many planted pots to keep the greenery near the house

b. Garden area up to 500

Households surrounding the old village are open to the external land, and have house gardens of maximum area of 500 meters. In addition households that lie under the steep mountain have limited access to land but still manage to plant their vegetables in small land slots which constitute their kitchen garden. These households combined represent another 25% of total households. In gardens of maximum 500 meter area, people plant several kinds of fruit trees, one or two of each kind mainly cherry, fig, apple, or peach. They also plant variety of vegetables. Depending on the preference of each family and the main constituents of their diet, planted food varies between zucchini, parsley, and mint, herbs like endive, cucumber, lettuce, eggplant, tomato, radishes, green onions, garlic, kidney beans, broad beans, and green beans. In addition they plant flowers, fragrant trees, and evergreen plants as shown in figure 9 and 10 below.

Figure 13 Small home garden where flowers, parsley and herbs are planted

Figure 14 Small piece of land is plowed and planted with vegetables for home consumption

c. Garden area from 500 to 2000 meter^2

The remaining 50% of households have enough space surrounding their houses reaching 2000 meters, but not everyone cultivates the entire area. Usually people assign certain section for kitchen gardening while the rest is designed to offer a nice view to the house. The kitchen garden area varies from one household to the other depending on personal preference and whether the owners are permanent or seasonal dwellers. Seasonal residents are less likely to have large kitchen gardens because they need more attention; in addition, most of the time, living outside the village changes the food lifestyle and makes them more dependent on purchase than growing their own food. However, seasonal residents constitute a small percentage. When land is available, the type and amount of food grown increase. Some people grow up to five different kinds of grape vines, more than one kind of fig trees (figure 11). Besides, people grow mulberry, green hummus, apricot, akidnaa tree or Indian apricot, and strawberries. In addition to all the other vegetable products mentioned in the earlier section on small home gardens, however in the case of larger gardens, people have the opportunity to grow relatively higher amounts based on their need. Moreover, people choose to grow watermelon, Cantaloupe melon, and some alien species such as kiwi and others.

Figure 15 Households with hanged vine at the main entrance

There are certain types of herbs that almost all households grow such as basil and oregano which are used in the main traditional dishes as added flavors, and sweet woodruff which is used to makes flavorful tea. In addition, they grow medicinal plants like sage, fennel, and rosemary which are used to treat stomach and headaches. These plants require little space as they are intended for local use and can be planted in small plastic pots. However, in gardens of area more than 500 meters, people plant them in higher quantities to serve as decorative and fragrant plants.

Interviews with people from Warhanieh revealed that the community cares about its diet and that people are in a continuous search for environmentally friendly and organic practices which will eventually make it easier for them to adopt vermicompost.

D. Vermicompost as circular-economy solution

Instead of sending the organic waste to landfills or to incinerators, recycling it back into the soil contributes to closing the system and reducing energy loss as clarified in figure 12 below. Vermicomposting at the household level in home gardens connects people more to the environment especially the new generation who is slowly abandoning farming practices and adopting the urban lifestyle. Vermicompost is highly demanded because of the above characteristics and since it is odorless and of good visual aesthetic. Besides it requires little space as shown in figure 2. If people consume home grown products of longer shelf life compared to the market purchases foods, it further prevents rotting and flies which help eliminate unnecessary offensive odors throughout the vermicomposting process. In addition to this, as discussed earlier Vermicompost will help regenerate the soil and improve its quality in terms of porosity, water holding capacity, and ph. Moreover it contributes to better food quality by increasing nutrient availability and uptake, flowering, and yields. Using Vermicompost at home gardens supports the families' health and wellbeing.

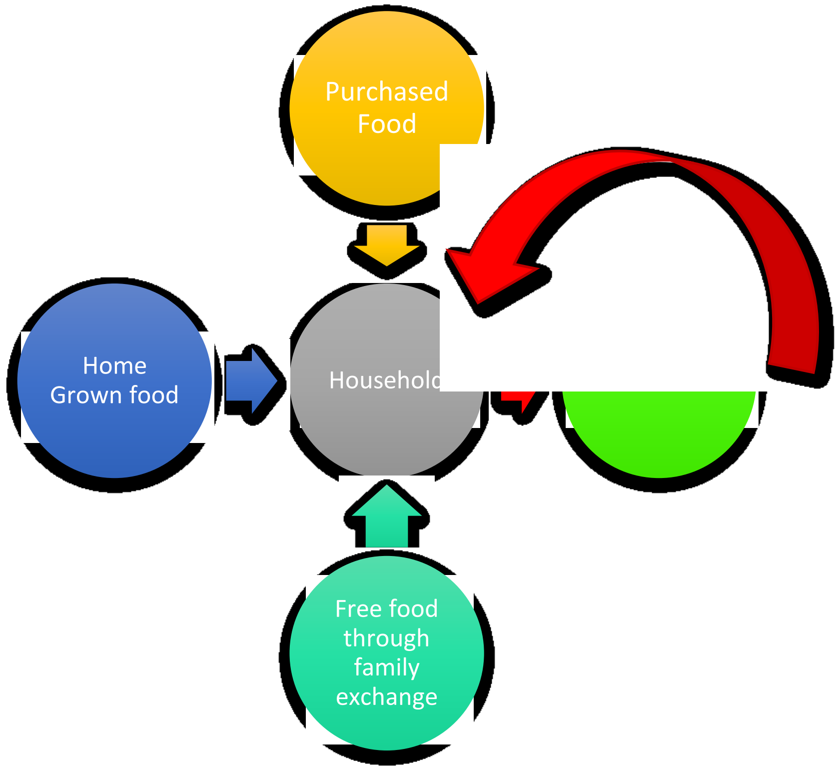

Figure 16 Household closed system – recycling back energy outputs

E. Conclusions

This study shows that in Lebanon the profit from selling homemade vermicompost as well as upgrading to municipal scale vermicomposting facility is low, meaning that money is not the main driver for adopting vermicompost. However, vermicomposting should be demanded for the ecological benefits it possesses, as well as the nutritious food products it produces. In addition, its contribution to closing the system by recycling the energy back into the system through processing the organic kitchen waste back into the soil makes it a powerful tool for alleviating the level of environmental awareness and socioeconomic status of rural families. All this further contributes to local food security which is becoming a pressing need in the current period. Vermicomposting at the household level is the most cost effective approach that will guarantee the continuity of the practice, and spreads its benefits to wider population. Our study is trying to help people consume nutritious food and promote healthy behaviors. On the other hand it is recommended, in case it is to be applied on a large scale, to establish horticultural and agricultural markets, well-trained sales staff, and a network of delivery and distribution facilities. Moreover, designing vermicomposting units for different sizes of home gardens would facilitate the application of the technology at different settings and increase its practicality which in turn increases the demand for its use.

CHAPTER VI

CONCLUSIONS

Vermicomposting technology has a promising future in Lebanon. This study succeeded in building bridges between scientists and village residents. The success of the project may have been due to the fact that the village has a relatively high education level, the villages are sensitive to their environment, and they were positive about collaborating with a local resident researcher. It is not known, however, where vermicomposting would be equally accepted in other rural villages or in cities. Although willingness to pay to establish a vermicomposting facility for managing the municipal organic waste was relatively high, the study revealed that it may not be economically feasible to install a large scale vermicomposting facility at the village. One reason being the absence of tax incentives; currently there is no mechanism that enables the deduction of the municipal tax on solid waste management from the total government tax for reasons related to the type of contract between the government and the company managing the waste in the Chouf area. Similarly vermicomposting at the household level did not prove to be profitable either especially in the absence of a vermicompost market. The findings suggest, however, that for owners of home gardens, vermicomposting at household level is beneficial in gardening as it reduces the need for synthetic fertilizers and pesticides. In this context, vermicomposting at household level contributes to local food security.

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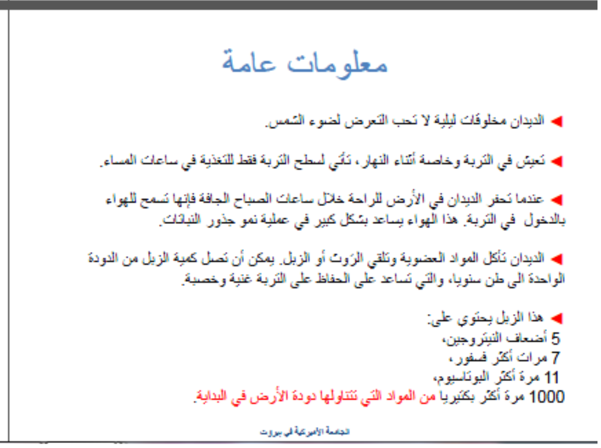
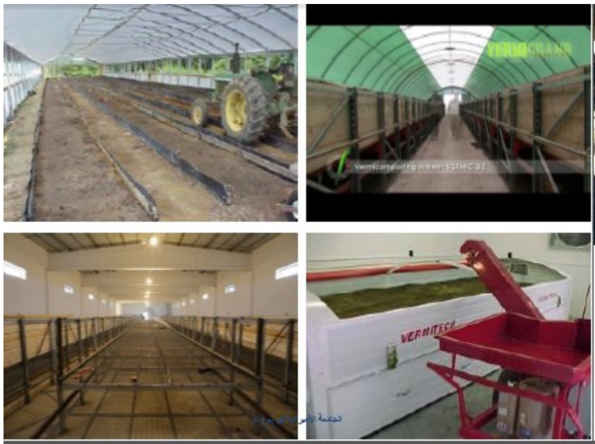
APPENDIX

Appendix 1. The Presentation of the Introductory Seminar Given to the community at Warhanieh




أشخاص عاديين ومن مختلف الأعمار
يقومون بتَربيةِ الديدان لإنتاج السماد



تربية الديدان لإنتاج السماد
Vermicompost

هو عبارة عن عملية تحويل النفايات العضوية عبر إستخدام دود الأرض وتحويله إلى سماد يعيد التوازن للتربة مما يزيد الإنتاج الزراعي.

يحتوي على غذاء للتربة بنسبة تتعدى النسبة الطبيعية الموجودة في السماد العضوي بخمسة أضعاف.

الدول المنتجة: الولايات المتحدة الأميركية، فرنسا، كندا، الهند، الفلبين، تايلاند، أستراليا، كوبا، أوكرانيا وغيرها.

الدول المجاورة:
- إيران لديها أكثر من 15 معمل لإنتاج ال Vermicompost
- تركيا بدأت حديثاً بإنتاجه واليوم تملك قرابة 5 معامل

ما هي فوائده الأخرى؟

على المزارعين:

تخفيض كلفة الإنتاج من خلال تدني إعتماد المزارع على الكيماوي

إرتفاع إنتاجية التربة بسبب تحسن نوعيته

محاصيل ذات نوعية أفضل و إنتاجية أكبر

مصدر دخل إضافي للعائلات التي تنتجه وتبيعه

على البيئة:

لا تعود النفايات مصدر تلوث بل مواد أولية قيمة لتعزيز خصوبة التربة

الجامعة الأميركية في بيروت

دراسة في ال AUB أثبتت فعاليته على النباتات

بقدونس Parsley

من أسفل إلى أعلى: 0%, 5%, 15%, 25%

روكا Rocca

من اليمين إلى اليسار: vermicompost 25%, 15%, 5%, 0%

الجامعة الأميركية في بيروت

تطوير نموذج
تربية الديدان لإنتاج السماد للتطبيق على الصعيد المنزلي

◄ قمنا بتطوير نظام التخمير لتجنب أي ملامسة بدود الأرض.
حيث يضاف دود الأرض في الشهر الأول، و ينتقل بمفرده بين الصندوقين.

◄ يشغل مساحة أقل.

◄ يكون الصندوق بوضعية ثابتة.

◄ تكون عملية الحصاد سهلة لا تتطلب جهد.

الجامعة الأميركية في بيروت

تطوير نموذج
تربية الديدان لإنتاج السماد للتطبيق على الصعيد المنزلي

لقد تم تطوير النموذج على عدة مراحل:
أكياس القمامة البلاستيكية،
الأواني البلاستيكية المستخدمة في الزراعة،
الأواني الفخارية،

صناديق الفاكهة البلاستيك،
المنسوجات

الجامعة الأميركية في بيروت

الدراسة الأولى في بتلون – صيف 2013

المنهج التطبيقي للدراسة

1. تعرب النفايات العضوية (خضار, فاكهة, تفل قهوة,أكياس شاي) بشكل يومي, لمدة سبعة أيام من أول كل شهر من حزيران إلى تشرين الثاني. كما يضاف إليها خليط من ديدان الأرض والتراب.
2. توضع النفايات يومياً في الصندوق المخصص للتخمير الذي يقدم مجاناً من الجامعة الأميركية في بيروت.
3. يجب أن يغطى الصندوق دائماً, يفتح فقط عند وضع النفايات.
4. عند إنقضاء السبع أيام يترك الصندوق في المكان المخصص له خارج المنزل.
5. عند إنقضاء أول شهر, تكون قد إنتهت عملية تحلل النفايات.
6. في الشهر الثاني , نبدأ بوضع النفايات بالصندوق الملاصق, و لمدة سبعة أيام متواصلة.
7. في الشهر الثالث، نزيل السماد من الصندوق الأول و نضع مكانه النفايات العضوية لمدة 7 أيام.

الجامعة الأميركية في بيروت

الهدف من الدراسة

- تطبيق التقنية على مستوى القرية الريفية
- تقييم فعالية الجهاز المعتمد
- تقييم مدى تقبل الناس لهذه التقنية عبر ملئ إستمارات خطية

اللجنة التحكيمية:
الدكتورة سلمى تلحوق،
الدكتور رامي زريق،
الدكتور إبراهيم علم الدين،
الدكتور علي شلق،
الدكتور محمد أبيض.

الجامعة الأميركية في بيروت

على الراغبين بالمشاركة في تطبيق التقنية تسجيل أسمائهم كي يحصلوا على الجهاز بالإضافة إلى كتيب الإرشادات.

سوف يتم متابعة المشاركين عن كثب للإجابة عن أية أسئلة والمساعدة عند الحاجة.

الجامعة الأميركية في بيروت

شكراً لحضوركم

الجامعة الأميركية في بيروت

Appendix 2. Distribution of vermicomposting units with the information sheet to the volunteers at Warhanieh.

Figure 17 the researcher while preparing the vermiculture set-ups at AUB (to the left), final set-up (to the right)

Figure 18 Figure showing the units piled in Warhanieh waiting to be distributed

After the introductory seminar units were distributed on people who volunteered to participate in the study.

Figure 19 Distributing the units on volunteers

Appendix 3. Collection of Photos showing the infield vermicomposting Application in Warhanieh

Figure 20 During the introductory seminar samples of vermicompost was distributed to all attendees and all the study stages and methodology explained.

Pictures taken during my routine follow up on the vermicomposting process inside the household bins. One can notice that each participant placed the bin in a special and different location that provides the best conditions required for the survival of the earthworms.

Figure 21 During the first trial, it shows how the unit was fully lined with cotton sheets


Green Food

Figure 22 Introductory seminar in Warhanieh on May 28, 2014, part of the attendees (to the left), the resident researcher (to the right)

Figure 23 The researcher with a farmer checking the vermiculture bin

Figure 24 Children (Rami and Rabih) holding an earthworm for the first time

Appendix 4. Contingent Valuation Survey Consent Form in Arabic as Approved by the Institution Research Board (IRB)

استمارة موافقة

ان الغرض من المشروع البحثي الحالي هو دراسة الجهوزية لتحمّل تكلفة نقل انتاج السماد العضوي في قرية تحت مسؤولية البلدية، مقابل الجهوزية لتطبيق تقنية انتاج السماد العضوي على المستوى الأسري كوسيلة من وسائل إدارة النفايات وتحسين التربة.

أنتم مدعوون للمشاركة في هذا المشروع البحثي الذي أجرته الجامعة الأميركية في بيروت لأنكم من " الو رهانية" ، القرية الزراعية الريفية التي اخترناها لإجراء المشروع البحثي الخاص بنا.

إن مشاركتكم في هذه الدراسة البحثية هي مشاركة طوعية. بامكانكم اختيار عدم المشاركة. وفي حال قررتم المشاركة فيها بامكانكم الإنسحاب في أي وقت. كذلك، لن تتعرضوا لعقوبة إذا قررتم عدم المشاركة في هذه الدراسة أو الانسحاب من المشاركة في أي وقت.في حال رفضتم المشاركة أو قررتم الانسحاب من الدراسة فهذا لا ينطوي على أي عقوبة أو خسارة من الفوائد لهذا الموضوع ، وكما أنه لن يؤثر على علاقتكم مع الجامعة الأميركية في بيروت.

ويشمل الإجراء تعبئة استطلاع يتطلب حوالي 30 دقيقة تقريباً. ستكون إجاباتكم سرية. ولن يتضمن الاستطلاع معلومات من شأنها أن تحدد هويتكم بغية المساعدة في الحفاظ على سريتها. سيتم استخدام نتائج هذه الدراسة لأغراض علمية فقط، ويجوز تبادلها مع ممثلي الجامعة الأميركية في بيروت. وسيتم رصد سجلات البحث ويمكن مراجعتها دون انتهاك السرية.

إذا كان لديك أي أسئلة، مخاوف أو شكاوى حول البحث يمكنك الاتصال:
بالدكتورة سلمى ن. تلحوق، أستاذ في قسم تصميم وإدارة النظم الإيكولوجية
معاون عميد كلية العلوم الزراعية والأغذية
عضو مؤسس لمركز AUB حماية الطبيعة - الجامعة الأميركية في بيروت ، شارع بلس،
صندوق بريد 11-0236 ، رياض الصلح 1107-2020، لبنان
هاتف: + 961-1-374374 تحويلة 4508/4578
فاكس: + 961-1-744460

تمت مراجعة هذه الدراسة وفقاً لإجراءات مجلس المراجعة المؤسساتي للعلوم الإجتماعية والسلوكية (IRB) التابع للجامعة الأميركية في بيروت حول الأبحاث التي تتعلق بالمواضيع البشرية. إذا أردت الاتصال بشخص ما مستقلة عن الفريق البحثي لأسئلة، مخاوف أو شكاوى حول البحوث؛ أسئلة حول حقك كمشارك؛ للحصول على المعلومات؛ يمكنك الاتصال أو البريد الإلكتروني IRB على العنوان التالي:

صندوق بريد F15 11-0236 رياض الصلح، بيروت 1107 2020 لبنان
هاتف: 00961 1 374374، تحويلة: 5445
الفاكس: 00961 1 374374، تحويلة: 5444
البريد الإلكتروني: irb@aub.edu.lb
الخط المباشر: 000961 1 738024

فاكس مباشر: 738025 1 000961

في حالة مشاركا الأميين، سوف يكون حاضرا شاهد مستقل عن فريق البحث أثناء عملية التوافق وسوف يوقع على استمارة الموافقة.

وينبغي أن يكون المشارك :
أي من الذكور الإناث الذين تتراوح أعمارهم بين 18-64 .
سكان الورهانية.
كليا أو جزئيا مسؤول عن كسب دخل الأسر و / أو اتخاذ القرارات.

يرجى تحديد اختيارك أدناه.
تشير عبارة "موافق" إلى:
- أنك قرأت المعلومات الواردة أعلاه
- أنك موافق طوعاً على المشاركة
- أن عمرك لا يقل عن 18 سنة

تشير عبارة "غير موافق" إلى عدم رغبتك بالمشاركة في الدراسة البحثية.
☐ موافق
☐ غير موافق

توقيع من أجريت معه المقابلة : ____________________

توقيع فريق البحث ___________________

توقيع الشاهد_____________________

التاريخ : ___________________

الوقت: _________________

وسيتم إعطاء المشاركين نسخة من استمارة الموافقة.

Appendix 5. Contingent Valuation Survey Form in Arabic as Approved by the Institution Research Board (IRB)

استبيان مسحي بشأن تقييم الجهوزية لتسديد الثمن واعتماد التقنية

تاريخ المقابلة: ____________________

اسم المقابل/المستجوب: ______________________

القسم الأول

أ. المخاوف الرئيسية:

أ.1 على مقياس من 1 إلى 5 ، حيث أن 1 تعني مقتنع جداً و 5 غير مقتنع مطلقاً، رجاءً ما هو مستوى اقتناعك لما يلي؟ رتب القطاعات المذطورة أدناه من الأكثر أهمية إلى الأقل أهمية (1 إلى 5)

	مقتنع جداً (1)	مقتنع إلى حد ما (2)	لا مقتنع ولا غير مقتنع (3)	غير مقتنع إلى حد ما (4)	غير مقتنع مطلقاً (5)	قم بالترتيب بحسب القطاعات (1 = الأكثر أهمية 5= الأقل أهمية)
التخلص من مياه الصرف الصحي						
الحصول على مياه شرب نظيفة						
جمع النفايات الصلبة والتخلص منها						
الوصول إلى وسائل النقل العام						
الإمدادات الكهربائية						

أ.2 على مقياس من 1 إلى 5 ، حيث أن 1 تعني موافق جداً و 5 غير موافق مطلقاً، إلى أي درجة توافق على كل من البيانات ؟

	موافق جداً (1)	موافق إلى حد ما (2)	لا موافق ولا غير موافق (3)	غير موافق إلى حد ما (4)	غير موافق جداً (5)
أ. هناك مشكلة انزعاج بشأن التخلص من النفايات الصلبة في هذه المنطقة					
ب. يعتبر التخلص النهائي من النفايات آمناً ومقبولاً حالياً من الناحية البيئية					

ج. تملك البلاد نظام جيد لإدارة النفايات					

أ.3 هل تعلم إلى أين يتم أخذ النفايات بعد نقلها من منطقتك؟
أ) نعم
ب) كلا

أ.4 هل أنت قلق حول ما إذا كان التخلص النهائي آمن ومقبول من الناحية البيئية؟
أ) نعم
ب) لا

القسم الثاني

ب. التقييم الطارئ

ينتج عن الأسر من خلال أنشطتها اليومية (الطبخ، الزراعة، الخ ...) الكثير من المخلفات الصلبة (مثل بقايا الخضروات، نفايات الفناء، المخلفات الزراعية بعد الحصاد الخ ...). وقد تنشأ عن هذه النفايات، إذا لم يجر حسن إدارتها والتخلص منها، مشاكل في النظافة العامة (الذباب، الروائح الكريهة، القمامة في الشوارع ... الخ) والصحة (مثل سرطان الرئة، والأمراض الميكروبية الخ ...). وقد سلّطت الأحداث التي جرت في مكب الناعمة مؤخراً الأضواء على جميع المشاكل المتعلقة بسوء إدارة النفايات الصلبة. بالإضافة إلى ذلك، نوعية التربة في لبنان في حالة متدهورة، وبالتالي تصبح المحاصيل المنتجة ذات قيمة غذائية منخفضة، الأمر الذي يؤثر على صحتنا بشكل مباشر.

يستند انتاج السماد العضوي على أنواع محددة من ديدان الأرض (الحمراء) لتحويل النفايات الصلبة العضوية (مثلا من بقايا الطعام) إلى سماد عضوي عالي الجودة يمكن استخدامه بدلاً من الأسمدة الكيماوية لتوفير مواد غذائية أربع مرات أكثر للمحاصيل المزروعة مقارنة بالسماد، وكذلك بدلاً من المبيدات في السيطرة على آفات المحاصيل، الأعشاب الضارة والأمراض.

هناك طريقة واحدة فعالة للحد من المشاكل المذكورة وهي "انتاج السماد العضوي باستخدام الديدان" التي يمكن تطبيقها وفق المقاييس الصغيرة والكبيرة في العمليات الزراعية. وهذا سيفيد المجتمع بطريقتين:

(1) في الحد من المشاكل الصحية والنظافة العامة المذكورة أعلاه و (2) في الحد من اعتماد المزارعين على الكيماويات الزراعية (مثل الأسمدة، المبيدات الحشرية الخ ...) التي قد تلوث مصادر المياه والإمدادات الغذائية والتربة لدينا بطرق مضرة بصحة الإنسان والبيئة.

تستعمل طريقة انتاج السماد العضوي باستخدام الديدان على نطاق واسع في الوقت الحاضر في أوروبا وأمريكا الشمالية. أما في الهند، ساهمت مبادرات انتاج السماد العضوي في حماية البيئة، التنمية الاقتصادية المحلية، وتعزيز الرفاهية الاجتماعية للمجتمعات المشاركة. وهي تطبق حديثاً في تركيا وإيران التي تملك 5 و 16 مرافق إنتاج على نطاق واسع.

لم تطبق هذه التقنية في لبنان حتى الآن. إلا ان تطبيقها على نطاق واسع يتطلب التكاليف. وهذه تشمل جمع النفايات واختيارها، النقل، إنشاء مصنع لإنتاج السماد، إنتاج السماد العضوي وتوزيعه على المزارعين المحليين. يمكن تطبيق هذه الخطة على مستوى البلديات حيث ستكون مسؤولة عن العملية برمتها. لذا بهدف تمويل تلك المبادرة وزيادة رأس المال المطلوب، يمكن للبلديات فرض الرسوم على الضرائب البلدية التي تدفعها الأسر في نطاق ولايتها.

ب.1 إلى اي درجة تعتقد أن انتاج السماد العضوي أمر مثير للاهتمام؟
أ) مثير جدا للاهتمام
ب) مثير للاهتمام إلى حد ما
ج) إنه مضيعة للوقت. لا أعتقد أن البرنامج سينجح
هـ) لا يساوي شيئا بالنسبة لي

ب.2 (إذا كانت الإجابة نعم) هل ترغب في استعمال السماد العضوي باستخدام الديدان بدلاً من السماد؟
أ) نعم
ب) كلا

ب.3 هل ترغب بانتاج السماد العضوي باستخدام الديدان في منزلك كي تنتج الأسمدة الخاصة بك؟
أ) نعم
ب) كلا

ب.4 لو كانت تلك المبادرة متوفرة لدى البلدية في منطقتك، إلى أي درجة ستكون مستعداً لتحمّل رسوم الضرائب الإضافية شهرياً كي تدفع ثمنها وتجعلها ممكنة؟

يرجى اختيار مبلغ من القائمة أدناه يناسب بشكل تقريبي استعدادك لتحمّل ضريبة إضافية.

$0 □				
$1 □	$8 □	$15 □	$22 □	$29 □
$2 □	$9 □	$16 □	$23 □	$30 □
$3 □	$10 □	$17 □	$24 □	$31 □
$4 □	$11 □	$18 □	$25 □	$32 □
$5 □	$12 □	$19 □	$26 □	$33 □
$6 □	$13 □	$20 □	$27 □	$34 □
$7 □	$14 □	$21 □	$28 □	$35 □

<u>الردود الاحتجاجية (لماذا لن تدفع)</u>
أ) لا يمكنني تحمّل الدفع حالياً
ب) ليس عدلاً أن تنتظروا مني الدفع
ت) أعارض البرامج الحكومية الجديدة
ث) يجب أن تدفع الحكومة لهذه العملية
ج) أعتقد أن هذا البرنامج سوف يفيدني لكن يمكن للآخرين أن يدفعوا
ح) لا أؤمن بانتاج السماد العضوي باستخدام الديدان
خ) غيرها: حدد..

ب.5 هل ترغب بانتاج السماد العضوي باستخدام الديدان في منزلك لو كنت قادراً على تحقيق إيراد من 3 دولار لكل 500 غ ؟
أ) نعم
ب) كلا

ب.6 هل تقوم حالياً بفرز النفايات الخاصة بك؟
أ) نعم ، جميعها

ب) نعم، جزء منها
ج) كلا..... انتقل إلى ب.6.1 و ب.6.2

ب.6.1 (إذا كانت الاجابة على ب.5 هي ج) هل ستقوم بالفرز إذا دفعت لك البلدية 5$ في الشهر؟
أ) نعم
ب) كلا

ب.6.2 (إذا كانت الاجابة على ب.5.1 هي ج) إذا تقاضت البلدية منك رسم 5$ لعدم الفرز، هل ستبدأ بالفرز؟
أ) نعم
ب) كلا

ب.7 هل تفضل أن تتولى البلدية عملية انتاج السماد العضوي باستخدام الديدان؟
أ) نعم
ب) كلا

ب.8 إلى كم فئة تفضل أن يتم الفرز؟
أ) الفرز غير مطلوب...... (انتقل الى السؤال التالي)
ب) 2 (المواد القابلة للتدوير، المواد غير القابلة للتدوير)
ج) 5 (ورق، زجاج، معادن، بلاستيك، غيرها) ---- (تذكر أن هذه تتطلب مساحة أكبر في منزلك)

ب.9 كيف تفضّل أن يتم الفرز؟
أ) الفرز المنزلي
ب) جمع النفايات غير المفرزة عن الرصف كي يتم فرزها لدى مرفق البلدية

ب. 10 كم مرة تفضل أن يتم جمع النفايات؟
أ) مرتين في الاسبوع
ب) 4 مرات في الاسبوع

القسم الثالث

ج. أسئلة إضافية

ج.1 هل تملك أراضي؟
أ) نعم
ب) كلا.................انتقل إلى القسم الرابع

ج.3 ما هي المساحة الإجمالية للأرض التي تملكها؟

____

ج.3 ما هي نوع الأسمدة التي تستخدمها؟
أ) كيميائية
ب) عضوية

ج.4 أي نوع من الأسمدة العضوية؟
ا) ماعز ب) بقر ج) دواجن د) سماد

القسم الرابع

د. الخصائص السكانية

د. 1 تحديد الأسر:
أ) رب الأسرة
ب) زوجة رب الأسرة
ج) غيرها...... يرجى الشرح...........................

د. 2 الجنس
أ) ذكر
ب) أنثى

د.3 كم عمرك؟
أ) 18-24 ث) 41-50
ب) 25-30 ج) 51-68
ت) 31-40 ح) 69- وما فوق

د. 4 هل تعيش في القرية؟
أ) بشكل منتظم
ب) في الصيف
ج) في الشتاء
د) بشكل موسمي/في العطل

د.5 ما هو مستوى تحصيلك العلمي؟

□ لم أحضر المدرسة على الإطلاق	□ معهد أو جامعة - BSc
□ مرحلة ما قبل المدرسة	□ معهد أو جامعة - MSc/PhD
□ الابتدائية	□ تعليم عالي- مهني/فني (مثلا TS/LT)
□ المتوسطة- عامة	□ غيرها:_____________
□ المتوسطة- مهنية	□ لا أعلم/أرفض الإجابة
□ ثانوية- عامة	
□ ثانوية- مهنية/فنية (BT/LP)	

د.6 ما هي أعلى درجة علمية متوفرة في هذه الأسرة؟

□ لم أحضر المدرسة على الإطلاق	□ معهد أو جامعة - BSc
□ مرحلة ما قبل المدرسة	□ معهد أو جامعة - MSc/PhD
□ الابتدائية	□ تعليم عالي- مهني/فني (مثلا TS/LT)

□ المتوسطة- عامة	□ غيرها: ____________
□ المتوسطة- مهنية	□ لا أعلم/أرفض الإجابة
□ ثانوية- عامة	
□ ثانوية- مهنية/فنية (BT/LP)	

د.7 ما هو مستوى دخل الأسرة؟ (كافة مداخيل الأسرة حتى لو كان أحدهم يعمل في الخارج)

□ $0- 500 $	□ 1.600 $ - 2.000 $
□ $600- 800 $	□ 2.100 $- 3.000 $
□ $900 - 1500 $	□ 3.100 $ وما فوق

د.8 في أي قطاع تعمل؟
أ) خاص
ب) عام
ج) غيرها: حدد................................

د.9 كم تنفق شهرياً على الأسرة؟

□ $150 - $200	□ $900- 1500 $	□ $3100
□ 300 $ - 400 $	□ 1600 $- 2000 $	
□ $500 - 800 $	□ $2100- $3000	

القسم الخامس

هـ. الملاحظات

هـ.1 حالة المنزل:
أ) جديد ب) قديم

هـ.2 حجم المنزل:
أ) كبير ب) صغير

هـ. 3 حالة الأثاث:
أ) متواضعة ب) عالية الجودة

هـ.4 وضع الأثاث:
أ) أثاث كامل ب) أثاث جزئي

"شكراً لمساهمتكم في هذا المسح"

و. 1 إذا كان هناك حاجة للحصول على مشورة إضافية منك، هل بامكاننا الاتصال بك مجدداً؟
أ) نعم
ب) كلا

ندى ر. غانم : nrg02@mail.aub.edu

6. Contingent Valuation Survey Consent Form as Approved by the Institution Research Board (IRB) in English

CONSENT FORM

The purpose of this research project is to study the willingness to pay for carrying vermicomposting in a village under the responsibility of the municipality, versus the willingness to apply the Vermincomposting technique at the household level as a waste management and soil betterment method.

You are invited to participate in this research project conducted by the American University of Beirut because you are from the rural agricultural village "Warhanieh" the village we chose to conduct our research project.

Your participation in this research study is voluntary. You may choose not to participate. If you decide to participate in this research survey, you may withdraw at any time. If you decide not to participate in this study or if you withdraw from participating at any time, you will not be penalized. Refusal to participate or deciding to withdraw from the study will involve no penalty or loss of benefits to which the subject is otherwise entitled and neither will it affect their relationship with AUB.

The procedure involves filling a survey that will take approximately 30 minutes. Your responses will be confidential. To help protect your confidentiality, the surveys will not contain information that will personally identify you. The results of this study will be used for scholarly purposes only and may be shared with American University of Beirut representatives. Research records will be monitored and may be audited without violating confidentiality.
If you have any questions, concerns, or complaints about the research you can contact the
Professor Salma N. Talhouk
Department of Landscape Design and Ecosystem Management
Associate Dean, Faculty of Agricultural and Food Sciences
Founding Member, AUB Nature Conservation Center
American University of Beirut Bliss Street, PO Box 11-0236
Riad El-Solh 1107-2020, Lebanon
Tel: +961-1-374374 ext 4508 /4578
fax: +961-1-744460.
This research has been reviewed according to American University of Beirut Institutional Review Board (IRB) procedures for research involving human subjects. If you want to contact someone independent of the research team for questions, concerns, or complaints about the research; questions about the subjects' rights; to obtain information; you can call or email the IRB on the following address:

American University of Beirut
PO BOX: 11-0236 F15
Riad El Solh, Beirut 1107 2020 Lebanon
Tel: 00961 1 374374, ext: 5445
Fax: 00961 1 374374, ext: 5444

Email: irb@aub.edu.lb
Direct Line: 000961 1 738024
Direct Fax: 000961 1 738025

Participant should be:

Any male of female aged 18-64;
Resident of Warhanieh;
Wholly or partially responsible for the household income earning and/or decision-making.

In case of illiterate participant, a witness independent of the research team will be present during the consenting process and sign the consent form.

If the above criteria apply, please select your choice below

"Agree" indicates that:

you have ready the above information

you voluntarily agree to participate

you are at least 18 years of age

“Disagree” indicates that you do not wish to participate in the research study.

- ☐ Agree
- ☐ Disagree

Interviewee’s signature: ____________________________

Participant’s signature: ___________________________

Witness signature: __________________________

Date: ______________________

Time: ____________________

Participants will be provided with a copy of the consent form.

Appendix

7. Contingent Valuation Survey Form in English as Approved by the Institution Research Board (IRB)

SURVEY QUESTIONNAIRE FOR ASSESSING WILLINGNESS TO PAY AND ADOPT

Date of interview: ________________________

Name of interviewer: _____________________

Section I

A. Major Concerns:

A.1 What is your level of satisfaction for each of the following on a scale from 1 to 5 where 1 is strongly satisfied and 5 is strongly dissatisfied? Rank the sectors that you think are more important (from 1 to 5).

	Strongly Satisfied (1)	Some-how Satisfied (2)	Neither Satisfied nor dissatisfied (3)	Somehow dissatisfied (4)	Strongly dis-satisfied (5)	Rank by sector (1=Most important 5=Least important)
Disposal of waste water						
Access to clean drinking water						
Solid waste collection and disposal						
Access to public transportation						
Electricity Supply						

A.2 To what degree do you agree with each of these statements on a scale from 1 to 5 where 1 is strongly agree and 5 is strongly disagree?

	Strongly agree (1)	Somehow Agree (2)	Neither agree nor disagree (3)	Somehow disagree (4)	Strongly disagree (5)
. There is a problem of nuisance from solid waste disposal in this area					
. Final disposal of waste is currently environmentally safe and acceptable					
. The country has a good waste management system					

A.3 Do you know where the waste is taken after it leaves your neighborhood?
a) Yes
b) No

A.4 Are you concerned about whether the final disposal is environmentally safe and acceptable?
a) Yes
b) No

Section II

B. Contingent Valuation

Through their everyday activities (cooking, farming etc…) households produce a lot of solid waste (e.g. vegetable leftovers, yard waste, agricultural residues after harvest etc…). This waste, if not properly managed and disposed of, may create public hygiene (flies, bad odors, rubbish in the streets etc…) and health (e.g. lung cancer, microbial diseases etc…) problems. Recently, the events in the Naameh landfill brought to light all the problems of bad solid waste management. In addition, soil quality is deteriorating in Lebanon, thus the produced crops are of low nutritional value which directly affects our health.

vermicomposting is relying on specific types of earthworms (red) to convert organic solid waste (e.g. from food leftovers) into high-quality organic compost that could be used instead of chemical fertilizers to provide four times more nutrients to grown crops compared to compost, and also instead of pesticides in controlling crop pests, weeds and diseases.

One effective way of reducing the mentioned problems could be "vermicomposting" which can be applied at both small and large scales of farming operations. This would benefit the society in two ways: (1) reducing the public health and hygiene problems described above, and (2) reducing the reliance of farmers on agrochemicals (e.g. fertilizers, pesticides etc…) that may contaminate our water sources, food supplies and soil in ways that are harmful to human health and the environment.

vermicompost use is widespread nowadays in Europe and North America. In India, vermicompost initiatives have contributed to environmental protection, local economic development, and enhanced social wellbeing of the participating communities. It is newly applied in Turkey, and Iran which have 5 and 16 large scale production facilities.

In Lebanon, this technology is not yet practiced. Yet to implement this technique on a large scale, costs are involved. These include waste collection and selection, transportation, setting up a compost production facility, production of the organic compost and its distribution to local farmers. This could be done at the level of municipalities where they would be in charge of the whole process. Therefore to finance such an initiative and raise the necessary capital, municipalities could collect levies on municipal taxes paid by household within its jurisdiction.

B.1 How much do you think vermicomposting is interesting?
a) Very interesting
b) Somehow interesting
c) It is bizarre; I don't think the program would work
e) Not worth anything to me

B.2 (If Yes) Would you like to use vermicompost as a fertilizer?
a) Yes
b) No

B.3 Would you carry out vermicomposting at your household to produce your own fertilizers?
a) Yes
b) No

B.4 If such an initiative were in place in your municipality, how much would you be willing to incur additional tax levies per month in payment for it and to make it possible?

Please choose an amount from the below list that best approximates your willingness to incur extra tax.

- ☐ $ 0

☐ $ 1	☐ $ 8	☐ $ 15	☐ $ 22	☐ $ 29
☐ $ 2	☐ $ 9	☐ $ 16	☐ $ 23	☐ $ 30
☐ $ 3	☐ $ 10	☐ $ 17	☐ $ 24	☐ $ 31
☐ $ 4	☐ $ 11	☐ $ 18	☐ $ 25	☐ $ 32
☐ $ 5	☐ $ 12	☐ $ 19	☐ $ 26	☐ $ 33
☐ $ 6	☐ $ 13	☐ $ 20	☐ $ 27	☐ $ 34
☐ $ 7	☐ $ 14	☐ $ 21	☐ $ 28	☐ $ 35

Protest Responses (Why They Would Not Pay):

a) I cannot afford to pay at this time
b) It is unfair to expect me to pay
c) I am opposed to new government programs
d) The government should pay for it
e) I think this program would benefit me but other people could pay
f) I don't believe in vermicomposting
g) Others: specify ____

B.5. Would you carry out vermicomposting at your household if you were able to generate a revenue of 3 dollars per 500 grams?

a) Yes
b) No

B.6 Do you currently sort your waste?

a) Yes, all the waste
b) Yes, part of the waste
c) No --------- Go to B.6.1 and B.6.2

B.6.1. (if the answer to B.5 was c) Would you sort if the municipality pays you $5 per month?

a) Yes
b) No

B.6.2. (if the answer to B.5.1 was c) If the municipality charges you a fee of $5 for not sorting, would you sort?

a) Yes
b) No

B.7. Would you prefer that the municipality handles the vermicomposting?

a) Yes
b) No

B. 8. Into how many categories do you prefer the sorting to be done?

a) No sorting required ----- (Go to next question)
b) 2 (recyclables, non-recyclables)

c) 5 (paper, glass, metals, plastic, other) ----- (Remember that this will occupy more space at your house)

B.8. How do you prefer the sorting to be done?

a) Home sorting

b) Curbside collection of un-sorted waste to be sorted by the facility at the municipality

B.10. How many times do you prefer the collection of waste to be done?

a) 2 times per week

b) 4 times per week

Section III

C. Further Questions

C.1. Do you own lands?

a) Yes

b) No ---- skip to section VI

C.2. What is the total area of the land you own?

____

C.3. Which kinds of fertilizers do you apply?

a) Chemical

b) Organic

C.4. Which kind of organic fertilizers?

a) Goat b) Cow c) Poultry d) Compost

Section IV

D. Demographics

D.1 Household identification:

a) Head of household

b) Spouse of head of household

c) Others please describe ___________________

D.2 Gender

a) Male

b) Female

D.3 How old are you?

a) 18 – 24 d) 41 – 50

b) 25 – 30 e) 51 – 68

c) 31 – 40 f) 69 - above

D. 4 Do you live in the village:
a) Regularly
b) In Summer
c) In winter
d) Occasionally/ vacation

D.6 What is your level of education?

- ☐ Never Attended
- ☐ Pre-school
- ☐ Primary
- ☐ Intermediate – general
- ☐ Intermediate – vocational
- ☐ Secondary – general
- ☐ Secondary–vocational/technical (BT/LP)
- ☐ College or University – BSc
- ☐ College or university – MSc/PhD
- ☐ Tertiary – vocational/technical (e.g. TS/LT)
- ☐ Other:____________
- ☐ I Don't Know/refuse to answer

D.7 What is the highest education degree received in this household?

- ☐ Never Attended
- ☐ Pre-school
- ☐ Primary
- ☐ Intermediate – general
- ☐ Intermediate – vocational
- ☐ Secondary – general
- ☐ Secondary–vocational/technical (BT/LP)
- ☐ College or University – BSc
- ☐ College or university – MSc/PhD
- ☐ Tertiary – vocational/technical (e.g. TS/LT)
- ☐ Other:____________
- ☐ I Don't Know/refuse to answer

D.8 What is the household income range? (All incomes of the family members even if have someone working abroad)

- ☐ US$ 0 – US$ 500
- ☐ US$ 600 – US$ 800
- ☐ US$ 900 – US$ 1500
- ☐ US$ 1,600 – US$ 2,000
- ☐ US$ 2,100 – US$ 3,000
- ☐ US$ 3,100 and Above

D.9 In which sector do you work?
a) Private
b) Public
c) Others

D.10 How much do you spend per month on the household?

- ☐ $ 150 – 200
- $ 300 - 400
- ☐ $ 500 – 800
- ☐ $ 900 – 1500
- ☐ $ 1600 – 2,000
- ☐ $ 2,100 – 3,000
- ☐ $ 3,100 – Above
- ☐
- ☐

SectionV

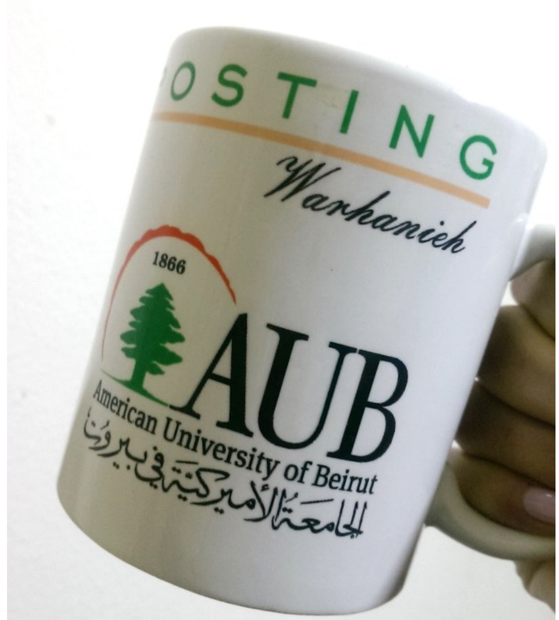
E. Observations

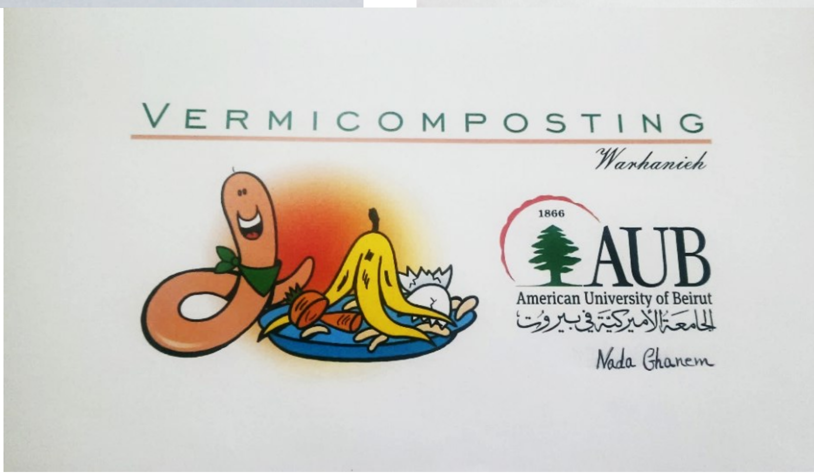
E.1 House situation:
a) New b) Old
E.2 House size:
a) Big b) Small
E.3 Conditions of the furniture:
a) Modest b) High quality
E.4 Furniture Situation:
a) Fully furnished b)Semi furnished

"Thank you for your contribution to this survey."

F.1. If there is a need to seek your advice further, may we contact you again?
a) Yes
b) No

Appendix 8. Distributed mugs on the households that agreed to Participate in the Survey



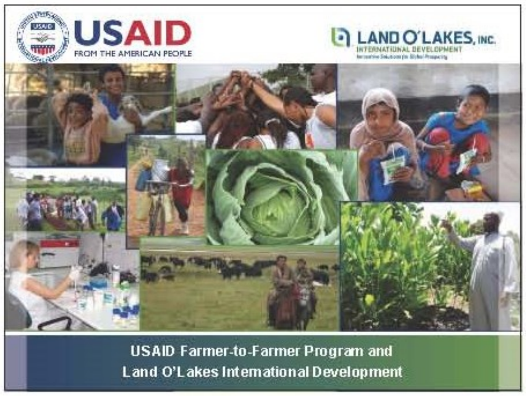


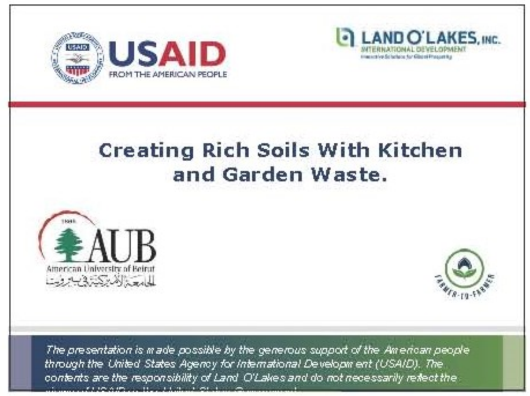
Appendix 9. Pictures taken during the surveying in Warhanieh

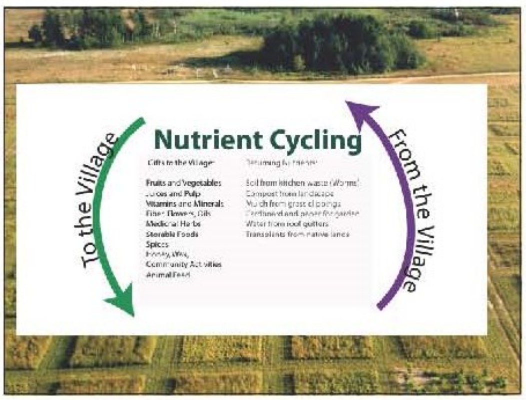
Pictures taken with two of the participants in the survey, the lady in the lower photo was preparing tomato paste at her home garden.

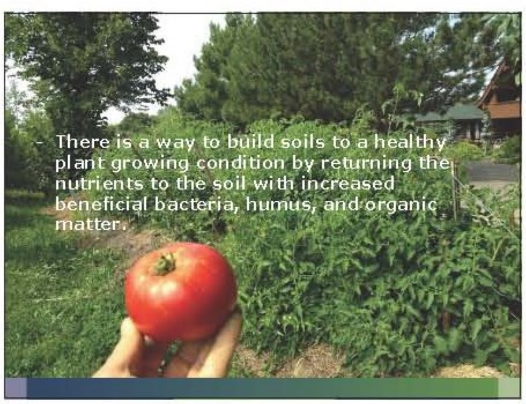
The team that helped me in conducting the surveys at the village are Mohammad, Nour, Rawan and Amina. They said the experience in Warhanieh was unique and developed their communication skills. They were surprised to notice that almost all the households expressed their love to the resident researcher. As they told me that some people did not want to participate in the survey but when they knew it was for my project they changed their minds and welcomed them. Also they met some people who were leaving their home in a hurry and when they told them it’s a study for me, they came back in and answered the whole survey. A lovely old lady who refused to participate insisted on the surveyor the instead of ticking “Do not want to participate” he writes on her survey sheet a statement to express her love to me. It said: “My dear Nada I love you very much but sorry I cannot participate in the survey”. The surveyors also appreciated the generosity of Warhanieh people, they used to come back with their pockets and hands full of different kinds of food.

Appendix 10. The Presentation Given by the Expert Dan Halesy at workshop Warhanieh









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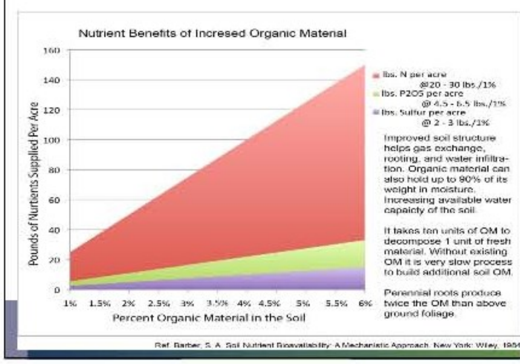
Composting

- Taking plants and piling them up in stacks to decompose.
- Issues:
  - It takes a lot of plants to create a pile that will heat up for decomposition and the heat that will kill disease and pests.
  - Large areas need to be used for static pile composting.
  - Smaller areas can be used if someone turns the soil every few days. Its labor intensive.
- This is good and is done all over the world, yet there is another step that creates biodiversity and a stabilized source of nutrients.

LAND O'LAKES, INC.
INTERNATIONAL DEVELOPMENT

An alternative is to use earth worms to accelerate the process and have choices.

1. **make the nutrients available for *immediate* use for the plants with Worm Tea**
2. **Make soil additives that create long-term time-released fertility, increased beneficial organisms, and biodiversity with worm castings.**
3. **Increase the amount of raw waste processed by growing more worms.**
4. **Grow more food in smaller spaces**



Ref. Barber, S. A. Soil Nutrient Bioavailability: A Mechanistic Approach. New York: Wiley, 1984

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INTERNATIONAL DEVELOPMENT

This is called Vermiculture

Using the ecological functions of the soil organisms that already exist, to return to the soil the nutrients ready for plant use, that we harvested for our use.

This way:

- we build a resilient soil resource.
- we use a system supported by nature.
- we use organic materials otherwise wasted.
- we rebuild depleted soils with living capital.

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INTERNATIONAL DEVELOPMENT

So what are the benefits of vermiculture?

- To increase the ***carrying capacity*** of the soil.
- To build soil as natural capital, a valuable asset, not to be eroded.
- Close the loop on nutrient cycling so our soil becomes richer each year, even after a harvest.
- Build a resilient source of nutrients held in the soil by the cycling of microorganisms.
- Reduced waste on the landscape
- It creates a valuable product for those not able to create it.

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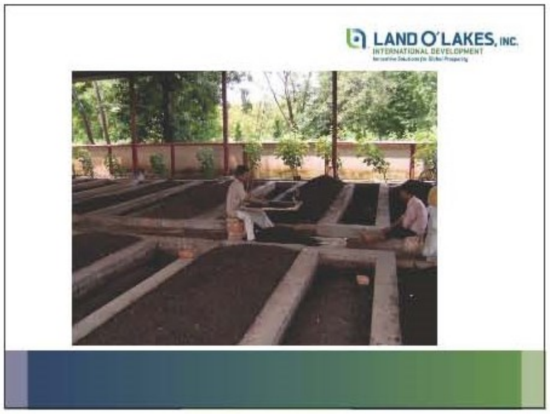
INTERNATIONAL DEVELOPMENT

Vermiculture Systems

- **Lateral Worm Beds for harvesting worm castings**
- **Vertical Worm Beds for collecting worm tea.**
- **Row beds to propagate worms for sale or feed.**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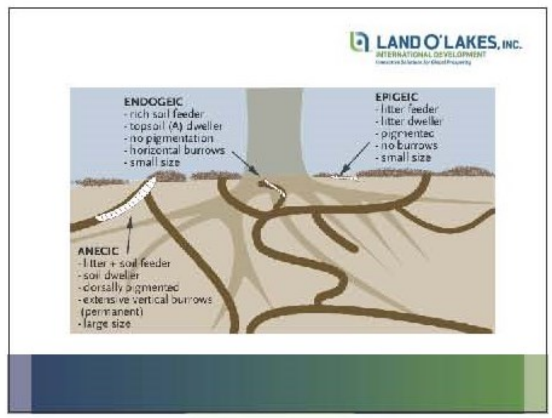
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ENDOGEIC
- rich soil feeder
- topsoil (A) dweller
- no pigmentation
- horizontal burrows
- small size
EPIGEIC
- litter feeder
- litter dweller
- pigmented
- no burrows
- small size
ANECIC
- litter + soil feeder
- soil dweller
- dorsally pigmented
- extensive vertical burrows (permanent)
- large size


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Figure 25 Seminar in Warhanieh for sharing experience with the permaculture expert, it shows part of the participants

Appendix 11. The visit of the professor from University of California Davis to Warhanieh

Professor Pramod Pendey from University of California Davis at the middle. I took him to the study area (Warhanieh) where we visited few households of those that participated in my study. Showed him the household vermicomposting setups and explained the way it works. Professor Pendey expressed his interest in my work and thought it was very important. Also, he was happy with the interaction with people of Warhanieh and the positive feedback on the project. Participants were very generous in offering food, fruits, and desserts. They explained to him how they take care of the worms and what they feed them, also they shared with him their experience with earthworms and how this project changed the way they view them. The visits were informal, friendly, and short.

Appendix 12. Description of the irrigation system at the agricultural land in Warhanieh, Chouf

Figure 26 Figure 1 Diversion canal from the Nabaa al-Safa (Safa River)

Figure 27 Irrigation canal pumping station

Figure 28 A farmer opens a diversion valve

Figure 29 Furrow for irrigation

Appendix 13. Maps showing the evolution of residential area in Warhanieh and the change towards an individualistic lifestyle.

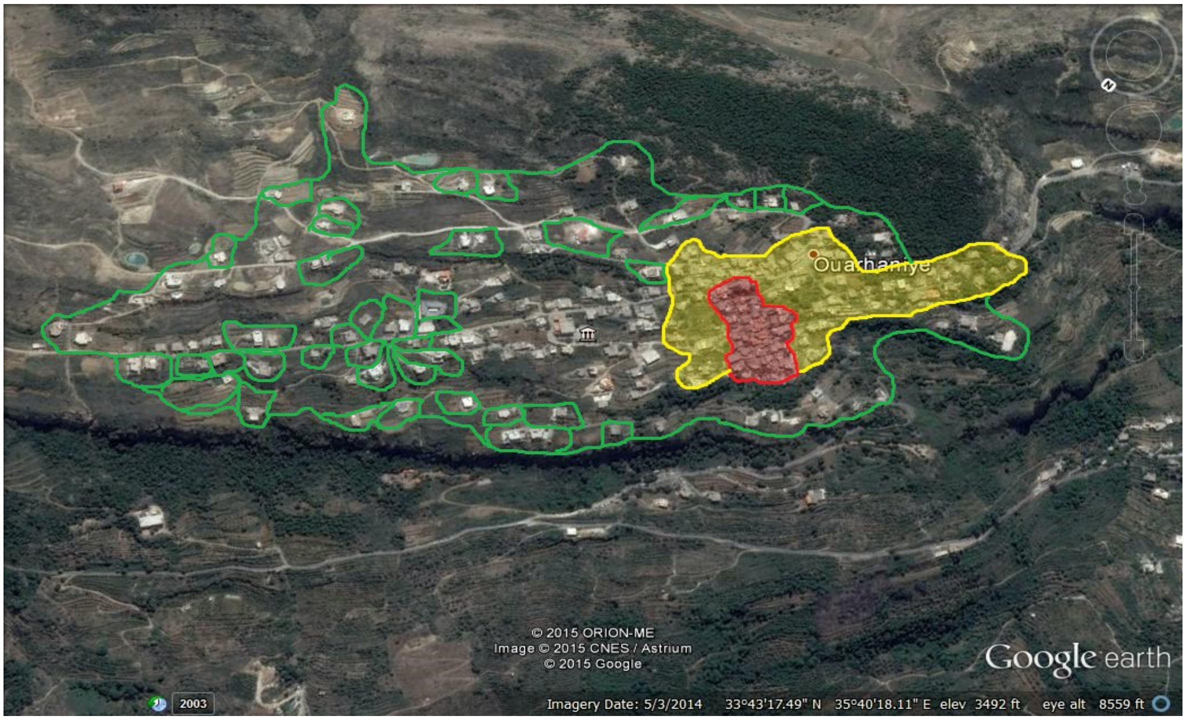

Figure 30 The evolution of the residential area in Warhanieh

Red zone represents the old village where there are no home gardens

Yellow zone represents the semi old region with home gardens of maximum 500 meter

Green zone is the newly expanded village with large home gardens

2. Sara Moledor's MS Thesis

Vermicomposting Research at American University of Beirut (AUB), Beirut, Lebanon

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

AMERICAN UNIVERSITY OF BEIRUT

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

by
SARA MOLEDOR

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Science in Environmental Sciences
of the Interfaculty Graduate Environmental Sciences Program
Ecosystem Management
of the Faculty of Agricultural and Food Sciences
at the American University of Beirut

Beirut, Lebanon
February, 2014

AMERICAN UNIVERSITY OF BEIRUT

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

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Date of thesis defense: February 25th, 2014

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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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CHAPTER 1

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).

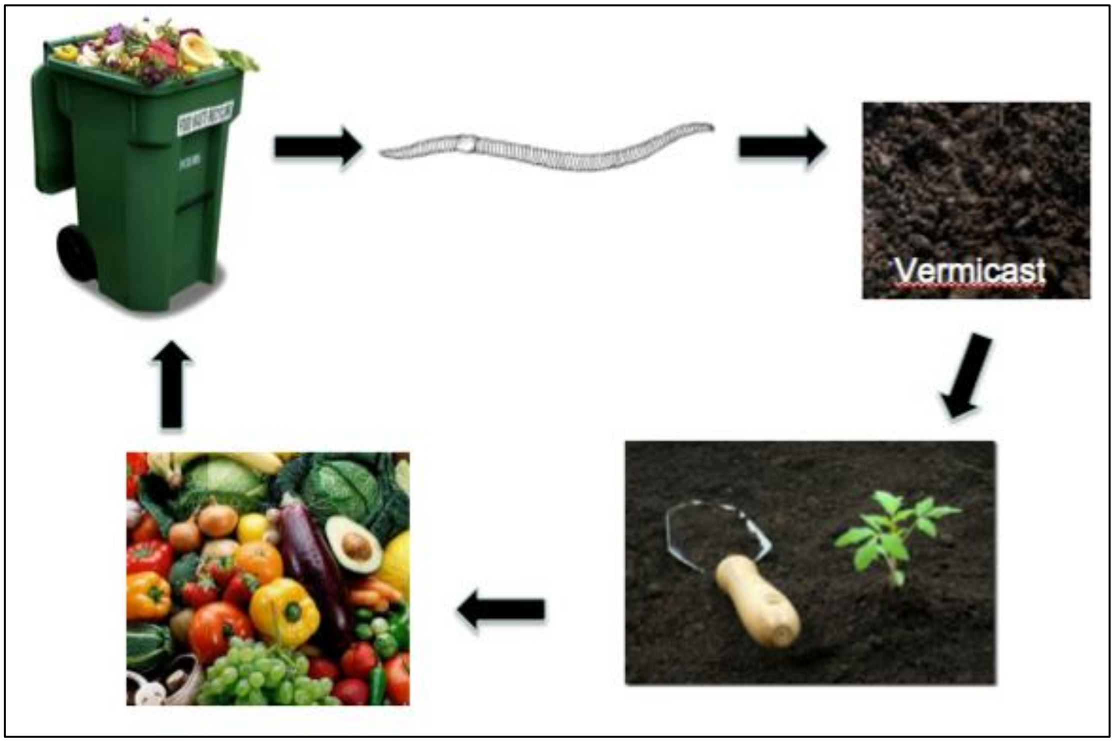


Figure 1: Circular Use of Resources

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

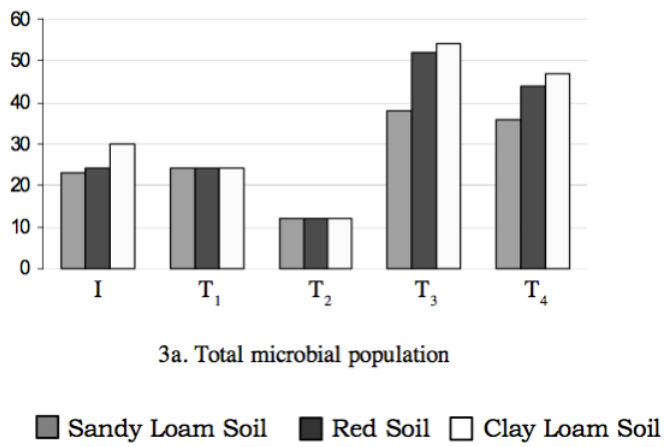
The above improvements are linked to subsequent improvements in water holding capacity. Vermicasts have a high surface area, providing strong absorbability (Atiyeh et al, 2000) and are therefore capable of storing water in higher quantities. They have been shown to increase total water holding capacity 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).

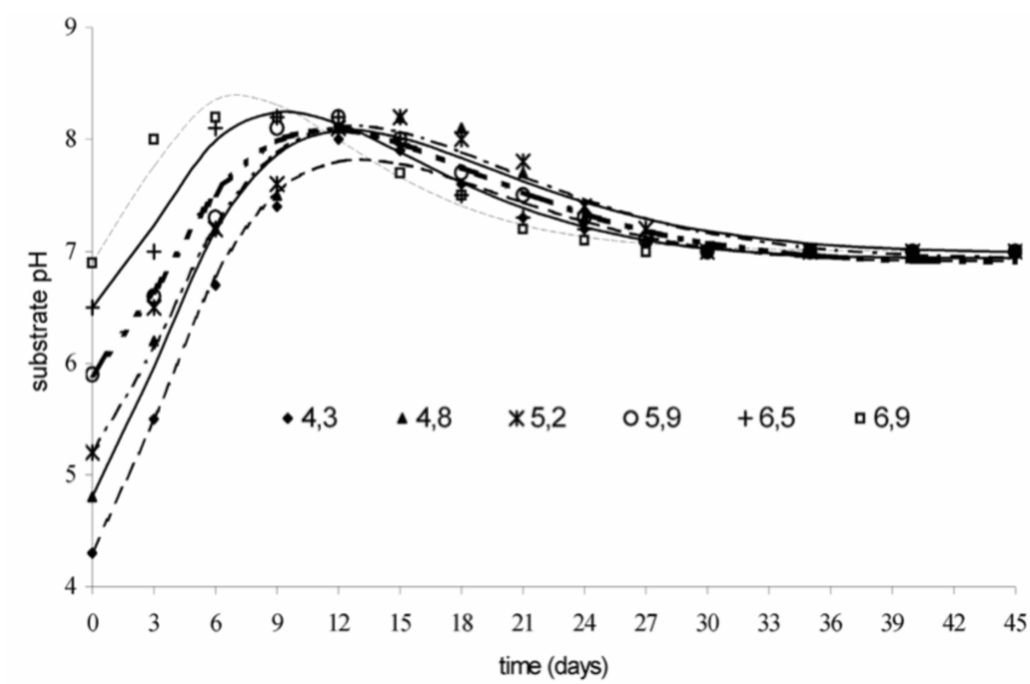


Figure 3: Variation of substrate pH with different initial substrate pH (from Singh et al, 2005)

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.

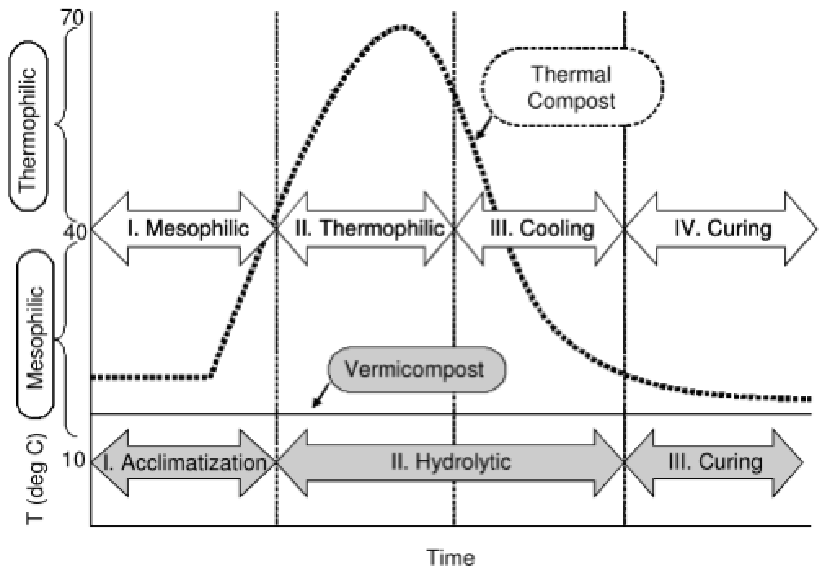


Figure 4: Time vs. Temperature for Compost and Vermicompost (from Jack & Thies, 2006)

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.

  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.

4.1.1.2 Collection Analysis

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.

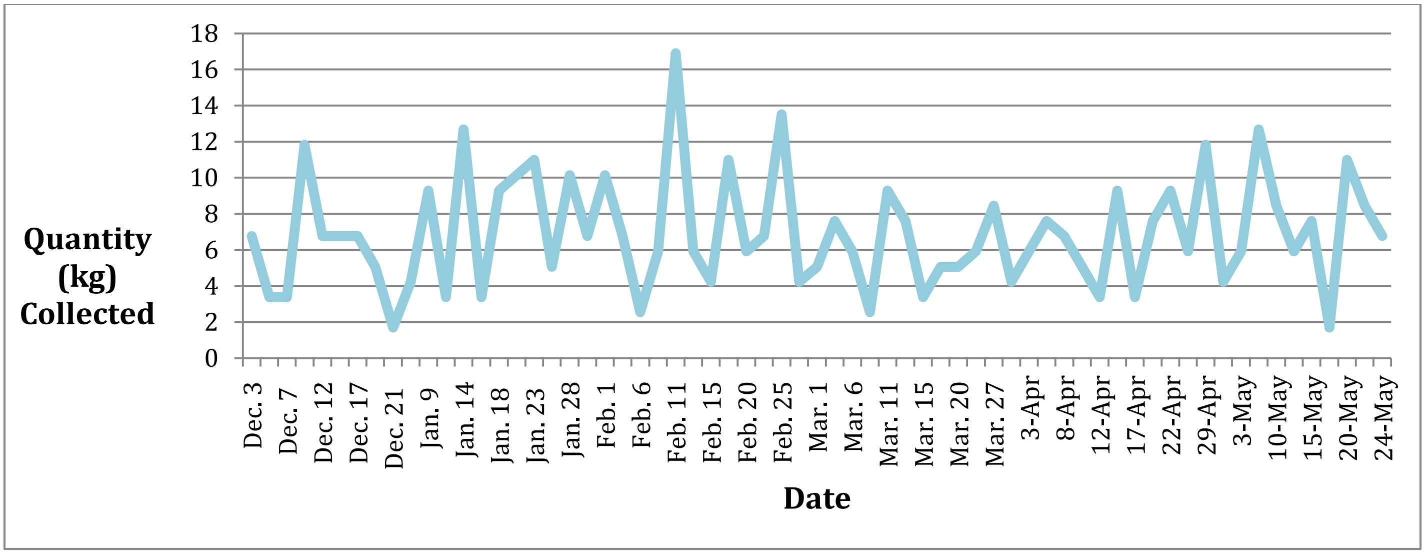


Figure 5: Waste Generation Patterns

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.

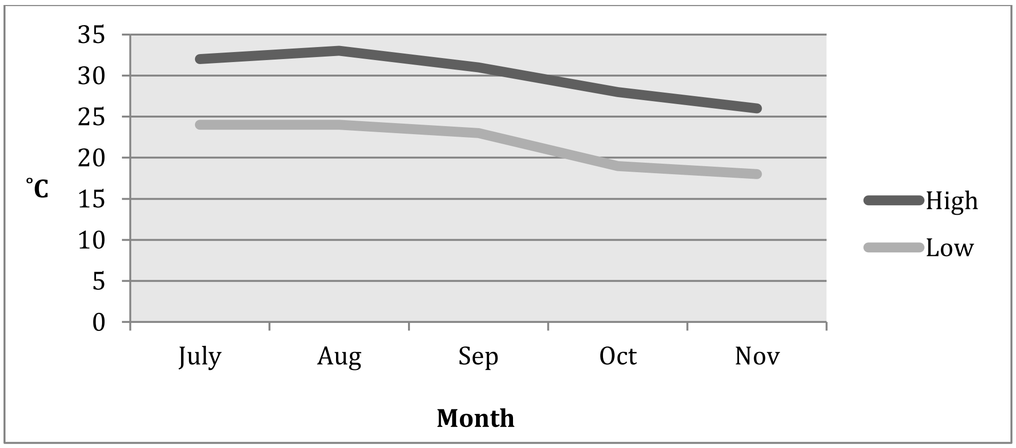


Figure 6: Average Temperatures in Batloun (July – November 2013)

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.

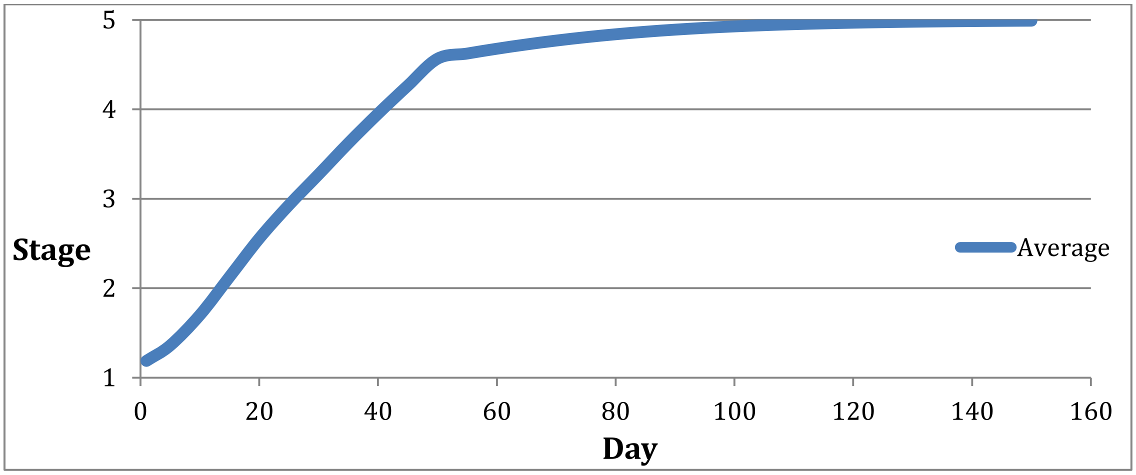


Figure 7: Average vermicompost conversion over time

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 20^{th} 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).

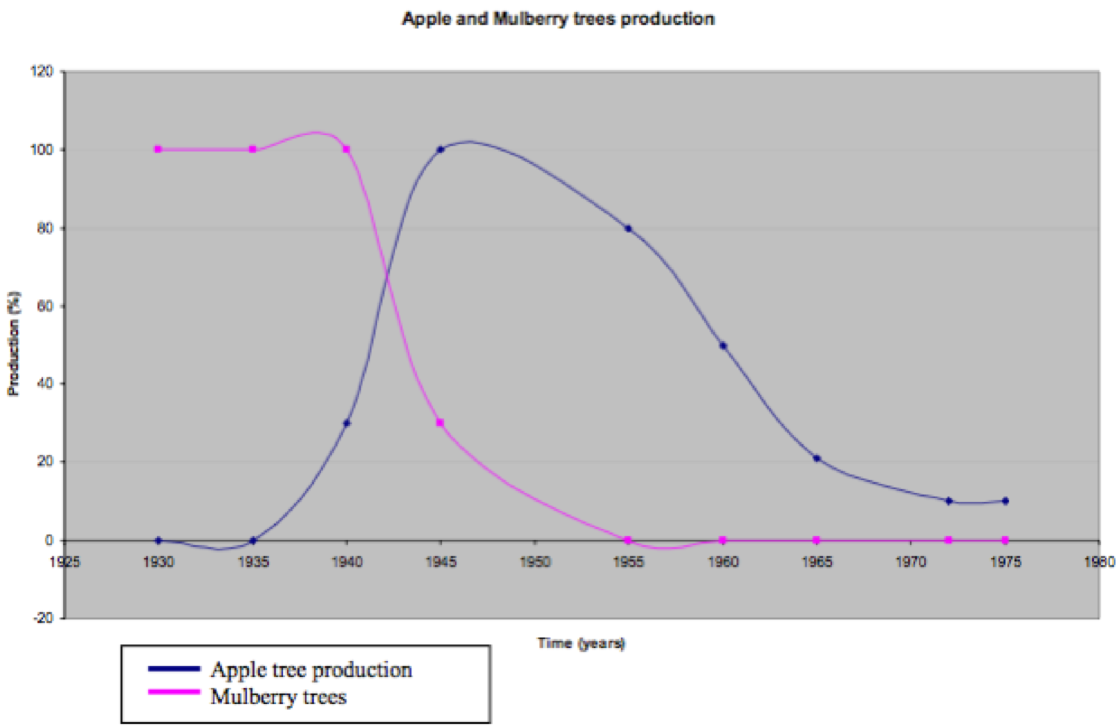


Figure 8: Apple and Mulberry Trees Production (from Rachid, 2007)

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).

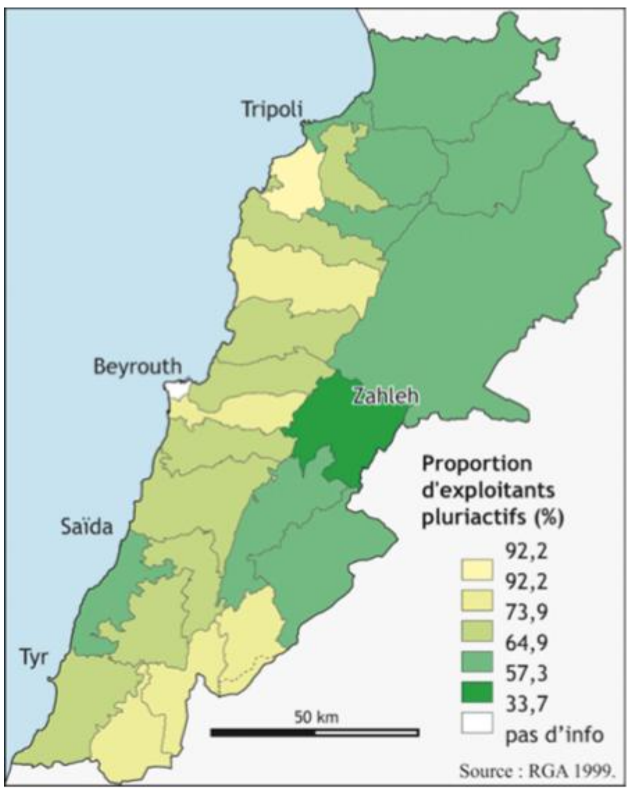


Figure 9: Map of Agricultural Diversification in Lebanon (from Asmar, 2011)

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.

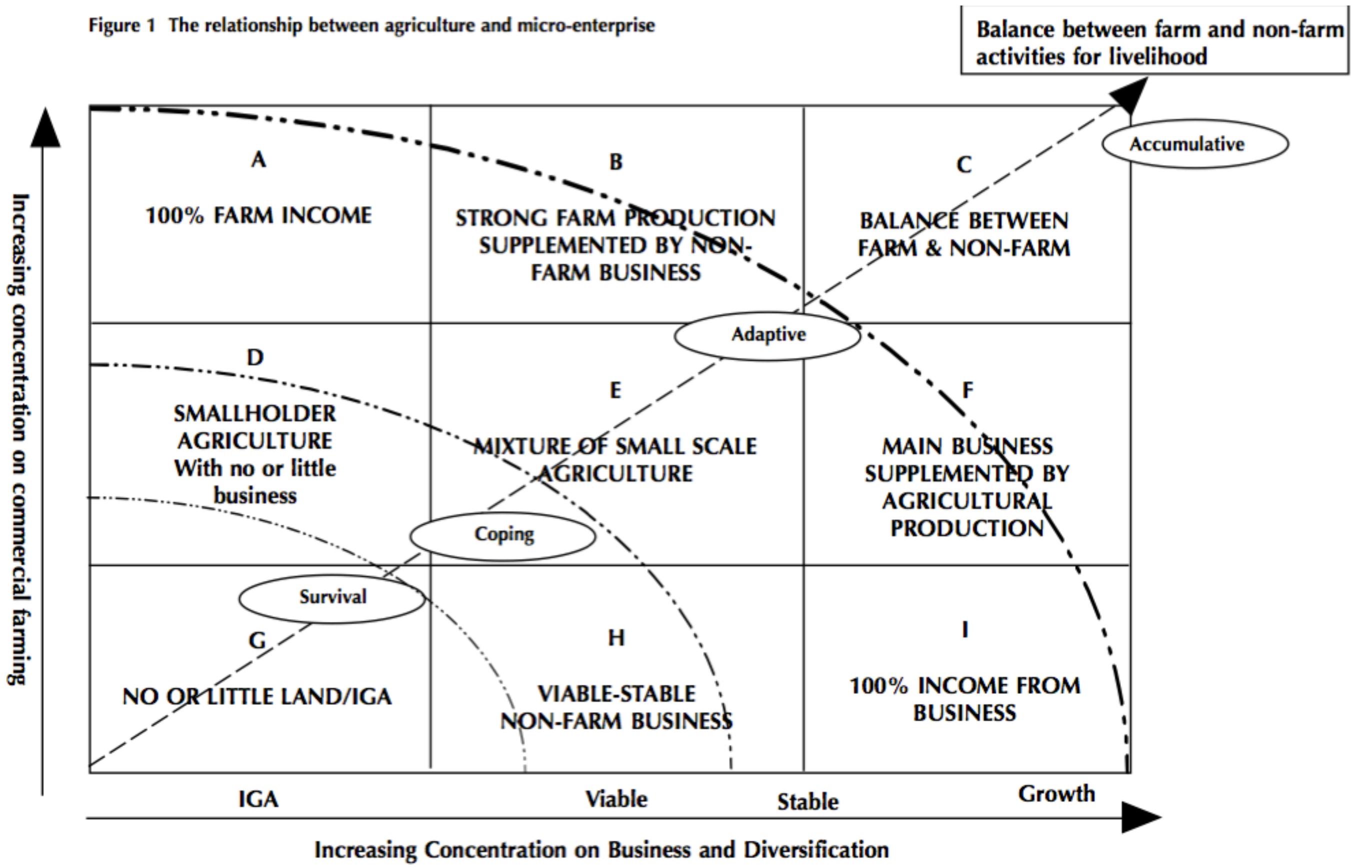


Figure 10: The Relationship Between Agriculture and Micro-Enterprise (from Orr & Orr, 2002)

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.

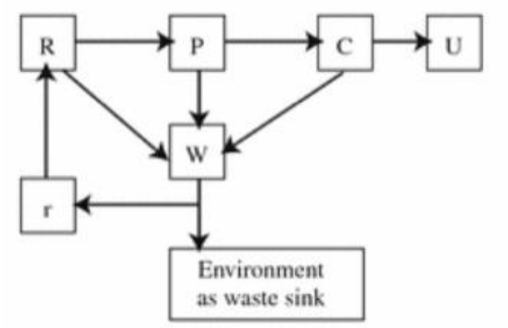


Figure 11: The Simplified Circular Economy (from Andersen, 2007)

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.

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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 عمـ لـ 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 لى .مـ تـ عـ فـ نة أو فـ ا سدة كـانـ 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 ناديـ 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

.ممـ تـ لـ ئ 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

. صـ غـ 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

ضع قفصاً فارغاً آخرا فوقه من أجل الظل والحماية.

قم بالمراقبة مرة واحدة كل أسبوعين. إحفر بلطف في زاوية القفص لكشف عن النفايات. تحقق أنها متحللة وأن الديدان هي بحالة صحية جيدة ونشيطة. قد تبدأ النباتات بالنمو، ولكن يمكن أن تترك في مكانها.

وإذا كانت المحتويات جافة، أضف بعض الماء. إذا كان المناخ حاراً وجافاً، قد تحتاج إلى إضافة الماء في أكثر الأحيان.

ينبغي أن يكون سماد الدود دائماً رطب قليلا.

بعد حوالي شهرين، تحقق من محتوياتها. إذا بدت مثل الاوساخ، ولها نسيج ناعم، وداكنة اللون فمن المحتمل أن تكون جاهزة للحصاد. من المحتمل أن يكون هناك بعض النفايات الصلبة، مثل الحفر وقشر البيض، التي لا تتحلل تماما. وهذا أمر طبيعي.

إذا كنت لا تزال تستطيع أن ترى وتحدد قطعاً من المنتجات، دع سماد الدود يكمل عمله لبضعة أسابيع أخرى.

الحصاد

ضع ورقة من البلاستيك على الأرض أو على طاولة في الهواء الطلق. صب أو قم بجرف محتويات القفص على ورقة من البلاستيك. إذا استخدمت مجرفة، إحفر بعناية حتى لا تجرح الديدان.

أزل على قدر الإمكان ديداناً وبيضاً من سماد الدود. أضفها إلى القفص الأم أو إلى مجموعة جديدة من النفايات.

سيكون أي من الديدان أو البيض المتبقي في سماد الدود بمثابة فائدة مضافة للمستهلك.

يمكن إزالة المواد الغير متحللة ووضعها في قفص جديد لمزيد من التحلل.

دع سماد الدود يجف في الشمس.

ضعه في كيس وقم بتسميته.

على الارجح أن مادة القماش تحمل العديد من الديدان والبيض. ويمكن إعادة استخدامها في قفص جديد.

التطبيق

أما النباتات المحفوظة بوعاء، فقم باستبدال ما يقرب من 15٪ من التربة في الوعاء بسماد الدود واخلطها.

لحديقة أو حقل ما قبل عملية البذر، إنشر سماد الدود وإدمجه في التربة. تتراوح الجرعات الموصى بها بين ٢-٥ طن للهكتار الواحد.

إذا تم بالفعل زرع النباتات، انشر سماد الدود، إدمجه حيثما كان ذلك ممكنا، ولكن على خلاف ذلك دع السماد يظهر على السطح.

إذا كان قد تم زرع الشتلات، أضف حفنة صغيرة من سماد الدود في الحفرة مع النبات.

لا تقلق إذا كان هناك الديدان في سماد الدود. الديدان هي جيدة للتربة.

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%.

PART 3

BIRZEIT UNIVERSITY

Developing and Integrated Approach for Assessment and Utilization of Biomass for Improving the Sustainability of a City

Objective 2:
Execute A Windrow Composting Research at Birzeit University

Prepared by

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April 2015

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Abstract

This study is being carried out to investigate the feasibility of a windrow composting pilot for domestic organic waste recycling, in order to overcome the problems related to waste collection and disposal and their negative impacts on human and environment health. The study aimed to reduce the amount of waste, promote recycling, and protect human and environment from pollution risks. The main objective of this study is conducting a scientific experiment by making yard compost and to assess the quality of the compost for land use. Research consisted from 5 piles with 5 different mixes, selected ratio was (2:1) ,Amir Hossein Nafez, et al., 2014, the mixes was “Organic + horse Manure + Saw dust”, “Organic + horse Manure”, “Organic + Sludge + Saw dust”, “Organic + Sludge”, “Organic + Saw dust only”. Mixtures quality was determined prior to composting in the BZU laboratory for all parameters. During composting, the process was controlled by regular measurements of moisture content, temperature and pH. Upon completion of the composting process after 3.5 months, the compost maturity was tested, all laboratory results showed that the compost quality conformed to USEPA regulations, E.Coli, Salmonella, and fecal coliform counts except for pile No. 3 (Organic + Sludge + Sawdust) . An overview of laboratory measurements is provided in Appendix 3. In terms of total coliform all laboratory results showed that 95% removal efficiency was achieved. Concluded that the composting will be effective in summer times where temperature is high and moisture content can be controlled better. Many difficulties were faced due to conducting this experiment in winter days. Whereas Pile No. 1 (Horse Manure, Organics, & Sawdust) lab results showed it’s the most pile match with the USEPA standards.

1. Background

1.1. Aim of the Study

This study is being carried out to investigate the feasibility of a windrow composting pilot for domestic organic waste recycling, in order to overcome the problems related to waste collection and disposal and their negative impacts on human and environment health. The study aimed to reduce the amount of waste, promote recycling, and protect human and environment from pollution risks. Composting is a basic element of Integrated Solid Waste management, ISWM, strategy which means the aerobic biological degradation of organic materials to produce carbon-dioxide, water, minerals and stabilized organic matter.

1.2. Objectives

The main objective of this study is conducting a scientific experiment by making yard compost in order to;

- Learn the steps of composting process
- Understand and observe the factors that affect composting process
- Determine amount of reduction of waste due to composting.
- Assess the quality of the compost for land use.

1.3. Research Question and Identified Problems

Palestinian towns and villages suffer from continuously problems of solid waste collection and disposal. Weak awareness of concerns of MSWM leads to misshaped landscape, as a result of accumulation of garbage in the streets. Garbage is collected and disposed in a wild unsanitary dump site; odors and smoke are seen all year around. The wind carries pollutants over the households creating health problems for human, animals, and plants. Leachate from the dumpsite forms one major pollution source for soil and ground water. This situation leads to a need for a study focused on the hypothesis that applying organic waste recycling through a pilot scale windrow composting for environmental benefits.

2. Background and Literature review

Composting is the aerobic biological degradation of organic materials to produce a stable humus-like product (EPA, 1995). Naturally biodegradation is an ongoing biological process. Food scraps rotting in a trash can be an example of natural and slow uncontrolled decomposition.

Controlling the environmental conditions during the composting process can significantly increase the rate of degradation and derive the most benefit from this natural process to obtain high quality compost (Illmer et al., 1997).

The end product of the compositing process is compost, in addition to water and carbon dioxide as by-products. Weed seeds and pathogens should be absent in the good compost. Temperature needed to reduce pathogens is 55º or over for 15 d at least, according to USEPA’s recommendations (Yaghmaein et al., 2005).

2.1. Factors affecting composting process:

2.1.1. C: N ratio

Some materials in solid waste are lack to nitrogen, so the nitrogen is a limiting factor in the composting process. The carbon to nitrogen ratio is considered critical in decomposition rate. The optimum initial ratio should be (30:1) carbon: nitrogen (EPA, 1995; Trautmann et al., 1997; Yaghmaeian et al., 2005). Higher ratios restrict the process because higher ratios do not provide sufficient nitrogen for optimal growth of the microbial populations. While lower ratios generate noxious odors (Trautmann et al., 1997).

2.1.2. Moisture:

Microorganisms within the compost pile need water. The ideal water content in the compost pile 50-60 % by weight (Fabrizio, et al., 2008; Trautmann et al., 1997; EPA, 1995). Water content must not be proceed this ratio to prevent leachate which creates potential water pollution and odor problems, in addition to anaerobic conditions because excess moisture decrease the porosity required for air flow.Since the amount of water produced from the decomposition process is less than that evaporated, water must be added to keep moisture at ideal levels (EPA, 1995).

2.1.3. PH:

During the composting process, the pH values vary between 5.5 and 8.5. The ideal range of pH for most efficient compositing is between 6 and 8 (EPA, 1995; Schneider et al., 2001).

2.1.4. Temperature

For measurement of temperature, thermometer was inserted into each pile at different stages. The biological systems activity is temperature sensitive (Schneider et al., 2001). Thus, temperature inside the windrow determines the rate of composting. Microorganisms involved in the composting process are need optimum temperature range between 32 C^{o} and 60 C^{o} (EPA 1995; Schneider et al., 2001).

Higher temperature denaturate microbial enzymes, and increase ammonia and VOCs emission (Comilis et al., 2004; Pagans et al., 2006). Lower temperature inhibits microbial enzymes activity. Consequently, composting rates will decrease in both higher and lower temperatures (Schneider et al., 2001). Stabilization of windrow temperature will occur when providing favorable environmental factors, such as ambient temperature, wind, shadow, and Humidity.

3. Methodology:

The researcher conducted the following activities:

1- Preparation of 5 piles (5 Trenches each one length 25cm x width 20cm and depth 50 cm)

2- Collection of 50 Kg organic waste (food scraps).

3- Selection of different organic Based on Amir Hossein Nafez, et al., 2014, selected ratio is (2:1) to mix the 5 piles as follows:

A- Organic + horse Manure + Saw dust
B- Organic + horse Manure
C- Organic + Sludge + Saw dust
D-Organic + Sludge
E- Organic + Saw dust only

4- Testing of above mixtures for the following parameters as per US EPA standards:
A- Total nitrogen
B- Heavy metals (Pb, Zn, Cd, Cu, Ni)
C- Organic matter
D- N: P: K: C
E- Pathogens (Total coliform, Salmonella, Ecoli, Fecal Coliform) . **Table 1** shows the initial results of the compost testing.

5- Spreading the mixed materials loosely in layers of 15 cm in each pile.

6- Covering the pile by thin plastic sheet.

7- Turning each pile initially for twice a week for 2 weeks using a fork, then once a week for the remaining duration.

8- Measuring Temperature inside the pile and for ambient air and recording them daily using alcohol.

9- Testing moisture content and make the proper control for it.

10- Monitoring the pH value for each pile.

11- Producing compost approximately after 20 weeks from beginning of the experiment.

12- Screening of the compost using a manual sieve of 0.4 cm pores.

13- Sampling of the mature compost by repeating the test mentioned in activity number 4.

14- Performing an analysis to the results of testing and compare them against the EPA standards in order to verify the quality of finished compost.

4. Time Schedule

The study has the following time schedule for conducting the different activities.

Activity Name	Duration (day)	Start	Finish
Literature Review and approvals from university to use the labs and preparing research procedures	15	10/1/2014	10/30/2014
Collecting Organic Materials, Sludge, horse manure & Saw Dust	14	10/31/2014	10/31/2014
Shredding and mixing the materials	19	11/1/2014	11/25/2014
Preparing piles and conducting sampling for initial testing	1	11/26/2014	11/26/2014
Windrow Compost Processing	139	11/26/2014	3/7/2015
Compost Screening, sampling and Testing	1	3/8/2015	3/8/2015

5. Equipment and Facilities:

The following equipment and facilities were used:

- Equipment: Scale, Shovel, Thermometers, Pail, Meter, Plastic sheets, Sign Boards and Car for transporting materials
- Facilities: All parameters analyzed at Birzeit University

6. Results and Discussion

6.1. Initial Results

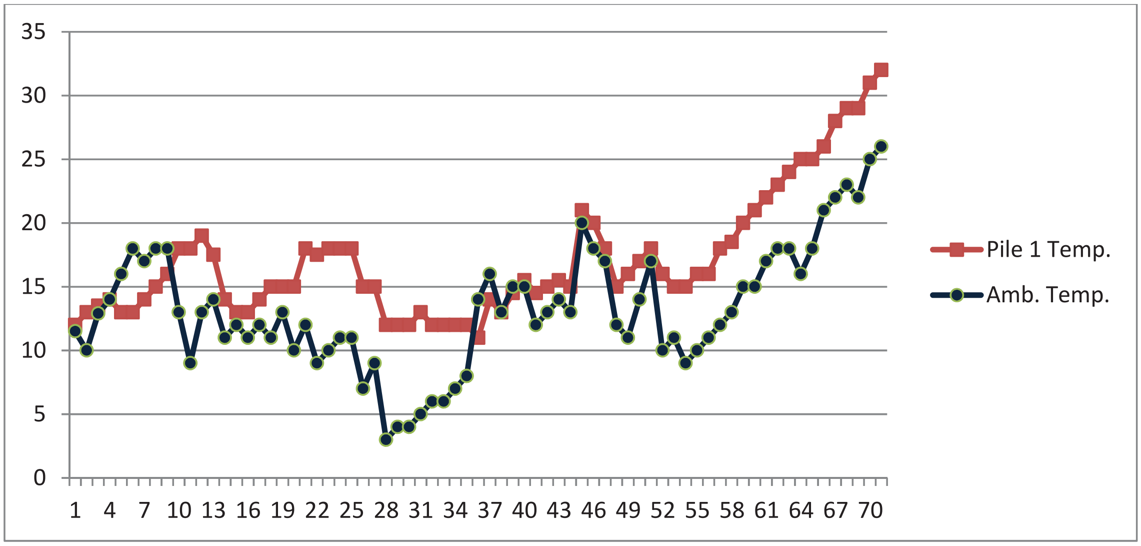
Table 1 shows the initial results of raw mixtures at the beginning of the experiment.

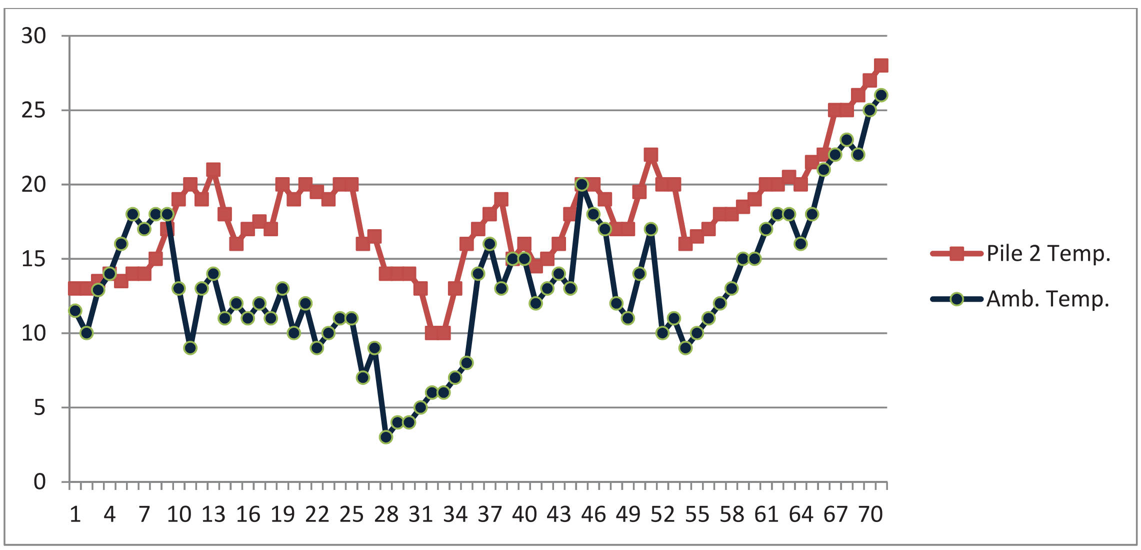
Parameter	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Total nitrogen	.39%	.37 %	.64 %	.90 %	.24 %	1.51 %	.67 %	.32 %
Nitrates	131.2 ppm	378.7 ppm	962.9 ppm	101.3 ppm	1005.9 ppm	10.8 ppm	8.4 ppm	756.9 ppm
Kjeldahl Nitrogen	.39%	.36 %	.64 % ppm	.89 % ppm	.22 %	1.51 %	.67 %	.3 %
Organic matter	20.25%	14.29%	13.22 %	11.25 %	14.11 %	13.68 %	18.15 %	6.94 %
Pb	Not detected	.82 ppm	1.52 ppm	1 ppm	Not detected	2.56 ppm	Not detecte d	Not detecte d
Zn	14.36 ppm	16.32 ppm	69.35 ppm	47 ppm	7.42 ppm	117 ppm	15.4 ppm	3.88 ppm
Cd	Not detected	Not detecte d	.33 ppm	.2 ppm	Not detected	.58 ppm	Not detecte d	Not detecte d
Cu	3.19 ppm	4.52 ppm	259.8 ppm	165.2 ppm	7.10 ppm	446.9 ppm	4.9 ppm	5.3 ppm
Ni	.87 ppm	2.40 ppm	1.77 ppm	1.24 ppm	.33 ppm	3.04 ppm	1.09 ppm	.23 ppm
P	1398 ppm	1070 ppm	2322 ppm	1846 ppm	450.8 ppm	3581 ppm	1878 ppm	438.8 ppm
K	2229 ppm	2400 ppm	1490 ppm	1770 ppm	2297 ppm	1184 ppm	2704 ppm	2663 ppm
Salmonella	Absent / 25g	Absent / 25g	Absent / 25g	Absent / 25g	Absent / 25g	Absent / 25g	Absent / 25g	438.8 ppm
Total coliforms	3500000 cfu/g	570000 cfu/g	730000 0 cfu/g	550000 0 cfu/g	1860000 0 cfu/g	690000 0 cfu/g	380000 0 cfu/g	2663 ppm
Fecal Coliforms	1168000 cfu/g	470000 cfu/g	15000 cfu/g	15000 cfu/g	240000 cfu/g	74000 cfu/g	808000 cfu/g	600 cfu/g
E. coli	220000 cfu/g	16000 cfu/g	5000 cfu/g	10000 cfu/g	10000 cfu/g	20000 cfu/g	190000 cfu/g	30 cfu/g
Carbon	11.75 %	8.29 %	7.67 %	6.53 %	8.18 %	7.93 %	10.53 %	4.02 %

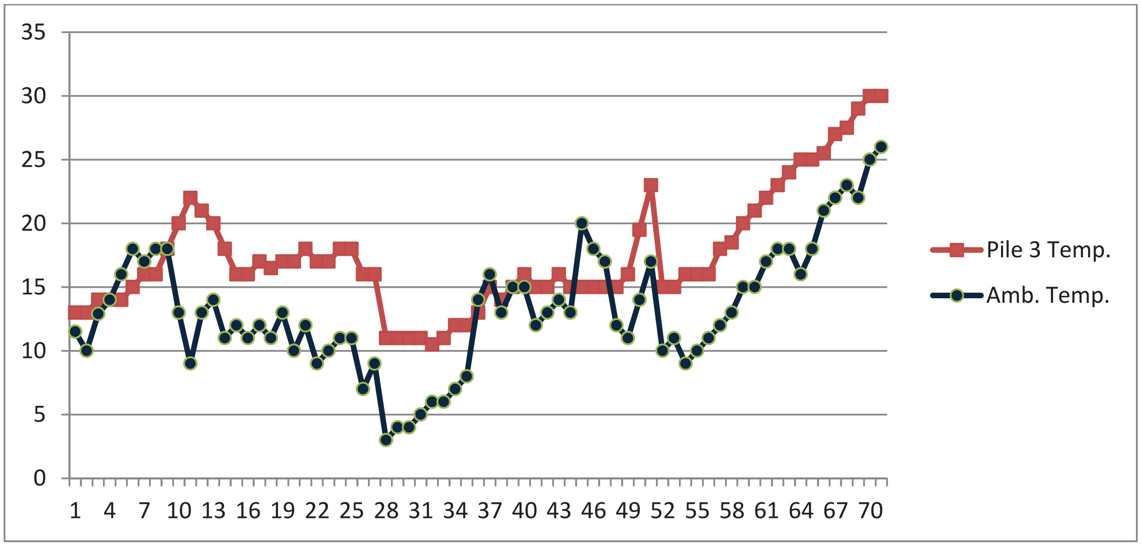
6.2. Periodical Field Measurements

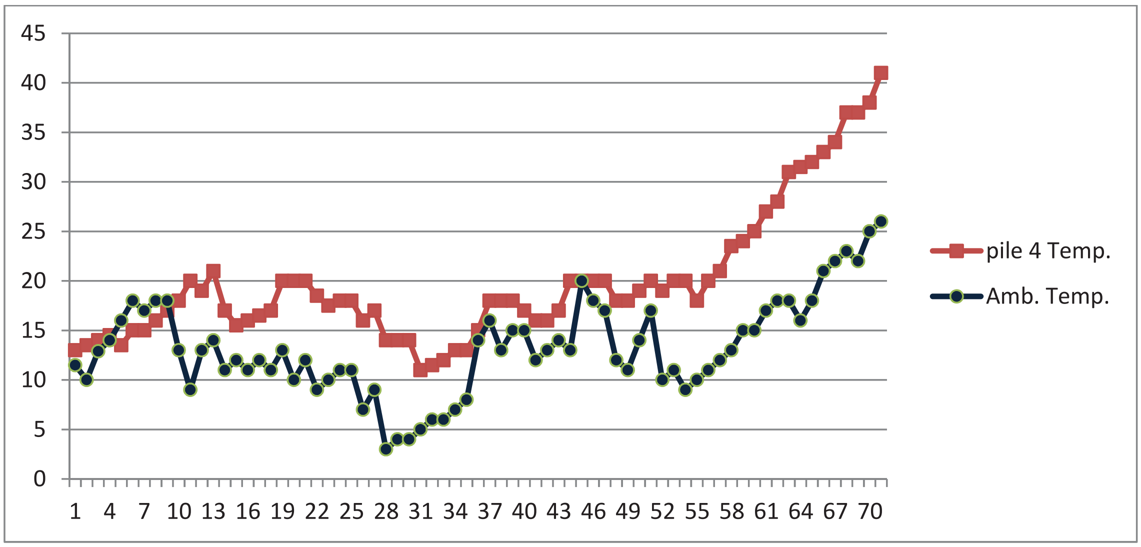
6.2.1. Temperature Measurement:

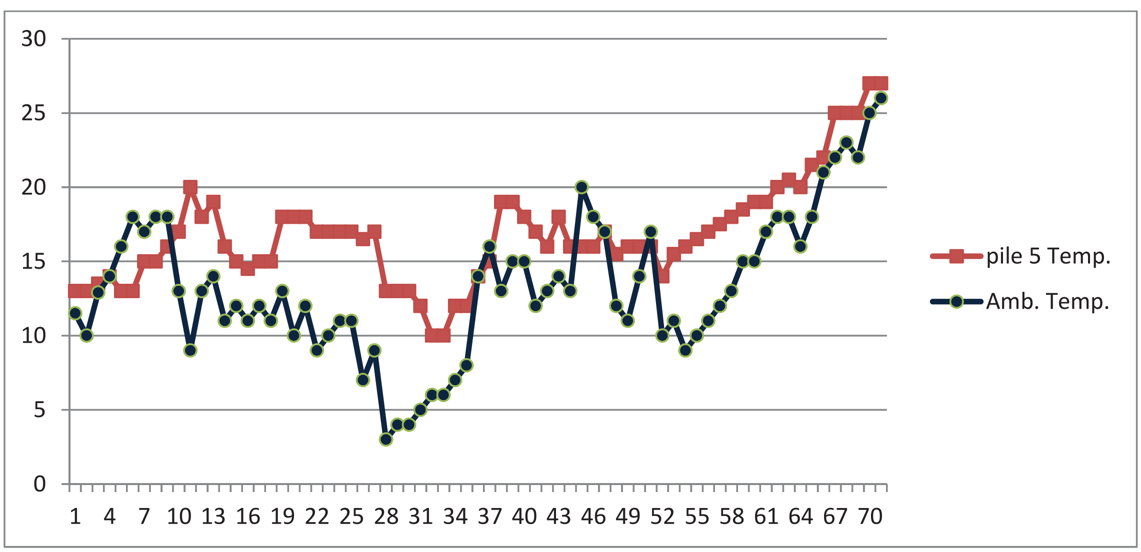
Daily measurements of temperature inside the compost piles, the ambient temperature, and times of turning the piles were recorded as shown Appendix 2. The curves below clarify variation in temperature with time. Max pile temperature was 41C at pile No. 4.







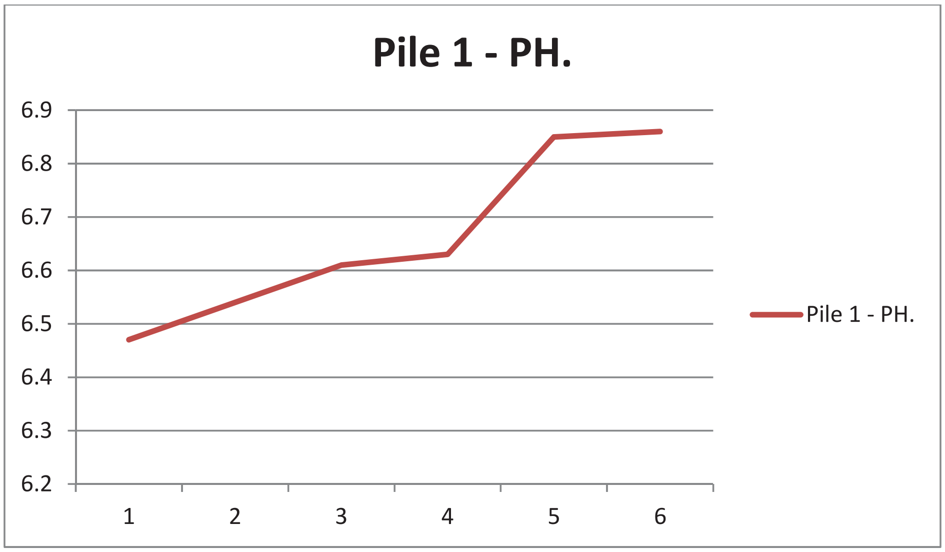


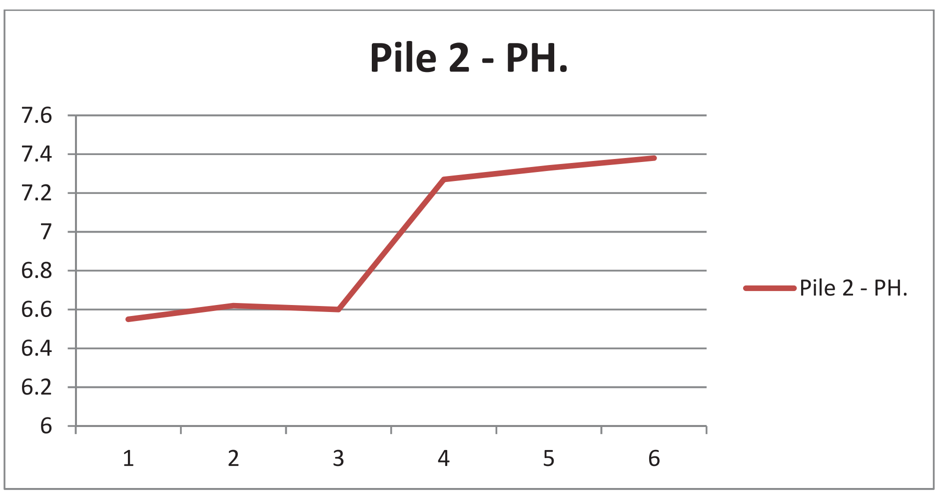


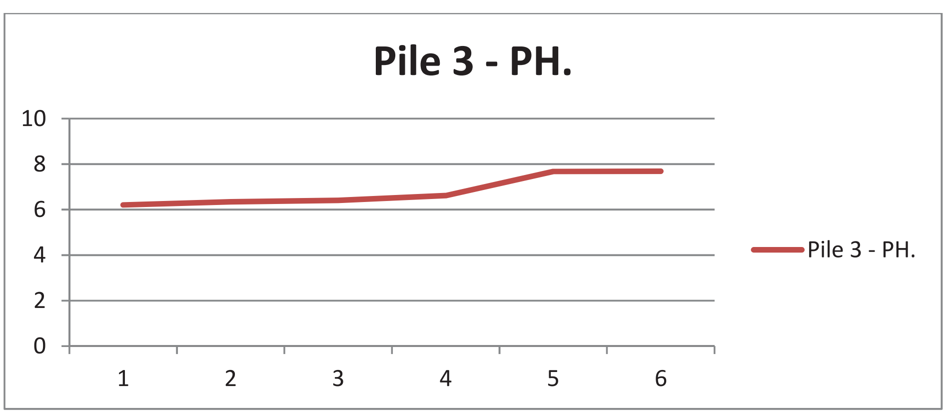
The experiment was conducted during a period experienced along day of cold fronts ended with a snow fronts were the temperature reached 3C degrees below zero. This is a reason of the low temperature of the compost and explains the instability in the temperature increase trends.

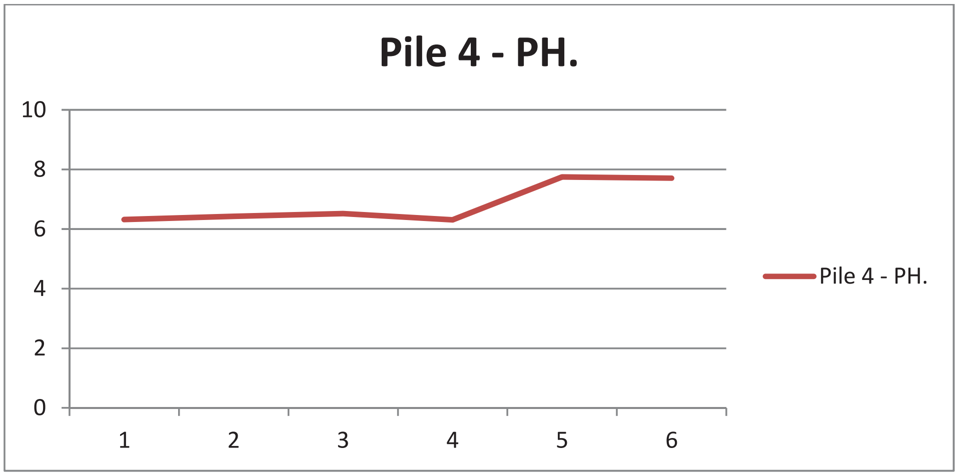
6.2.2. PH Measurements

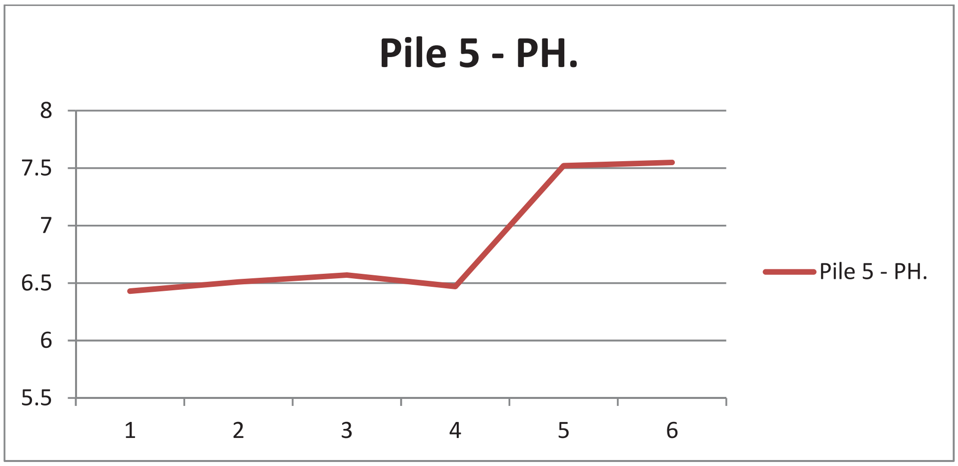
The pH values were recorded weekly. The curves below show variation in PH values with time.







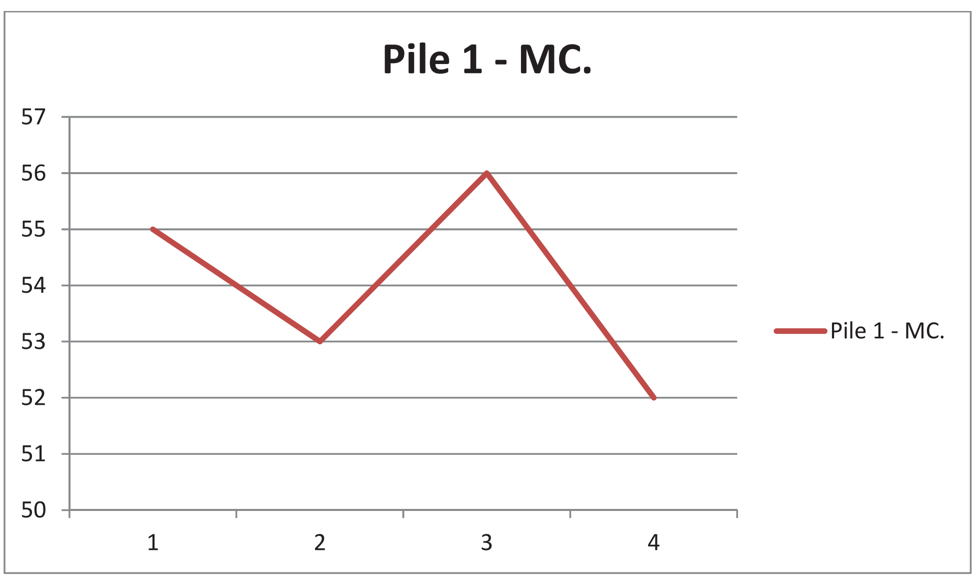


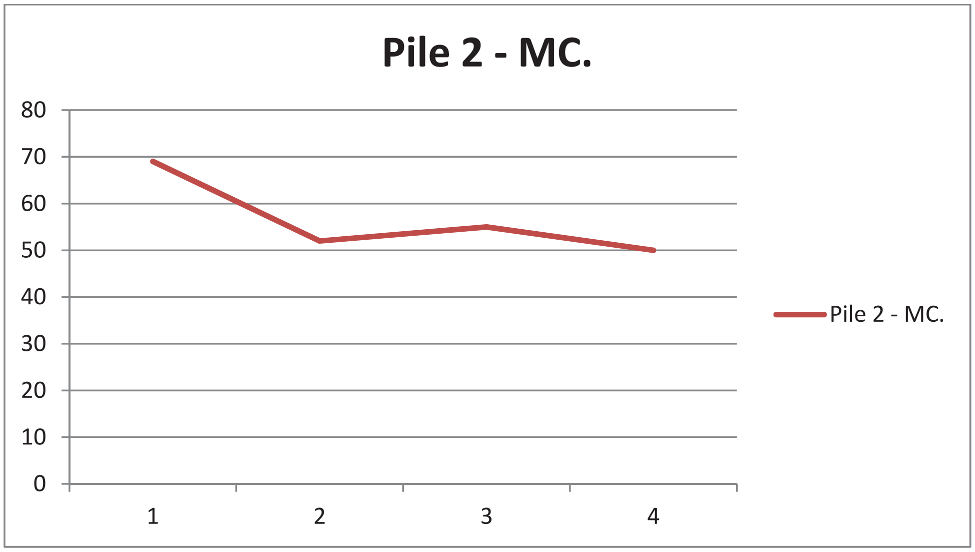


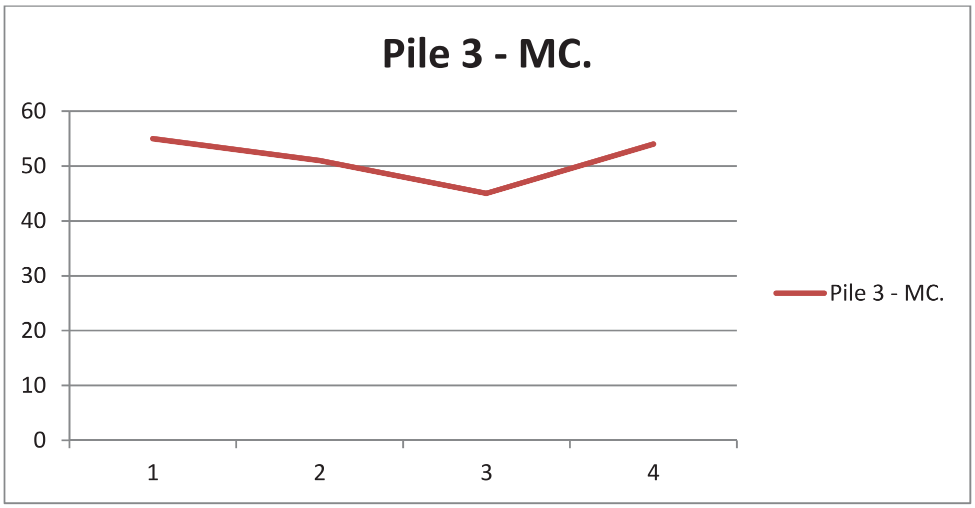
The experiment experienced a consistent value of pH by performing the proper monitoring and control of the piles. All readings were conformed to US EPA limits.

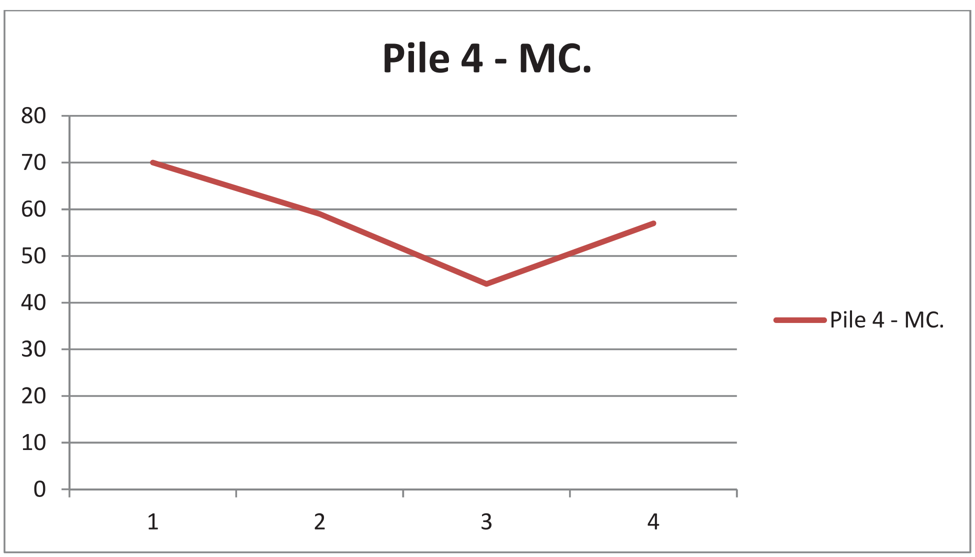
6.2.3. Moisture Content, MC:

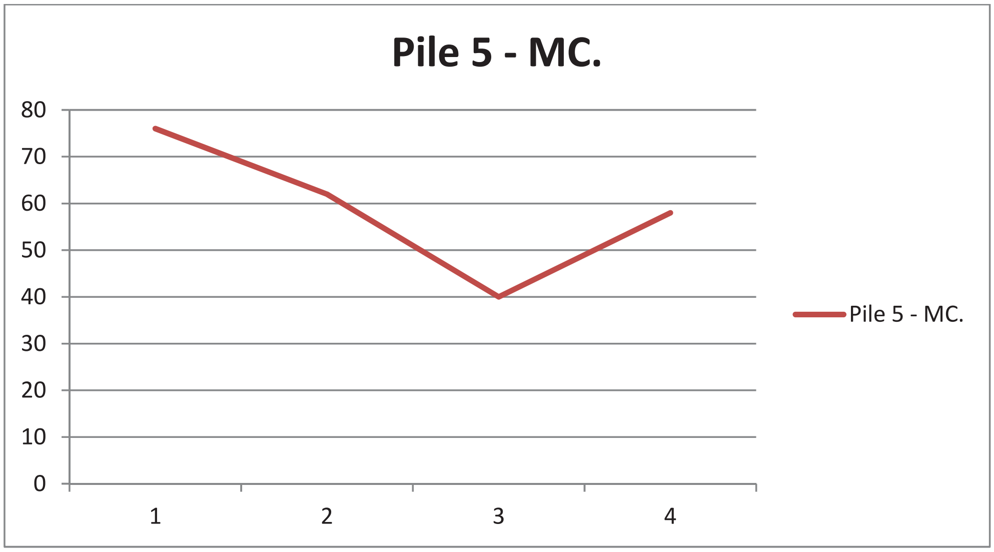
The moisture content percentages were recorded. Curves below show variation in percent of moisture content values in each pile with time.




Pile 2 - MC.
80
70
60
50
40
30
20
10
0
1
2
3
4
Pile 2 - MC.


Pile 3 - MC.
60
50
40
30
20
10
0
1
2
3
4
Pile 3 - MC.


Pile 4 - MC.
80
70
60
50
40
30
20
10
0
1
2
3
4
Pile 4 - MC.



Moisture content was controlled by;

- Adding water when MC is less than 50%
- Turning the piles when the MC is more than 60%

6.3. Final Product Measurements

The following parameters were measured for the final product after 3.5 months from the start of the experiment. These parameters were compared against the US EPA standards to make sure that the final product is an environment friendly product for land application.

Parameter	US EPA	Pile 1	Pile2	Pile3	Pile4	Pile5
Total nitrogen		.351 %	.72 %	.345 %	.46 %	.208 %
Nitrates		400 ppm	1429.3 %	840.8 ppm	788.8 ppm	448.3 ppm
Kjeldahl Nitrogen		.3418 %	.6867 %	.3255 %	.4221 %	.1975 %
Organic matter		6.6 %	28.88 %	21.46 ppm	25 %	12 %
Pb	300 ppm	7.6 ppm	3.8 ppm	5.3 ppm	5 ppm	6.4 ppm
Zn	2800 ppm	49.8 ppm	71.8 ppm	68.5 ppm	68.8 ppm	55.7 ppm
Cd	39 ppm	-	-	.35 ppm	.3 ppm	.24 ppm
Cu	1500 ppm	12.5 ppm	23.3 ppm	100.6 ppm	83.5 ppm	19.3 ppm
Ni	420 ppm	31.2 ppm	22.5 ppm	24.3 ppm	27.3 ppm	31.2 ppm
P		1425 ppm	5256 ppm	2294 ppm	2475 ppm	1555 ppm
K		6535 ppm	9970 ppm	5760 ppm	5309 ppm	4885 ppm
Salmonella	3	-	-	-	-	-
Total coliform		200000 cfu/g	2600	34000 cfu/g	32000 cfu/g	140000 cfu/g
Fecal Coliform	1000	100 cfu/g	-	3200 cfu/g	50 cfu/g	70 cfu/g

E. coli	100	60 cfu/g	-	1700 cfu/g	10 cfu/g	30 cfu/g
PH		7.257	7.024	6.459	7.157	6.96

Mixtures quality was determined prior to composting in the BZU laboratory for all parameters. During composting, the process was controlled by regular measurements of moisture content, temperature and pH. Upon completion of the composting process after 3.5 months, the compost maturity was tested.

All laboratory results showed that the compost quality conformed to USEPA regulations, E. coli, Salmonella, and fecal coliform counts except for pile No. 3 (Organic + Sludge + Sawdust) for fecal coliform which could be affected by the low value of pH (6.4). At this value it’s difficult to control the reduction of fecal coliform as observed in WWT studies, Adela Fernández et al, 1992. An overview of laboratory measurements is provided in Appendix 3.

In terms of total coliform all laboratory results showed that 95% removal efficiency was achieved.

In terms of heavy metals, some values were increased but still within the limits of USEPA knowing that the project area has no industries that may produce high levels of heavy metals.

7. Conclusions

- The experiment was conducted during a period experienced along day of cold fronts ended with a snow fronts were the temperature reached 3C degrees below zero. This is a strong reason of the low temperature of the compost and explains the instability in the temperature increase trends.
- The second run of test conducted after 3.5 months of starting the experiment was more consistent as the ambient temperature increased after the third week of February.
- The piles have saw dust in the mix design was more rapid to be composted materials.
- The period of time consumed to produce compost depends on several factors mentioned previously (including the size of the compost pile, particle size and the surface area of the materials, types of materials used, and frequency of turning, high temperatures and sun rays availability).
- Heavy metals values in initial and final compost were within the limits. This is due to the fact that no heavy industry is located in the project area where heavy metals could be produced.
- Composting was demonstrated to be a sustainable technology for stabilizing the different mixtures and reducing the volume and the need for the landfilling of solidwaste.
- The weight of end product (compost) from each pile ranged from (6.5 to 7.5 Kg) (percentage of compost yield = 46 to 50 %).

8. Recommendations

- Composting will be effective in summer times where temperature is high and moisture content can be controlled better. Many difficulties were faced due to conducting this experiment in winter days. Temperature required many days more than required to reach needed levels.

- Pile No. 1 (Horse Manure, Organics, & Sawdust) was the best mixture to conduct composting processes.

- A new project is recommended to confirm, at a commercial scale, the potential for composting at Turmus'ayya and Jericho Equestrian Clubs. The new project would confirm the potential for lower capital and operating costs for a new soil amendment for agriculture.

- This recommended project would include the construction of a compost facility, the establishment of a Reuse Extension Service Center, an institutional capacity building program, and a Public Awareness and Outreach Program for farmers that will use the compost.

9. References:

- Amir Hossein Nafez, et al., 2014
- Comilis et al., 2004; Pagans et al., 2006.
- Yaghmaein et al., 2005.
- EPA, 1995; Trautmann et al., 1997; Yaghmaeian et al., 2005.
- EPA, 1995; Schneider et al., 2001.
- Illmer et al., 1997.
- Fabrizio, et al., 2008; Trautmann et al., 1997; EPA, 1995.
- Adela Fernández et al, 1992.

10. Appendices:

1. **Photos**
2. **Temperature values**
3. **Lab analytical report for the raw materials and the final Maturity product**

Appendix 1 - Photos

Materials collection

Assembled shredder along with starting the collection and shredding of organic materials

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BIRZEIT UNIVERSITY
معهد الدراسات البيئية والمائية

20/10/2014

لمن يهمه الأمر

الطالب علي تيسير عودة هو طالب ماجستير هندسة مياه وبيئة في جامعة بيرزيت. ضمن رسالة الماجستير يقوم بإعداد دراسة عن "جدوى تحويل المواد العضوية إلى دبال".

الرجاء مساعدة الطالب قدر الإمكان ليتمكن من إعداد رسالة الماجستير.

مع فائق الشكر والتقدير،،

معهد الدراسات البيئية والمائية

Coordination with the university to do the experiment at the green house

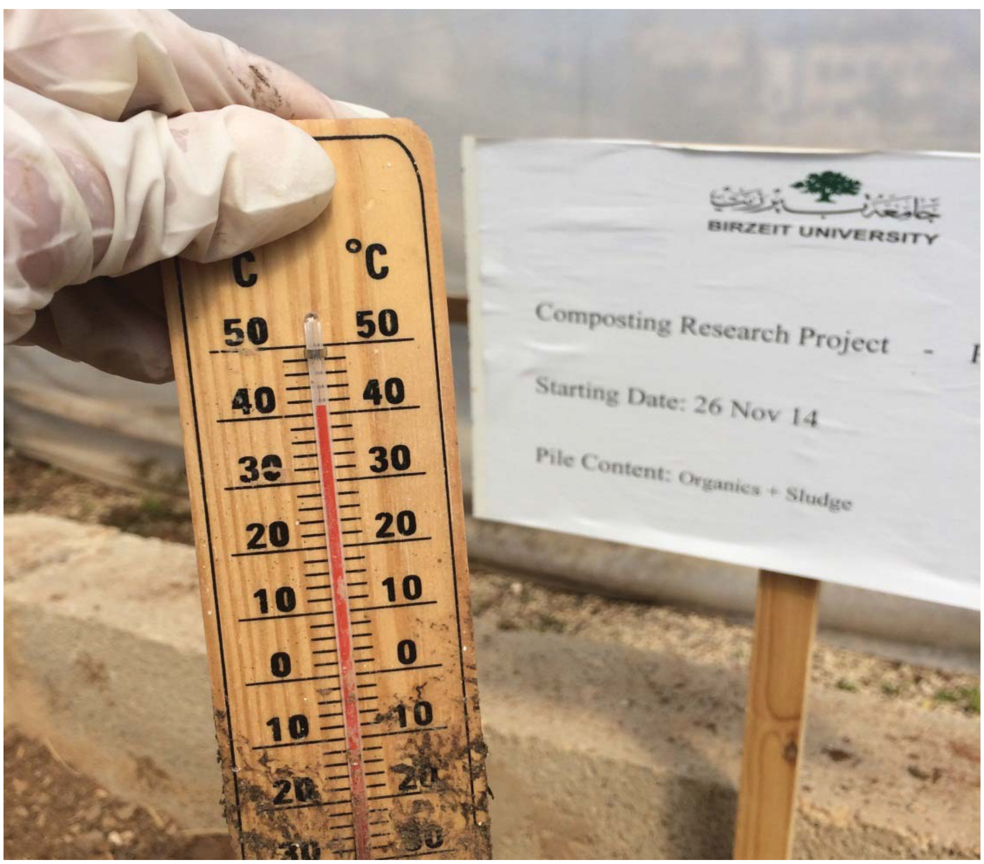
Piles preparation and preparing mixed raw materials for the composting piles

Piles preparation and preparing mixed raw materials for the composting piles

Sampling for testing the raw materials

Spreading raw materials at the trenches

Installation Sign board for each pile



Measuring temperature at each pile

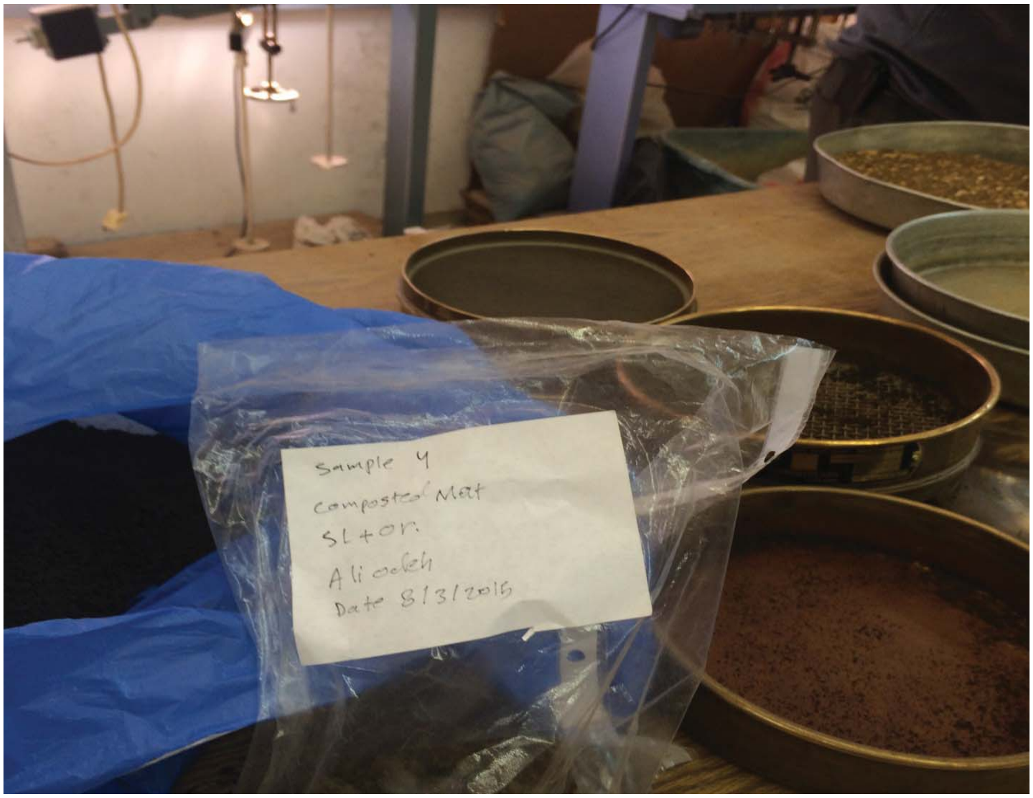
Snow at end of one snow fronts through January, 2015

Sampling for PH and moisture content periodical tests

Periodical pH Testing

Periodical Moisture content Testing

Collection, transfeer and screening the mature materials using a manual sieve.



Sampling for testing the maturity materials

Demobilization and cleaning the research area

Appendix 2 - Temperature values

Day	Pile 1 Temp. (C)	Pile 2 Temp. (C)	Pile 3 Temp. (C)	Pile 4 Temp. (C)	Pile 5 Temp. (C)	Amb Temp. (C)
1	12	13	13	13	13	11.5
2	13	13	13	13.5	13	10
3	13.5	13.5	14	14	13.5	12.9
4	14	14	14	14.5	14	14
5	13	13.5	14	13.5	13	16
6	13	14	15	15	13	18
7	14	14	16	15	15	17
8	15	15	16	16	15	18
9	16	17	18	17	16	18
10	18	19	20	18	17	13
11	18	20	22	20	20	9
12	19	19	21	19	18	13
13	17.5	21	20	21	19	14
14	14	18	18	17	16	11
15	13	16	16	15.5	15	12
16	13	17	16	16	14.5	11
17	14	17.5	17	16.5	15	12
18	15	17	16.5	17	15	11
19	15	20	17	20	18	13
20	15	19	17	20	18	10
21	18	20	18	20	18	12
22	17.5	19.5	17	18.5	17	9
23	18	19	17	17.5	17	10
24	18	20	18	18	17	11
25	18	20	18	18	17	11
26	15	16	16	16	16.5	7
27	15	16.5	16	17	17	9
28	12	14	11	14	13	3
29	12	14	11	14	13	4
30	12	14	11	14	13	4
31	13	13	11	11	12	5
32	12	10	10.5	11.5	10	6
33	12	10	11	12	10	6
34	12	13	12	13	12	7
35	12	16	12	13	12	8
36	11	17	13	15	14	14
37	14	18	15	18	15	16
38	13	19	14	18	19	13
39	14.5	15	15	18	19	15
40	15.5	16	16	17	18	15
41	14.5	14.5	15	16	17	12
42	15	15	15	16	16	13
43	15.5	16	16	17	18	14
44	15	18	15	20	16	13
45	21	20	15	20	16	20
46	20	20	15	20	16	18
47	18	19	15	20	17	17
48	15	17	15	18	15.5	12

Day	Pile 1 Temp. (C)	Pile 2 Temp. (C)	Pile 3 Temp. (C)	Pile 4 Temp. (C)	Pile 5 Temp. (C)	Amb Temp. (C)
49	16	17	16	18	16	11
50	17	19.5	19.5	19	16	14
51	18	22	23	20	16	17
52	16	20	15	19	14	10
53	15	20	15	20	15.5	11
54	15	16	16	20	16	9
55	16	16.5	16	18	16.5	10
56	16	17	16	20	17	11
57	18	18	18	21	17.5	12
58	18.5	18	18.5	23.5	18	13
59	20	18.5	20	24	18.5	15
60	21	19	21	25	19	15
61	22	20	22	27	19	17
62	23	20	23	28	20	18
63	24	20.5	24	31	20.5	18
64	25	20	25	31.5	20	16
65	25	21.5	25	32	21.5	18
66	26	22	25.5	33	22	21
67	28	25	27	34	25	22
68	29	25	27.5	37	25	23
69	29	26	29	37	25	22
70	31	27	30	38	27	25
71	32	28	30	41	27	26

Appendix 3

Lab analytical report for the raw materials and the final Maturity product

Raw Materials Lab Results

جامعة بيرزيت
BIRZEIT UNIVERSITY
Birzeit University Testing Laboratories

Environmental Unit
PS/ISO 17025 Accredited
Phone : 02-2982010/ 02-2982102
Fax : 02-2982166

Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153653
Source Sample Code	: Sample 1
Sample Name	: Organic + Horse Manoure + Sawdus
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.39 %	StMe		09 MAR 2015
Nitrates	131.2 ppm	StMe		05 MAR 2015
Kjeldahl Nitrogen	0.39 %	StMe		09 MAR 2015
Organic Matter	20.25 %	StMe		09 MAR 2015
Pb	Not detected	ICP		05 MAR 2015
Zn	14.36 ppm	ICP		05 MAR 2015
Cd	Not detected	ICP		05 MAR 2015
Cu	3.19 ppm	ICP		05 MAR 2015
Ni	0.87 ppm	ICP		05 MAR 2015
P	1398.0 ppm	ICP		05 MAR 2015
K	2229.0 ppm	ICP		05 MAR 2015
Salmonella	Absent /25g	ISO		03 MAR 2015
Total Coliforms	3500000 cfu/g	ISO		11 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153653
Source Sample Code	: Sample 1
Sample Name	: Organic + Horse Manoure + Sawdus
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	1168000 cfu/g	ISO		03 MAR 2015
Escherichia coli	220000 cfu/g	ISO		03 MAR 2015
Carbon	11.75 %	StMe		09 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 11 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153654
Source Sample Code	: Sample 2
Sample Name	: Organic + Horse Manure
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.37 %	StMe		09 MAR 2015
Nitrates	378.7 ppm	StMe		05 MAR 2015
Kjeldahl Nitrogen	0.36 %	StMe		09 MAR 2015
Organic Matter	14.29 %	StMe		09 MAR 2015
Pb	0.82 ppm	ICP		05 MAR 2015
Zn	16.32 ppm	ICP		05 MAR 2015
Cd	Not detected	ICP		05 MAR 2015
Cu	4.52 ppm	ICP		05 MAR 2015
Ni	2.40 ppm	ICP		05 MAR 2015
P	1070.0 ppm	ICP		05 MAR 2015
K	2400.0 ppm	ICP		05 MAR 2015
Salmonella	Absent /25g	ISO		03 MAR 2015
Total Coliforms	570000 cfu/g	ISO		03 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 11 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153654
Source Sample Code	: Sample 2
Sample Name	: Organic + Horse Manure
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	470000 cfu/g	ISO		03 MAR 2015
Escherichia coli	16000 cfu/g	ISO		03 MAR 2015
Carbon	8.29 %	StMe		09 MAR 2015

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Analytical Report

Report Date : 11 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code : ES-20153655
Source Sample Code : Sample 3
Sample Name : Organic + Sludge + Sawdust
Sample Receiving Date : 25 February 2015
Category : Sludge
Batch No. :
Sample Size : 1 Kg
Origin : Institute of Environmental and Water Studies
Representative :
Container Type : Plastic
Sample Condition : ok
Sampled By : Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.64 %	StMe		09 MAR 2015
Nitrates	962.9 ppm	StMe		05 MAR 2015
Kjeldahl Nitrogen	0.64 %	StMe		09 MAR 2015
Organic Matter	13.22 %	StMe		09 MAR 2015
Pb	1.52 ppm	ICP		05 MAR 2015
Zn	69.35 ppm	ICP		05 MAR 2015
Cd	0.33 ppm	ICP		05 MAR 2015
Cu	259.8 ppm	ICP		05 MAR 2015
Ni	1.77 ppm	ICP		05 MAR 2015
P	2322.0 ppm	ICP		05 MAR 2015
K	1490.0 ppm	ICP		05 MAR 2015
Salmonella	Absent /25g	ISO		03 MAR 2015
Total Coliforms	7300000 cfu/g	ISO		03 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 11 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153655
Source Sample Code	: Sample 3
Sample Name	: Organic + Sludge + Sawdust
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	15000 cfu/g	ISO		03 MAR 2015
Escherichia coli	5000 cfu/g	ISO		03 MAR 2015
Carbon	7.67 %	StMe		09 MAR 2015

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153660
Source Sample Code	: Sample 4
Sample Name	: Organic + Sludge
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.90 %	StMe		11 MAR 2015
Nitrates	101.3 ppm	StMe		05 MAR 2015
Kjeldahl Nitrogen	0.89 %	StMe		11 MAR 2015
Organic Matter	11.25 %	StMe		10 MAR 2015
Pb	1.0 ppm	ICP		05 MAR 2015
Zn	47.0 ppm	ICP		05 MAR 2015
Cd	0.20 ppm	ICP		05 MAR 2015
Cu	165.2 ppm	ICP		05 MAR 2015
Ni	1.24 ppm	ICP		05 MAR 2015
P	1846.0 ppm	ICP		05 MAR 2015
K	1770.0 ppm	ICP		05 MAR 2015
Salmonella	Absent /25g	ISO		03 MAR 2015
Total Coliforms	5500000 cfu/g	ISO		03 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153660
Source Sample Code	: Sample 4
Sample Name	: Organic + Sludge
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	15000 cfu/g	ISO		03 MAR 2015
Escherichia coli	10000 cfu/g	ISO		03 MAR 2015
Carbon	6.53 %	StMe		10 MAR 2015

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153656
Source Sample Code	: Sample 5
Sample Name	: Organic + Sawdust
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.24 %	StMe		09 MAR 2015
Nitrates	1005.9 ppm	StMe		05 MAR 2015
Kjeldahl Nitrogen	0.22 %	StMe		09 MAR 2015
Organic Matter	14.11 %	StMe		09 MAR 2015
Pb	Not detected	ICP		05 MAR 2015
Zn	7.42 ppm	ICP		05 MAR 2015
Cd	Not detected	ICP		05 MAR 2015
Cu	7.10 ppm	ICP		05 MAR 2015
Ni	0.33 ppm	ICP		05 MAR 2015
P	450.8 ppm	ICP		05 MAR 2015
K	2297.0 ppm	ICP		05 MAR 2015
Salmonella	Absent /25g	ISO		03 MAR 2015
Total Coliforms	18600000 cfu/g	ISO		03 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153656
Source Sample Code	: Sample 5
Sample Name	: Organic + Sawdust
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	240000 cfu/g	ISO		03 MAR 2015
Escherichia coli	10000	ISO		03 MAR 2015
Carbon	8.18 %	StMe		09 MAR 2015

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Analytical Report

Report Date : 11 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code : ES-20153658
Source Sample Code : Sample 6
Sample Name : Sludge
Sample Receiving Date : 25 February 2015
Category : Sludge
Batch No. :
Sample Size : 1 Kg
Origin : Institute of Environmental and Water Studies
Representative :
Container Type : Plastic
Sample Condition : ok
Sampled By : Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	1.51 %	StMe		09 MAR 2015
Nitrates	10.8 ppm	StMe		05 MAR 2015
Kjeldahl Nitrogen	1.51 %	StMe		09 MAR 2015
Organic Matter	13.68 %	StMe		09 MAR 2015
Pb	2.56 ppm	ICP		05 MAR 2015
Zn	117.0 ppm	ICP		05 MAR 2015
Cd	0.58 ppm	ICP		05 MAR 2015
Cu	446.9 ppm	ICP		05 MAR 2015
Ni	3.04 ppm	ICP		05 MAR 2015
P	3581.0 ppm	ICP		05 MAR 2015
K	1184.0 ppm	ICP		05 MAR 2015
Salmonella	Absent /25g	ISO		03 MAR 2015
Total Coliforms	6900000 cfu/g	ISO		03 MAR 2015

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Analytical Report

Report Date : 11 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153658
Source Sample Code	: Sample 6
Sample Name	: Sludge
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	74000 cfu/g	ISO		03 MAR 2015
Escherichia coli	20000 cfu/g	ISO		03 MAR 2015
Carbon	7.93 %	StMe		09 MAR 2015

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Analytical Report

Report Date : 11 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153659
Source Sample Code	: Sample 7
Sample Name	: Horse Manure
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.67 %	StMe		10 MAR 2015
Nitrates	8.4 ppm	StMe		05 MAR 2015
Kjeldahl Nitrogen	0.67 %	StMe		10 MAR 2015
Organic Matter	18.15 %	StMe		10 MAR 2015
Pb	Not detected	ICP		05 MAR 2015
Zn	15.40 ppm	ICP		05 MAR 2015
Cd	Not detected	ICP		05 MAR 2015
Cu	4.90 ppm	ICP		05 MAR 2015
Ni	1.09 ppm	ICP		05 MAR 2015
P	1878.0 ppm	ICP		05 MAR 2015
K	2704.0 ppm	ICP		05 MAR 2015
Salmonella	Absent /25g	ISO		03 MAR 2015
Total Coliforms	3800000 cfu/g	ISO		03 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 11 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153659
Source Sample Code	: Sample 7
Sample Name	: Horse Manure
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	808000 cfu/g	ISO		03 MAR 2015
Escherichia coli	190000 cfu/g	ISO		03 MAR 2015
Carbon	10.53 %	StMe		10 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153657
Source Sample Code	: Sample 8
Sample Name	: Organic
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.32 %	StMe		09 MAR 2015
Nitrates	756.9 ppm	StMe		05 MAR 2015
Kjeldahl Nitrogen	0.30 %	StMe		09 MAR 2015
Organic Matter	6.94 %	StMe		09 MAR 2015
Pb	Not detected	ICP		05 MAR 2015
Zn	3.88 ppm	ICP		05 MAR 2015
Cd	Not detected	ICP		05 MAR 2015
Cu	5.30 ppm	ICP		05 MAR 2015
Ni	0.23 ppm	ICP		05 MAR 2015
P	438.5 ppm	ICP		05 MAR 2015
K	2663.0 ppm	ICP		05 MAR 2015
Salmonella	Absent /25g	ISO		03 MAR 2015
Total Coliforms	1410000 cfu/g	ISO		03 MAR 2015

* The Center is only responsible for the results of the sample tested.

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153657
Source Sample Code	: Sample 8
Sample Name	: Organic
Sample Receiving Date	: 25 February 2015
Category	: Sludge
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	600 cfu/g	ISO		03 MAR 2015
Escherichia coli	30 cfu/g	ISO		03 MAR 2015
Carbon	4.02 %	StMe		09 MAR 2015

* The Center is only responsible for the results of the sample tested.

Signatures:

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Analytical Report

Report Date : 19 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153675
Source Sample Code	: Sample 1
Sample Name	: HM+Org+SD
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.351 %	StMe		16 MAR 2015
Nitrates	400.0 ppm	StMe		12 MAR 2015
Kjeldahl Nitrogen	0.3418 %	StMe		16 MAR 2015
Organic Matter	6.6 %	StMe		19 MAR 2015
Pb	7.6 ppm	ICP		12 MAR 2015
Zn	49.8 ppm	ICP		12 MAR 2015
Cd	Not detected	ICP		12 MAR 2015
Cu	12.5 ppm	ICP		12 MAR 2015
Ni	31.2 ppm	ICP		12 MAR 2015
P	1425.0 ppm	ICP		12 MAR 2015
K	6535.0 ppm	ICP		12 MAR 2015
Salmonella	Absent /25g	ISO		16 MAR 2015
Total Coliforms	200000 cfu/g	ISO		14 MAR 2015

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Composted Materials Lab Results

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Analytical Report

Report Date : 19 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153675
Source Sample Code	: Sample 1
Sample Name	: HM+Org+SD
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	100 cfu/g	ISO		14 MAR 2015
Escherichia coli	60 cfu/g	ISO		14 MAR 2015
pH	7.257	StMe		19 MAR 2015
Carbon	3.83 %	StMe		19 MAR 2015

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Analytical Report

Report Date : 19 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153676
Source Sample Code	: Sample 2
Sample Name	: HM+Org
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.720 %	StMe		16 MAR 2015
Nitrates	1492.3 ppm	StMe		12 MAR 2015
Kjeldahl Nitrogen	0.6867 %	StMe		16 MAR 2015
Organic Matter	28.88 %	StMe		19 MAR 2015
Pb	3.8 ppm	ICP		12 MAR 2015
Zn	71.8 ppm	ICP		12 MAR 2015
Cd	Not detected	ICP		12 MAR 2015
Cu	23.3 ppm	ICP		12 MAR 2015
Ni	22.5 ppm	ICP		12 MAR 2015
P	5256.0 ppm	ICP		12 MAR 2015
K	9970.0 ppm	ICP		12 MAR 2015
Salmonella	Absent /25g	ISO		16 MAR 2015
Total Coliforms	2600 cfu/g	ISO		14 MAR 2015

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Analytical Report

Report Date : 19 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153676
Source Sample Code	: Sample 2
Sample Name	: HM+Org
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	Nil /g	ISO		14 MAR 2015
Escherichia coli	Nil /g	ISO		14 MAR 2015
pH	7.024	StMe		19 MAR 2015
Carbon	16.75 %	StMe		19 MAR 2015

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153677
Source Sample Code	: Sample 3
Sample Name	: SD+Org+SL
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.345 %	StMe		16 MAR 2015
Nitrates	840.8 ppm	StMe		12 MAR 2015
Kjeldahl Nitrogen	0.3255 %	StMe		16 MAR 2015
Organic Matter	21.46 %	StMe		19 MAR 2015
Pb	5.3 ppm	ICP		12 MAR 2015
Zn	68.5 ppm	ICP		12 MAR 2015
Cd	0.35 ppm	ICP		12 MAR 2015
Cu	100.6 ppm	ICP		12 MAR 2015
Ni	24.3 ppm	ICP		12 MAR 2015
P	2294.0 ppm	ICP		12 MAR 2015
K	5760.0 ppm	ICP		12 MAR 2015
Salmonella	Absent /25g	ISO		16 MAR 2015
Total Coliforms	34000 cfu/g	ISO		14 MAR 2015

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Analytical Report

Report Date : 25 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153677
Source Sample Code	: Sample 3
Sample Name	: SD+Org+SL
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	3200 cfu/g	ISO		14 MAR 2015
Escherichia coli	1700 cfu/g	ISO		14 MAR 2015
pH	6.459	StMe		19 MAR 2015
Carbon	12.45 %	StMe		19 MAR 2015

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Analytical Report

Report Date : 24 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153678
Source Sample Code	: Sample 4
Sample Name	: Org+SL
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.460 %	StMe		16 MAR 2015
Nitrates	788.8 ppm	StMe		12 MAR 2015
Kjeldahl Nitrogen	0.4421 %	StMe		16 MAR 2015
Organic Matter	25.0 %	StMe		19 MAR 2015
Pb	5.0 ppm	ICP		12 MAR 2015
Zn	68.8 ppm	ICP		12 MAR 2015
Cd	0.30 ppm	ICP		12 MAR 2015
Cu	83.5 ppm	ICP		12 MAR 2015
Ni	27.3 ppm	ICP		12 MAR 2015
P	2475.0 ppm	ICP		12 MAR 2015
K	5309.0 ppm	ICP		12 MAR 2015
Salmonella	Absent /25g	ISO		16 MAR 2015
Total Coliforms	32000 cfu/g	ISO		14 MAR 2015

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Analytical Report

Report Date : 24 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153678
Source Sample Code	: Sample 4
Sample Name	: Org+SL
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	50 cfu/g	ISO		14 MAR 2015
Escherichia coli	10 cfu/g	ISO		14 MAR 2015
pH	7.157	StMe		19 MAR 2015
Carbon	14.5 %	StMe		19 MAR 2015

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Analytical Report

Report Date : 24 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153679
Source Sample Code	: Sample 5
Sample Name	: Org+SD
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Total Nitrogen	0.208 %	StMe		16 MAR 2015
Nitrates	448.3 ppm	StMe		12 MAR 2015
Kjeldahl Nitrogen	0.1975 %	StMe		16 MAR 2015
Organic Matter	12.0 %	StMe		19 MAR 2015
Pb	6.4 ppm	ICP		12 MAR 2015
Zn	55.7 ppm	ICP		12 MAR 2015
Cd	0.24 ppm	ICP		12 MAR 2015
Cu	19.3 ppm	ICP		12 MAR 2015
Ni	31.2 ppm	ICP		12 MAR 2015
P	1555.0 ppm	ICP		12 MAR 2015
K	4885.0 ppm	ICP		12 MAR 2015
Salmonella	Absent /25g	ISO		16 MAR 2015
Total Coliforms	140000 cfu/g	ISO		14 MAR 2015

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Analytical Report

Report Date : 24 March 2015
Customer : Institute of Environmental and Water Studies

Sample Code	: ES-20153679
Source Sample Code	: Sample 5
Sample Name	: Org+SD
Sample Receiving Date	: 09 March 2015
Category	: Compost
Batch No.	:
Sample Size	: 1 Kg
Origin	: Institute of Environmental and Water Studies
Representative	:
Container Type	: Plastic
Sample Condition	: ok
Sampled By	: Ali Odeh

Test	Result	Method	Comments	Test Date
Fecal Coliforms	70 cfu/g	ISO		14 MAR 2015
Escherichia coli	30 cfu/g	ISO		14 MAR 2015
pH	7.276	StMe		19 MAR 2015
Carbon	6.96 %	StMe		19 MAR 2015

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