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Urine diverting vermicomposting toilets for Durban, South Africa

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Acknowledgements

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1 Abstract

Although being the third largest city in South Africa, the outskirts of Durban are scarcely populated. Due to economic limitations, the drainage and fresh water pipes from the city are not extended to the outskirts. One of the most important issues concerning human health is that of sanitation and waste management. Lack of sanitation leads to the spreading of pathogens and often results in outbreaks of infectious diseases, such as cholera; one outbreak motivated eThekwini Municipality to install 100,000 urine-diverting toilets in rural areas of Durban. The use of UD toilets can be improved by the use of vermicomposting. Vermicomposting uses earthworms to facilitate degradation of organic material.

The aim for this project was to establish whether vermicomposting could improve the function of dry toilet systems, mainly by reducing the volume of the solid fraction.

Three toilets were chosen as testing sites. Vermicomposts were created in plastic boxes by adding different types of compost materials, so-called bedding materials, and worms. Two types of bedding material were used, vegetable compost and local topsoil were compared to potting soil and fully digested sludge mixed with soil.

Once the vermicomposts had been installed in the toilets, experiments were conducted to determine the performance of the composts. Samples were taken in the field and analysed in the lab. The number of worms and cocoons were counted and the pH, temperature and total and volatile solids were measured and calculated. Solvita® tests were made to determine the state of the composts.

In the laboratory test it appeared that the bedding material consisting of potting soil and fully digested sludge was more suitable for vermicomposting; however, no difference could be found in the field. The worms seemed to survive well in the composts. The pH levels were similar to that of the initial pH, which could suggest that the pH stayed relatively stable in the compost. The temperature in the compost stayed close to that of the outside air temperature. The composts could have had been too dry for the worms, but there was a lot of organic matter present. The composts were well matured or under ideal curing.

Because of the short time period and the insufficient number of vermicomposts tested, no definite conclusions could be made. However, indications were seen during the project that there was potential for functioning vermicomposting in UD toilets in South Africa and that it would be of great interest to continue the studies further.

Keywords:
Vermicompost, urine diverting toilets, *Eisenia Foetida*, faeces, sanitation

2 Introduction

Durban, the third largest city in in South Africa, is one of the major centres of tourism and the busiest port in South Africa. Yet the outskirts of the city are scarcely populated and lacking in sanitation as there are no of extensions of drainage and fresh water pipes from the city due economic limitations. One of the most important issues concerning human health is that of sanitation and waste management. Lack of sanitation leads to the spreading of pathogens and often results in outbreaks of infectious diseases, such as cholera. In August 2000, there was an outbreak of cholera in South Africa, which directed the government's attention to sanitation. As a reaction to the outbreak, the eThekwini Municipality installed 100,000 urine diverting dry toilets (UDDT or short UD toilets) in rural areas of Durban. The benefits of UD toilets are that they are affordable and simple, yet they are able to prevent diseases and the spreading of environmental pollutants if managed correctly. Thus, they are a good alternative for low-income areas with water shortages. With the use of vermicomposting, the time intervals between emptying the toilets may be increased up to five times. Vermicomposting uses earthworms, most commonly *Eisenia foetida*, to facilitate the degradation of organic material. The vermicomposted material is stable and homogeneous, and may have reduced levels of contamination. For this reason, it is valuable and marketable as plant growth medium.

2.1 Objective

The aim for this project was to establish whether vermicomposting could improve the function of dry toilet systems in Durban, mainly by reducing the volume of the solid fraction. Specific objectives were to:

- Monitoring the number of worms and cocoons in the composts;
- Follow the development of physico-chemical parameters in vermicompost;
- Monitor and regulate the water content and biological activity for optimised vermicomposting.

2.1.2 Delimitations

Although of great interest, this project could not analyse the reduction of pathogens in the composts. The UD toilets used in this project were situated in co-operative gardens, which were only open during working hours and only used by few workers in the gardens.

3 Background

3.1 South Africa

South Africa borders the Atlantic and Indian oceans from the west to the east and is also the southernmost part of the African continent. The country's area is 1,219,090 km^2 and borders Namibia, Botswana and Zimbabwe to the northwest and to the east Mozambique and Swaziland (Figure 1). Within South Africa, the country Lesotho is surrounded by South African territory in the southeast (South African Government Information, 2013).

Figure 1. Map of the KwaZulu- Natal and Durban district in South Africa (inset) (Google 2013).

The population in South Africa is 51.8 million (Statistics South Africa, 2013) and is affluent when it comes to variety in cultures.

Durban and the municipality eThekwini are situated in the South African province KwaZulu-Natal (Figure 1). The population in the eThekwini municipality is estimated to be around 3.5 million people. The climate is warm and subtropical and the land area approximately 2 297 km^2 (eThekwini Municipality, 2013).

3.1.1 History of South Africa and Durban

To understand the social situation of South Africa today, it is important to understand the country's long history of colonialism, racial segregation and discrimination.

The first European settlement was started in the 17th century around the Cape of Good Hope as a re-supply point for the ships of the Dutch East India Company on their journeys towards

India (South Africa Info, 2013). To the settlements, slaves were later imported. South Africa was later colonised by both the British and the French, which formed the beginning of the Afrikaner nation.

In the beginning of the 20th century, racial segregation started becoming incorporated into the national laws. Law acts were passed to ensure white power, such as the Masters and Servants Acts as well as the Land Act in 1913, reserving 90% of the country's area for white ownership, and black people were barred from being members of the parliament. In 1948 the Nationalist Party won the election and apartheid became the official ideology. It was not until the 1990s, when South Africa began to see the end of apartheid, that the first democratic election was held. In April 1994, the African National Congress (ANC) gained power and Nelson Mandela was sworn in as president on May 10 1994.

The city of Durban was originally established by the British as a colony called Port Natal. Around the area of Natal, the European settlers found resistance from the Zulu nation, ruled by the leader King Shaka (South Africa Info, 2013). The sugar cane production in Natal lead to labourers being imported from India. Many of the labourers decided of free will to stay behind in Durban, thus Durban's large population of people of Indian decent.

3.1.2 On-going projects in Durban

In the eThekwini municipality, there are on-going projects to control the hygiene related problems, such as diarrhoea (My virtual paper, 2013). Rotavirus were found in more than 50% of the samples collected in eThekwini region (My virtual paper, 2013). Rotavirus causes severe diarrhoea, which is common among children and infants (WHO, 2013a). Recently these kinds of issues have decreased in the eThekwini region by the spreading of information and education about hygiene and sanitation (My virtual paper, 2013).

3.2 Cholera and ascariasis

Lack of adequate sanitation may lead to the spreading of pathogens and diseases (WHO, 2013 b). Two health issues in South Africa that are strongly connected to the country's situation concerning sanitation are outbreaks of cholera and the spreading of ascariasis.

In 2008, Zimbabwe had a cholera outbreak, which also affected South Africa. The Ministry of Health in South Africa confirmed more than 160 cholera incidents, including Johannesburg and Durban (Mandhlate et al., 2008). It is therefore important to prevent the bacteria *Vibrio cholerae* to contaminate water and eventually infect food. Cholera causes watery diarrhoea that can lead to dehydration and in some cases death if treatment is not given (WHO, 2013b).

Ascariasis is caused by *Ascaris lumbricoides*, a large roundworm, which causes infection of the small intestine (WHO, 2013c). *Ascaris lumbricoides* eggs are found in soil contaminated by human faeces or in uncooked food. A person becomes infected by accidently swallowing or inhaling the eggs. The eggs hatch into larvae within the intestine and the female adult worm can grow to over 30 cm in length. The eggs become infective after 2-3 weeks and can remain infective for several months or years. The largest risk group are children around the age of 3-8 years old, who often become infected after playing in the contaminated soil and putting their hands into their mouths.

3.3 UD toilets

Safe sanitation is one of the most important issues in the world today and is mentioned in the sixth and seventh Millennium Development Goals set up by the UN for year 2015 (Millenium Project, 2013). Spreading of pathogens can be prevented with proper sanitation, of which one important aspect is the use of suitable toilets. Without toilets, open defecation may contaminate people indirectly through contaminated soil and/or ground water, or through direct contact with the faeces. Pit latrines may also contaminate the surrounding soil and water, if the ground water level is in line with, or higher, than the bottom of the pit (SIDA, 2008).

One type of dry toilet commonly used is the urine-diverting (UD) toilet. The urine is diverted to a tank outside the toilet, occasionally buried in the ground, whereas the faeces get collected in a vault under the toilet bowl (SuSanA, 2013). There are two separate vaults under the toilet and the toilet bowl is located over one of the vaults (Figure 3). When the vault is filled, the toilet is moved to the other vault. The filled vault is emptied when the vault in use has filled up. This occurs with an interval of approximately six months. The faecal matter at this stage is comparable to soil in texture if managed properly.

The UD toilets must eventually be emptied and in order to minimize contact with the faeces, and there is an interest of finding a way to increase the time intervals between emptying. This can be achieved by reducing the mass of faeces. There is also an interest in finding a way of recycling the nutrients to be used in agriculture (SIDA, 1998). There are indications that vermicomposting (compost using worms) may be used to achieve both mass reduction (Ndegwa et al, 2000) and pathogen removal (Eastman et al, 2001).

Figure 3. Double vault toilet (Drawing by Annie Danger) (Greywater action, 2013).

Because of the high nutrient values of human waste, great value could be obtained from finding safe ways of reusing urine and faecal matter. Although containing less nutrients than urine, humans on average excrete 25-50 kg of faeces per year, which contain up to 0.55 kg of nitrogen, 0.18 kg of phosphorus and 0.37 kg of potassium (Jönsson, 1997).

3.3.1 Social history of toilets in South Africa

Although abandoned, the apartheid system has still left its mark and there is today a strong collective memory in South Africa concerning the management of faecal matter. During the apartheid system, people in the black communities were forced to defecate in buckets (Velkushanova, 2013). Therefore, many people do not welcome the use of buckets inside their toilets. There is also a strong feeling that UD toilets are less developed than flushing toilets, leading people to distrust the UD toilets the eThekwini municipality build for free in the communities and many of the UD toilets are never used (Buckley, 2013).

3.3.2 UD toilets using vermicompost

Vermicomposting can be used in UD toilets as a method of reducing the volume of the faeces (Figure 4). It is a suitable option for treatment of human wastes as it combines the benefits of UD toilets and of vermicomposting. UD toilets are suitable because they reduce the contamination of the surrounding ground water and vermicomposting because it reduces the fill up of faecal matter (Otterpohl & Buzie, 2011). According to previous studies (Gupta & Garg, 2008, cited in Yadav et al, 2011), there are also indications that the level of harmful pathogens might be reduced. The worms ingest and digest the organic fraction in the faeces. There is an interest in finding alternative ways of dealing with human waste for best nutrient recovery and vermicomposting might become a suitable option. If the vermicompost is well functioning, vermicomposted human waste may be used as fertilizers (Anand & Apul, 2013).

When designing the vermicompost, it is important to create an environment in which the worms will thrive. There are critical levels of ammonia, pH and temperature that must be not be exceeded for the worms to survive in the compost (Dominguez & Edwards, 2010). It is also important that the container for the compost is of a non-toxic material for the worms and that the container is without any holes for the worms to crawl out of (Vinnerås, 2013).

Figure 4. Plastic boxes used as vermicomposting boxes during project. Photo: Nazanin Mahmoudi

3.4 Earthworms in vermicomposting

There are several species of earthworms suitable for vermicomposting, e.g. *Eisenia foetida*, *Eudrilus eugeniae* and *Perionyx excavatus* (Reinecke et al. 1992). The limiting factor for which species to use for vermicomposting is temperature. The ideal temperature for the worms to thrive is 25°C, but as temperatures often tend to either exceed or go below 25°C, it is important to use a species tolerant of a wide temperature span. The worms used in this project are of the species *Eisenia foetida*, which in studies have been proven to be the most suitable for regions in South Africa (Reinecke et al. 1992). They have, in comparison to the other species mentioned, a broader tolerance span of temperatures and can survive in temperatures down to 5°C and even up to 43°C. It is their suitability for vermicomposting as well as their wide temperature tolerance that make them the best suited for vermicomposting in South Africa. They are according to Reynolds (1977, cited by Beyer et al, 1985), originally native to Europe and Asia, although now they have become widely distributed in North and South America, as well as Africa and Australia.

According to Reinecke et al. (1992), *Eisenia foetida* grow better at fluctuating temperature and they showed fully developed after 59 days at 25°C (Figure 5). At the age 74 days, *Eisenia feotida* start producing cocoons at 25°C and the mean number of produced cocoons per worm and days is 0.24 at 25°C.

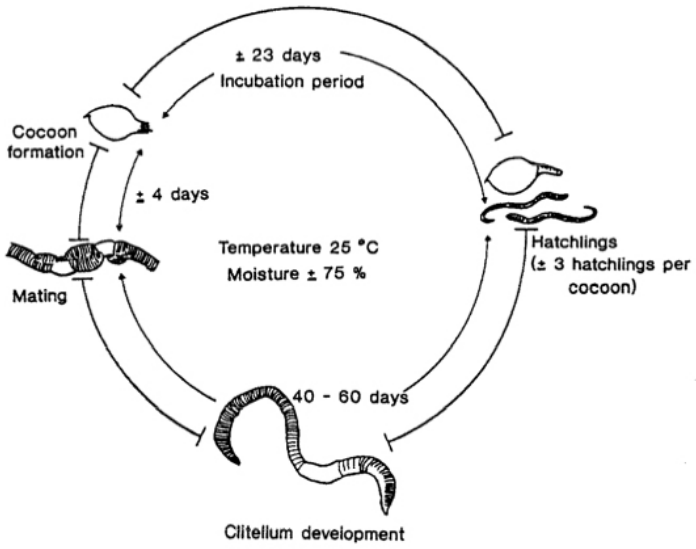

Figure 5. The life cycle of *Eisenia foetida*, (Venter and Reinecke, 1998).

Eisenia foetida live in or near organic surface litter. They feed primarily on coarse particulate organic matter and consume large amounts of undecomposed litter (Dominguez et al., 2004); such as animal excreta, sewage sludge, human faeces, crop residues and agricultural wastes and raw organic wastes.

4 Materials and methods

4.1 Experimental sites and toilet set-up

4.1.1 UD toilets in eThekwini Municipality

Currently a lot of research on different use of UD toilets is conducted in the eThekwini Municipality. The toilets bowls are produced locally by Ecosan. Three UD toilets were used in this project, two of them situated in the Seziphapheme garden (Figure 6a) and one in the Sukumani garden (Figure 6b). A plan for designing UD toilets in the Seziphapheme and Sisonke gardens is displayed in Appendix I. The toilet chambers and vaults were made of concrete. There were two lids to the vaults, one for each, made of plastic. To each vault a plastic pipe was attached to decrease the smell in the toilet. In the vault, there is a ramp of approximately 45° slope. On the inside of the toilet chamber, there was a toilet bowl and a urinal made of plastic.

Although of the same design, differences between the toilets occur due to differences in that way in which they were constructed. The pipes inside the vaults are meant to be at level with the ceiling of the vault, but may often have slid down before the concrete set and may turn out to be an obstacle when inserting boxes into the vault. The opening of the toilet vaults may also be of different sizes from the plans.

a) b)

Figure 6. UD toilet in Seziphapheme; a) the outside and b) the inside. ***Photo: Carolina Gårdefors***

4.1.2 Research sites

Two different co-operative gardens were chosen as testing sites for the project. The gardens were built by the eThekwini municipality, and were supplied with compost materials and seeds from the Agriculture Hub at Newlands Mashu. The gardens were started as a project to teach the local people, including people with less or no income, knowledge of how to cultivate the local soil (IOL, 2013).

The gardens were located mainly in Inanda. The two sites used in this project were called Seziphapheme and Sukumani, and both were situated near Inanda Dam. There were two UD toilets in Seziphapheme (Figure 7) and one in Sukumani (Figure 8).

Figure 7. Two UD toilets in Seziphapheme garden. ***Photo: Nazanin Mahmoudi***

The gardens produced cabbage, sweet potato, tomato and spinach among other crops, and were maintained by local people under the guidance of qualified horticulturalists. The gardens provided not only food for the people, but also income-generating opportunities. The idea was that by learning land cultivation at the garden sites, the people would be able to use the knowledge to later set up small, income-generating, businesses of their own (IOL, 2013).

Figure 8. Sukumani garden, UD toilet can be seen to the left in the picture. ***Photo: Nazanin Mahmoudi***

4.1.3 Toilet measurements

Before visiting the sites, a toilet design from Envirosan (Appendix I) was used to gather information about the UD toilet dimensions (Rust, 2013). The toilet plan had the same design as the majority of the UD toilets in eThekwini municipality, although almost every toilet in the project had their own distinctions. Measurements of UD toilets vault opening and faeces compartment made it easier to decide the size of vermicomposting boxes. It was important to choose a material that would not affect the worms. Plastic boxes appeared to be the most appropriate selection, since it does not release any chemical substances, which can affect the worms. As the plastic boxes had a compact bottom, it also made it more difficult for the worms to escape from the boxes.

The volume of the faeces compartment and the dimension of the existing opening into which the plastic box was inserted were decisive in determining the volume of the plastic boxes. Within the plan it was possible to decide UD toilets dimensions in reality by using a ruler. The existing openings were given in the toilet plan.

Because of a slope in the toilets it was also necessary to have a plastic box with small wheels attached to it.

It was found that the maximum size that the vermicomposting boxes could be was:
Depth – 1.10 m;
Width – 0.74 m;
Height – 0.40 m.

This means that it was most sufficient to use plastic boxes, which had the dimensions approximately 1 m x 0.5 m x 0.5 m (Figure 19).

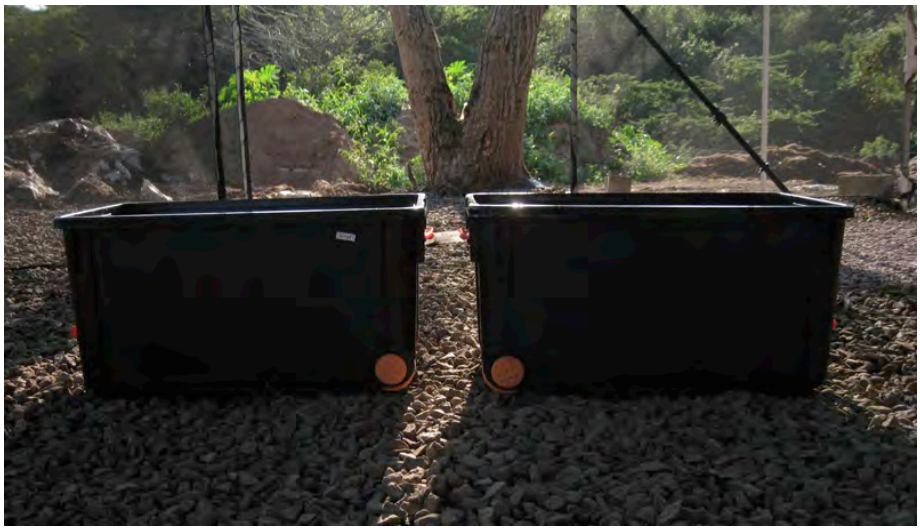

Figure 19. Plastic boxes that have been used throughout the project. Photo: Nazanin Mahmoudi

Metal boxes are not preferable as the leaching of metals such as aluminium might poison the worms (Vinnerås, 2013). Wooded boxes are not recommendable either as there is a risk the worms might escape from gaps in the corners (Vinnerås, 2013). Plastic boxes are the most optimal material to use, as there are no chemicals leaching and no risks of holes in the boxes.

4.1.4 Setting up the vermicompost

The worms *Eisenia foetida* are sensitive to heat and are likely to die if the temperature increases above 43°C if they cannot escape, as was mentioned in Section 3.4. It was therefore important that the vermicompost was designed in such a way that temperature would be tolerable for the worms, by not including too high quantities of energy-rich materials. In compost that consists entirely of fresh faeces, there is a possibility that the ammonia concentration could be too high for the worms. A safety zone is necessary within the compost for the worms to retreat if the conditions become unfavourable to the worms. The safety zone in this project consists of different kind of so-called bedding materials.

The setup of bedding materials should resemble mature compost in characteristics, as mature compost is relatively stable. The materials should not be active, as active compost might lead to heat build-up. The bedding materials should also have a pH buffering capacity, as it is likely that the addition of ammonia occurs from urine.

In this project, two different compositions of bedding materials were used: one of vegetable compost (Figure 9a) and local topsoil (Figure 9b) and the other one of potting soil and fully digested sludge mixed with soil (Figure 10). The vegetable compost, the topsoil and the potting soil were all taken locally at the Newlands Mashu Agriculture site, whereas the digested sludge was collected from the Phoenix Treatment Plant.

a) b)

Figure 9. Vegetable compost (a) and local top soil (b) used as bedding material. ***Photo: Carolina Gårdefors***

Figure 10. Potting soil used as bedding material. ***Photo: Carolina Gårdefors***

Before the bedding materials were introduced into the vermicompost, a layer of wet, rolled up newspapers were placed at the bottom of a large plastic container, to encourage cocoon laying (Lalander, 2013). The bedding materials were mixed and put into the container. Each composition was mixed in a 1:1 ratio. The bedding materials were placed on top of the newspapers, completely covering it (Figure 11).

Figure 11. The plastic container used as collection bin of the solid toilet fraction, in which the vermicomposting took place. Wet rolled up newspaper covered the bottom of the bin. ***Photo: Carolina Gårdefors***

The newspapers and the bedding materials together filled up about a third of the container volume. The worms were added into the compost once all materials were mixed in the containers (Figure 12).

Figure 12. The earthworms ***Eisenia foetida*** **used for vermicomposting.** ***Photo: Carolina Gårdefors***

The containers were fitted into the toilets, with one container each put into the vault of each UD toilet. The idea was that the faeces would be added into the compost continually as the toilets were being used.

The hypothesis was that the vermicomposting in the toilets would become mostly self-governing, and would only need to be watered at need and emptied once filling the composting bin (Vinnerås, 2013).

4.2 Sampling and analyses

Sampling and analyses were performed on three occasions during a two-week period.

4.2.1 Experimental set-up

Three toilets were monitored. Two toilets were used as testing sites and one was used as a control. In the two testing sites, two different experimental set-ups were used (Table 1). Worms were added to both testing sites.

Table 1. The set-up of the different materials used in the experiment.

Compost	Contents at the start of experiment	Number of worms
Control	Human faeces	0
Compost 1	Vegetable compost and local top soil	Approx. 2000
Compost 2	Potting soil and digested sludge	Approx. 2000

4.2.2 Titration of bedding material

Urine is rich in ammonia (NH_3); it is possible, and likely, that the addition of urine could therefore increase the amount of NH_3 in the compost. The concentration of NH_3 can be related to the pH level; the higher the amount of NH_3 the higher the pH (Emerson et al, 1975). The ratio of ammonia (NH_3)/ammonium (NH_4) can be evaluated by measuring the pH. The worms are sensitive to high concentrations of NH_3; it is thus important that the bedding material can sustain the right pH level for the worms to survive, even if some urine would enter the compost. That is, the compost should preferably have a good capacity of buffering addition of base and the buffer regions of the materials were of interest in determining their suitability for vermicomposting. A titration was performed on each bedding material to determine the pH region at which the highest buffering occurred.

Four materials (vegetable compost, top soil, potting soil and digested sludge) were used for making two different bedding materials: the first composition (Compost 1) consisted of vegetable compost and topsoil while the second (Compost 2) consisted of potting soil and digested sludge. For each of these four materials, 100 g of the dry material was mixed with 400 g of distilled water in a kitchen blender. For Compost 1, 20 ml of the blended solution of vegetable compost was mixed with 20 ml of the blended topsoil solution. For Compost 2, 20 ml of the blended potting soil solution was mixed with 20 ml of the blended digested sludge solution. As this analysis aimed to find the pH buffering region concerning addition of NH_3, a basic solution of 0.1 M NaOH was used. The solution was made by dissolving 4.007 g of NaOH-pellets in 1000 ml of distilled water.

The titration was performed using a “Tim 870” titrator. One titration per sample was performed. The 40 ml solution was put into a plastic cup, to which a magnetic stirrer was added. The titrator added 1 ml base solution per second to the mixture, in which a pH meter measured the pH level continuously. The titrator was programmed to add the base solution at the given rate until the desired pH level, in this case pH = 12, was reached. The titrator documented the experiment and presented a graph of the pH of the solution against the amount of added base, from which the pH buffering region could be determined.

4.2.3 Counting of worms and cocoons

A sample of a specified volume was taken from each compost and the number of worms and cocoons in the sample determined. A 100 ml beaker was pushed sideways down into the middle of the compost, in order to get a cross-sectional representation of the compost (Figure 16).

Several cross-section samples of a 100 ml were taken from the composts and the number of worms and cocoons in each sample were counted (Table 2). The samples were taken from the middle of the composts. The composts were approximately 40 cm deep. Three samples were taken from the composts within a time period of two weeks. A control sample was taken from the compost before being put into the UD toilet.

Figure 16. A 100 ml beaker pushed sideways down into the compost for collection of a cross-sectional representation of the compost. ***Photo: Nazanin Mahmoudi***

4.2.4 Solvita®

Solvita® is a respiration test system to acquire information about the maturity of a compost. The Solvita® test is an easy to use test, which measures the release of carbon dioxide (CO_2) and NH_3; gaseous emissions that are the most prominent in active composts (Official Solvita Guideline, 2012). Through measurements of the amount of CO_2 and NH_3 emissions it is possible to evaluate whether the compost is active or matured.

A small jar and two different kinds of sensors were used to estimate the compost maturity; the two different kinds of sensors measure CO_2 and NH_3 concentration, respectively (Figure 17).

Figure 17. The Solvita® sampling jars with the CO_2 (purple) and NH_3 (yellow) sensors prior to use (Solvita, 2013).

Before starting with the Solvita® test, it was important to find out if the sample was sufficiently moist. If the sample was too dry, it was necessary to moisten the sample for one day, otherwise it was approvable to start with the Solvita® test directly. By doing the so-called snowball test, it was possible to found out if the sample was dampened enough. The snowball test was conducted by grabbing a piece of sample and shaping it into a snowball. If the sample could be shaped into a ball without falling apart and a small amount of liquid dripped between your fingers, the sample was moisturized enough (Official Solvita Guideline, 2012).

Solvita® test is feasible by adding two sensors into a small plastic jar (Figure 8). Separate readings of CO_2 and NH_3 were obtained; the color of the sensor after 4 h is correlated to an accompanying colour schemes, one for the CO_2 sensor and one for NH_3 sensor (Figure 18). The Solvita® indexes for NH_3 and CO_2 gives a combined Solvita® index (Official Solvita Guideline, 2012), (table of NH_3 and CO_2 indexes, see Appendix II).

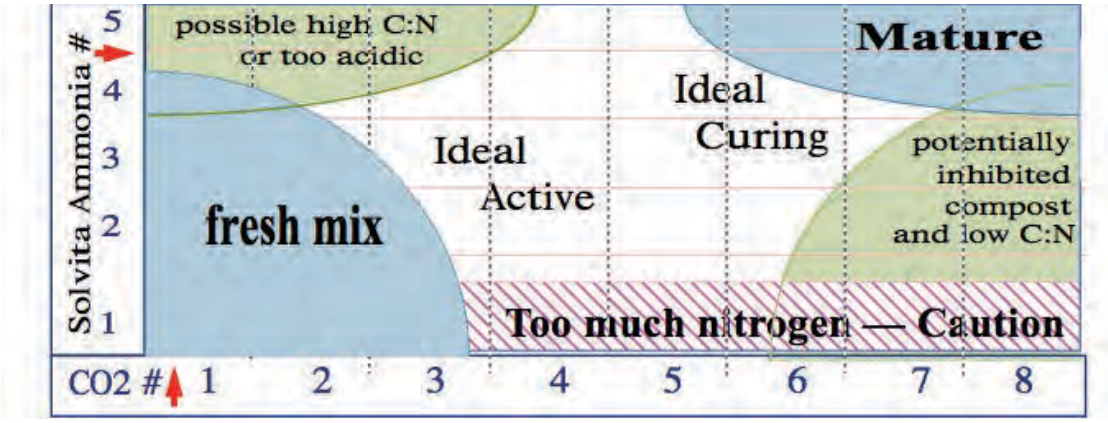

Figure 18. A graph showing the status of the composting process that can be measured using the Solvita® test kit (Solvita, 2013).

4.2.5 pH

pH measurements of the compost materials were conducted by collecting 100 g of material and removing all the worms and cocoons. The sample was diluted in 400 ml deionized water and mixed into sludge using a kitchen blender, upon which the pH was measured.

4.10 Temperature

The temperature was measured approximately 5 cm into the compost.

4.2.6 Total solids and total volatile solids

Matter suspended or dissolved in water is referred to as suspended and dissolved solids (Standard Operation Procedure, 2013). Total solids (TS) include total suspended solids and total dissolved solids and are the residual material after evaporating a sample at a defined temperature for a defined time (Standard Operation Procedure, 2013). The residue of the total solids after heating to dryness at a specified temperature for a specified time is referred to as fixed solids and the weight loss on ignition is called volatile solids (VS) (Standard Operation Procedure, 2013) and is a measure of the organic content in the TS. In this project, analyses were made for TS and VS.

TS was measured by evaporating a known volume of a well-mixed sample in a porcelain crucible at 105 °C for 24 h. For performance characteristics each sample was divided in equal amount into two crucibles. After heating the samples in the oven for 24 hours, the crucibles were put into a desiccator to cool down. When the samples had cooled down, the weight of the sample and the crucible were measured and documented. In the project, 14 samples were examined 3 times during two weeks. VS was analysed at 550°C for about 4 h, upon which the crucibles were put into the desiccator to cool down and be weighed.

The TS and VS were measured using the equations below (Standard Operation Procedure, 2013):

$$Total\ Solids\ [g/g] = \frac{(W_2 - W_{crucible})}{W_{sample}} \quad (1)$$

$$Volatile\ Solids\ [g/g] = \frac{(W_3 - W_{crucible}) - (W_2 - W_{crucible})}{W_{sample}} \quad (2)$$

$$Ash\ [g/g] = \frac{W_3 - W_{crucible}}{W_{sample}} \quad (3)$$

where:
W_{sample} = weight of sample before heating for 105° in oven [g] without crucible;
$W_{crucible}$ = weight of crucible [g];
W_2 = weight of sample [g] + crucible [g] after heating for 105°C in oven;
W_3 = weight of sample + crucible after heating for 550°C in furnace.

4.3 Safety equipment for sample collection

Because of the environment and the risk of contamination, it was important to use safety equipment; rubber boots, arm length rubber gloves with another pair of smaller rubber gloves underneath, were used. Over a blue cotton overall, a lab coat was worn, for simple removal when not dealing with toilets, faeces or worms. To avoid aerosol particles from the UD toilets, a gasmask was used.

Figure 13. Sample collection using full protective equipment. ***Photo: Nazanin Mahmoudi.***

5 Results

5.1 Titration of bedding material

A titration was performed on the two bedding materials to find the pH buffer region (Figure 20). The initial pH was approximately 8 for Compost 1 (vegetable compost and topsoil) and approximately 6 for Compost 2 (potting soil and digested sludge). The pH levels increased continuously up to about pH 10 for both compositions, after which the increase slowed down until reaching pH 12. The pH levels increased faster for Compost 1 with less amount of added base solution.

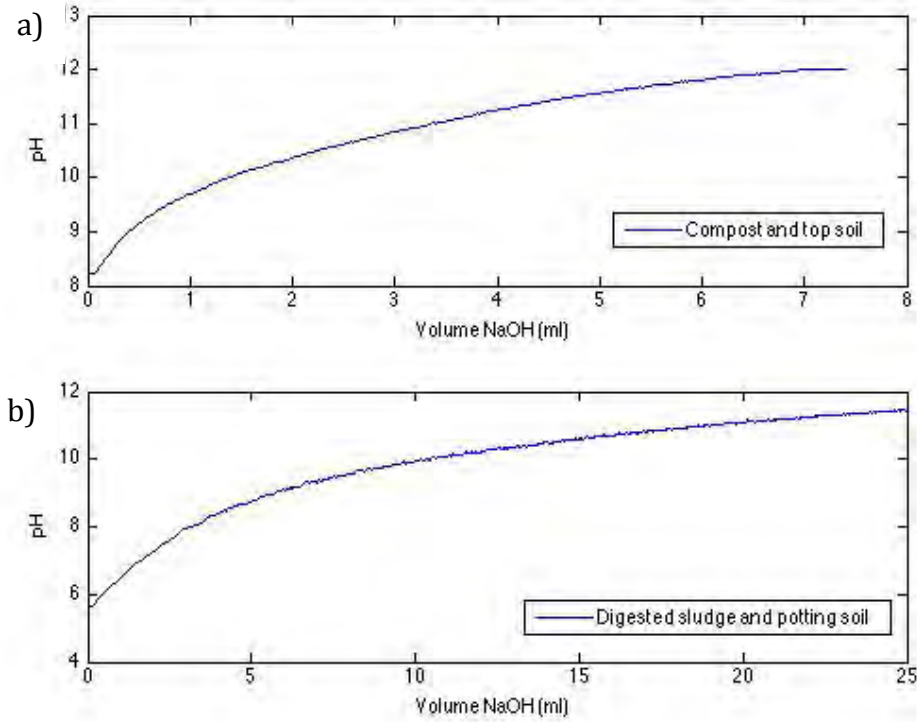

Figure 20. The buffer regions of a) compost and top soil and b) of digested sludge and potting soil.

5.3 Counting of worms and cocoons

Most worms and cocoons were found in Compost 1, while there appeared to be an increase in Compost 2 (Table 2).

Table 2. Number of worms and cocoons in a 100 ml cross section sample.

Material	Date	Worms (worm/100 ml compost)	Cocoons (cocoons/100 ml compost)
Compost prior to start	130802	40	9
Compost 1	130802	160	25
	130805	73	11
	130807	78	16
Compost 2	130802	74	14
	130805	53	6
	130807	103	14

5.4 Solvita®

The control test, formed prior to placing the composts into the UD toilets, suggested that the composts initially had ideal curing (Compost 1) and were well matured (Compost 2) (Table 3). The Solvita® index of faeces suggested that composted faeces hold the same characteristics as mature compost. During the experiment, the Solvita® index suggested that all composts had either ideal curing or were well matured.

Table 3. Solvita® index for the composts and of the faeces.

Material	Date	Solvita® NH_3	Solvita® CO_2	Solvita® Index	Comment
Compost 1 (control)	130714	5	6	6	Ideal curing
Compost 2 (control)	130714	5	7	7	Well matured
Compost 1	130802	4	6	6	Ideal curing
	130807	5	7	7	Well matured
	130812	5	6	6	Ideal curing
Compost 2	130802	5	6	6	Ideal curing
	130807	5	6	6	Ideal curing
	130812	5	7	7	Well matured
Faeces	130802	5	8	8	Mature

5.5 pH

The pH levels stayed relatively stable during the experiment, around pH 7-8 for Compost 1 and around pH 5-6 for Compost 2. The pH in the control toilet increased from around pH 7 in the first test to about pH 9 in the two following measurements.

Table 4. pH for different sites for different dates and samples.

Date	Sample	pH		
		Control	Compost 1	Compost 2
130802	1		8.12	5.99
	2	7.96	8.67	6.32
	3		7.81	6.02
130807	1		7.8	6.1
	2	9.19	8.52	6.35
	3		7.74	5.85
130811	1		8.01	6.68
	2	9.22	7.52	6.48
	3		8.36	6.49

5.6 Temperature

The temperature was measured in the composts in order to control the potential temperature increase (Table 5). The temperature was found to be approximately the same as the surrounding air temperature, between 21-24°C.

Table 5. Temperature for different sites for different dates and samples

Date	Sample	Temperature (°C)		
		Control	Compost 1	Compost 2
130802	1		23.8	23.3
	2	21.6	21.2	22.3
	3		23.9	23.1
130807	1			
	2			
	3			
130811	1		21.8	
	2		21.1	22.4
	3			

5.7 Total solids and total volatile solids

The TS and the VS were calculated using Equations 1-3 (Table 6). More detailed results can be seen in Appendix III, Table 1-3. The TS were between 50-60% for both composts and around 70-80% for the faeces. The VS were between 8 – 30 % for both composts, thus a relatively low amount of organic matter in the samples. The VS of faeces were approximately around 5-6 % and contained approximately 70 % of ash.

Table 6. TS and VS in the composts and control toilet.

Sample Name	TS [g/g]	VS [g/g]	Ash [g/g]
Compost 2	0,55	0,17	0,38
	0,54	0,17	0,37
Compost 2	0,51	0,17	0,34
	0,50	0,18	0,33
Compost 2	0,54	0,16	0,38
	0,52	0,16	0,35
Compost 1	0,62	0,10	0,51
	0,61	0,11	0,50
Compost 1	0,52	0,11	0,41
	0,55	0,10	0,45
Compost 1	0,53	0,12	0,41
	0,53	0,12	0,42
Faeces (Control toilet)	0,78	0,06	0,71
	0,79	0,05	0,73

6 Discussion

6.1 Toilet measurements

It was found that every UD toilet in Durban was unique. The UD toilets own distinctions made it more challenging to decide the appropriate box size for the toilets. It was important to choose a plastic box that could handle the amount of material produced within the six months before eThekwini municipality would empty the vaults. Therefore, the plastic box with the measurements 1 m x 0.5 m x 0.5 m were the most appropriate choice compared to other smaller boxes. The size was suitable for the 2,000 worms used in the project, the faeces material and bedding material, though sometimes the UD toilet visitors would throw newspapers or even sand to cover material on top of plastic boxes. To avoid situations like this, it was important to spread information about not throwing other items except for toilet papers into UD toilets. Otherwise foreign objects could disturb the vermicomposting process and complicate the follow-up procedure.

6.2 Bedding material

The initial pH level for the compost and topsoil solution was approximately 8, which was relatively close to the critical pH levels where the worms might die. The initial pH value for the digested sludge and potting soil mixture was approximately 6.

The pH levels for Compost 1 increased to the maximum levels with a lesser amount of added base than for Compost 2. The results suggest that there is a risk in using the first combination of bedding materials, as there could be a risk that the critical pH level could be exceeded in the compost with relatively little addition of urine. Based solely on the results of the titration, the results suggest that Compost 2 would be more suitable for vermicomposting, although no distinct difference could otherwise be seen between the materials in the project, although the time period was not long enough for any conclusions to be made.

6.3 Counting of worms and cocoons

The number of worms and cocoons in the different composts varied during the two weeks, and there are numerous uncertainties as to why. All samples were taken as a cross section in the middle of the composts, but there are no certainties that the samples were representable for the number of worms in the whole compost. When examining the composts, it was found that the majority of the worms were situated in the rolled up newspapers at the bottom of the plastic boxes. For simplicity, no newspaper was included in the samples taken for counting. The short time period and the few sampling occasions makes it difficult to determine how well the composts were functioning, but the results suggests that there was a high possibility the worms could survive, and multiply, in the composts.

When the composts were inspected one week after installation, one vermicompost container was almost filled completely with newspaper used for anal cleansing, but at inspection after yet another week, almost all the newspaper had disappeared, possibly digested by the worms.

6.4 Solvita®

The result suggests that the composts stayed either curing or well matured during the project. None of the composts reached the state of active compost during the experiment period. This indicates that there are no obvious reasons such as weather and climate conditions why vermicomposting would not be a suitable option for UD toilets in South Africa, although a longer experiment period and a greater number of experimental composts would have been necessary in order to draw any conclusions.

During control tests, Solvita® tests of faeces were proven to be mature. This is unlikely as fresh faeces still contain decomposable organic matter, which means there should still be some decomposition activity within the material. The result might be due to the faeces being mixed up with ash or sand or any other material used to cover the faeces.

The humidity was around 80 % and there was no need to damp the composts throughout the project for the last two weeks. Before installing the vermicomposting boxes in the UD toilets, the humidity was below 80% and had to be humidified. Reason for this might be the lack of lack of faeces.

6.5 pH

The pH levels were relatively constant around pH 8 for Compost 1 and around pH 6 for Compost 2. The pH in the composts corresponded well to the initial pH obtained from the titration, which suggests that the pH levels stayed stable during the period the vermicomposts were installed in the UD toilets and that the pH did not reach, for the worms, critically high levels. The pH of faeces in the control experiment was 7 for the first measurement, but increased to pH 9 in the two following measurements. The difference between the first value and the two following might be due to the first sample being taken from on top of the pile, where the faeces were most recently produced, and the others from deeper into the composts. Ash is sometimes used to dry out the faeces in the toilets; therefore different contents of ash in the samples might also explain the difference in pH.

6.6 Temperature

Throughout the project the temperatures in the vermicomposting boxes were around 22-28°C. The temperature interval was good as it did not exceed the maximum temperature level of >35°C. Though, it is hard to decide if the activity was too high or low since the follow-up did not go for as long a period as expected. Depending on season, the climate might have the ability to affect the temperature rate in the vermicomposting boxes. As the analysis was done during the winter period in Durban, it can be different compared to summer season when the humidity and temperature is higher.

6.7 Total Solids & Total Volatile Solids

Expected value for the TS from composting is approximately 20-30% and optimum for the worms is up to about 40%. The results from the TS measurements showed that the compost was dry, almost too dry for the worms. However, this was the result from the first week, and might change as the compost progresses. The results from the VS measurements showed that there was a low amount of organic material in the compost. This is probably a result of a high amount of ash in the sample.

7 Conclusions

The project only progressed for two weeks, which made it challenging to draw any definite conclusions. As there have been good conditions to start the research, e.g. environment, material and field, there are possibilities to do further research for a longer period of time. During winter season the temperature varied from 22-28°C, which can be considered as an ideal temperature range. The Solvita® test also indicated that the samples were curing or well matured, which means that the compost material was not too active. This is considered ideal, as the temperature would not rise significantly. The pH was stable throughout the project and the pH values from the compost were similar to the initial pH from the titration. The initial pH of Compost 2 (potting soil and fully digested sludge) were lower compared to Compost 1 (vegetable compost and local top soil), which suggests it might be more suitable for vermicomposting, as there is a higher tolerance range concerning the addition of urine.

It was difficult to determine the amount worms and cocoons in the boxes since the worms usually were situated towards the bottom of box, mostly in the rolled up newspaper at the bottom. The analysis only progressed for two weeks and there were therefore difficulties in making statistical statements about the amount of worms and cocoons.

There were complications when it came to deciding the size of the plastic boxes. To determine the size of plastic box, it was essential to visit the sites and take measurements of the UD toilets in reality. Since it was not possible to visit the sites until the last three to four weeks, decisions had to be made quickly. All the required materials for the project were thus obtained before visiting the sites. Even though there were difficulties because of the circumstances, the plastic boxes were ideal for the project.

TS for both of the vermicomposts were around 50-60%, which could suggest that the composts were too dry. The optimal value is 70-85% water and 40% TS. This means it was necessary to water the vermicomposts more often. The VS was low, which means that there little organic matter in the compost, as well as high contents of ash. As the VS test only went through for one week, it is hard to tell how well the vermicomposts decomposed the faeces or if the faeces were even included in the compost circulation.

In conclusion, the project showed that there is clearly a potential for vermicomposting in UD toilets in South Africa, but further studies would be needed to confirm this hypothesis. There is also an interest in finding ways of reusing human waste. Studies of the reducing of pathogens in the composts would be of great interest.

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Appendix I

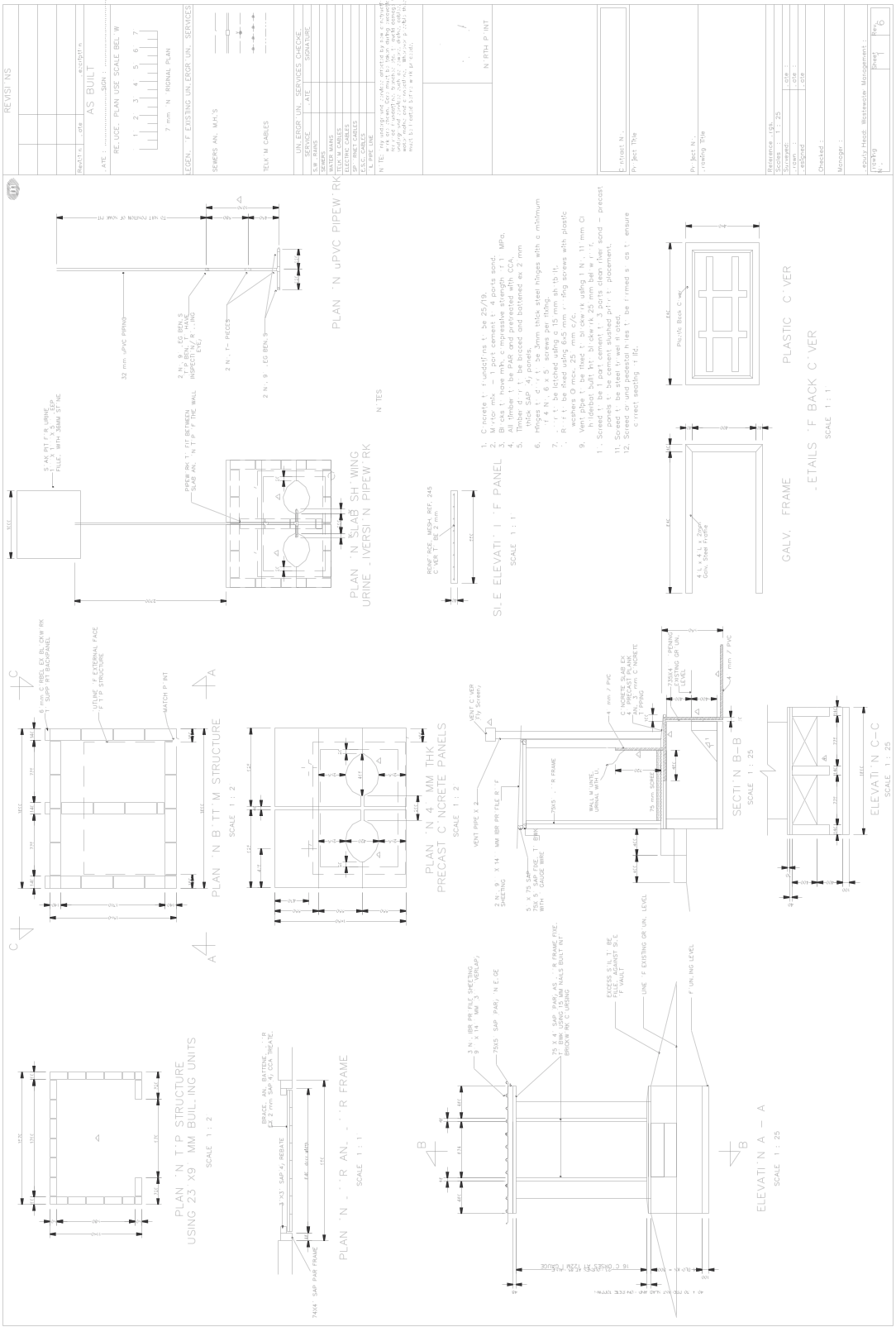

Figure 1. UD toilet plan from Envirosan (Rust, 2013).

Appendix II

Table 1. Maturity of the compost from the Solvita test.

8	Inactive, highly mature compost, very well aged, possibly over-aged, like soil; no limitations for usage	"FINISHED" COMPOST
7	Well matured, aged compost, cured; few limitations for usage	
6	Curing; aeration require reduce; compost ready for piling; reduced management requirements. Solvita 6 *and above is commonly recognized as suitable maturity for official uses*	Curing
5	Compost is moving past the active phase of decomposition and ready for curing; reduced need for intensive handling	"ACTIVE" COMPOST
4	Compost in medium or moderately active stage of decomposition; needs on-going management	
3	Active compost; fresh ingredients, still needs intensive over-sight and management	Very active
2	Very active, putrescible fresh compost; high-respiration rate; needs very intensive aeration and/or tuning	"RAW" COMPOST
1	Fresh, raw compost; typical of new mixes; extremely high rate of decomposition, putrescible or very odorous material	

Appendix III

Total Solids and Total Volatile Solids

Table 1. Results from Total Solids and Total Volatile Solids. Date: 05-08-13

Sample Name	Crucible No.	Crucible Mass (g)	Sample Mass (g)	Residue + Crucible Mass after Oven (g)	Residue + Crucible Mass after Furnace (g)
Compost 2 (1)	1	37.5616	10.0351	43.0661	41.3871
	2	38.8443	10.0277	44.2733	42.5772
Compost 2 (2)	1	39.8982	10.0025	45.0292	43.3089
	2	36.8474	10.0489	41.8767	40.1178
Compost 2 (3)	1	35.5149	10.0144	40.9254	39.3135
	2	39.6841	10.0902	44.8836	43.2365
Compost 1 (1)	1	34.0319	10.0584	40.2255	39.1706
	2	28.3066	10.0327	34.3856	33.3107
Compost 1 (2)	1	41.1904	10.0664	46.4331	45.3584
	2	40.2531	10.02	45.8089	44.7776
Compost 1 (3)	1	33.222	10.065	38.5674	37.3751
	2	34.7843	10.0374	40.1503	38.9658
Faeces (Sukumani)	1	40.1852	10.0655	47.9096	47.2992
	2	34.8409	10.1173	42.7934	42.2417

Table 2. Results from Total Solids and Total Volatile Solids. Date: 06-08-13

Sample Name	Crucible No.	Crucible Mass (g)	Sample Mass (g)	Residue + Crucible Mass after Oven (g)	Residue + Crucible Mass after Furnace (g)
Compost 2 (1)	1	34.0328	10.0286		37.8074
	2	39.6881	10.0548		43.4543
Compost 2 (2)	1	41.1912	10.0365		44.4737
	2	35.5158	10.03041		39.0914
Compost 2 (3)	1	34.7853	10.0987		38.6672
	2	37.5628	10.0073		41.4856
Compost 1 (1)	1	38.8427	10.027		43.2289
	2	40.2532	10.0492		44.3867
Compost 1 (2)	1	39.8998	10.1569		44.9182
	2	28.3076	10.0013		33.6109
Compost 1 (3)	1	40.1867	10.0043		46.7972
	2	33.2724	10.065		39.6834
Faeces (Sukumani)	1	30.4451	10.0858		44.038
	2	36.9289	10.0215		37.5266

Table 3. Results from Total Solids and Total Volatile Solids. Date: 11-08-13

Sample Name	Crucible No.	Crucible Mass (g)	Sample Mass (g)	Residue + Crucible Mass after Oven (g)	Residue + Crucible Mass after Furnace (g)
Compost 2 (1)	1	30.4437	10.0928		33.7977
	2	33.2201	10.0276		36.5342
Compost 2 (2)	1	49.2516	10.0078		43.6757
	2	40.185	10.0483		43.7911
Compost 2 (3)	1	28.3069	10.0124		31.7822
	2	41.189	10.0465		44.4108
Compost 1 (1)	1	34.7844	10.0995		39.4969
	2	39.8984	10.0371		44.5273
Compost 1 (2)	1	36.9292	10.1766		40.8007
	2	38.8414	10.0385		42.0755
Compost 1 (3)	1	37.517	10.0747		43.5537
	2	39.6845	10.0914		45.3161
Faeces (Sukumani)	1	35.5149	10.0731		41.2722
	2	34.0319	10.1361		40.7797