Pathogen Destruction and Aerobic Decomposition in Composting Latrines: A Study from Rural Panama

By

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This report "Pathogen Destruction and Aerobic Decomposition in Composting Latrines: A Study from Rural Panama" is hereby approved in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING.

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Preface

This report is based on my experiences and research during the 27 months I spent as a Peace Corps Volunteer in Panama, Central America from August 2006 to October 2008. I worked as an environmental health extension agent in Tolothe, Panama in the indigenous region, la Comarca Ngöbe-Buglé.

This report is submitted to complete my master's degree in Environmental Engineering from the Master's International Program in Civil and Environmental Engineering at Michigan Technological University. It focuses on the surveying of composting latrines in several indigenous communities I visited while conducting my research.

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Abstract

The United Nations estimates that 2.5 billion people worldwide lack access to basic sanitation (United Nations, 2008). Inadequate sanitation causes diseases and deaths—about 2 million people die every year from diarrheal diseases (WHO, 2008). In Panama, while 90% of the population has some form of sanitation, only 25% of those living in the indigenous reservation, Comarca Ngöbe -Buglé, has access to sanitation (ANAM, 2006).

Composting latrines are a common sanitation solution in rural Panama. These latrines are assumed to effectively destroy pathogens in human excrement through aerobic decomposition at high temperature—the composting process. However, according to several studies (summarized in Hurtado, 2005; Kaiser, 2006), the majority of composting latrines in developing countries never reach high enough temperatures for pathogen removal. Instead, studies (summarized in Kaiser, 2006) suggest that desiccation at high pH may be the responsible means of pathogen removal; yet, the breakdown of organic matter is hindered at high pH and low moisture levels.

To assess the relationship between temperature, high pH, desiccation, decomposition, and pathogen destruction, a survey to observe the use of desiccant and obtain temperature and pH measurements was conducted on 63 composting latrines in five indigenous communities. Furthermore, compost samples were taken to a laboratory for chemical and microbiological analysis to test for pH, % moisture, carbon-to-nitrogen (C/N) ratio, and presence of pathogens.

The temperature results support previous findings that compost latrines do not get hot enough to kill pathogens; rather, the latrines remained close to ambient temperatures. The pH results show that many latrines were operating within the range for ideal decomposition, pH of 7.5-8.5 (Jenkins, 1994), but only 17% of latrines measured pH 9 or above, the recommended pH for pathogen destruction (WHO, 2006). Most composting latrine users added desiccant materials, sawdust and wood ash, to lower the moisture level and provide the necessary carbon for decomposition. However, it seems not enough desiccant materials were added because moisture levels remained above the suggested maximum of 25% for pathogen destruction (WHO, 2006) and C/N ratios were in the range of the ratio of raw human faeces. More importantly, the results of the microbiological analysis show various pathogens, mainly helminthes, still present in the compost samples that had been stored for the recommended 6-month storage time.

From these results, it follows that pathogens are not being removed in composting latrines nor is aerobic decomposition taking place. As a means of sanitation, composting latrines must be operated to destroy pathogens. Storage time should be increased to a minimum of 1-year, and users should be instructed to add more desiccant materials of both the high pH type (e.g., wood ash) and bulky type (e.g., sawdust). The current composting latrine design used in Panama will need to be adjusted for the longer storage time.

Chapter 1: Introduction

Basic sanitation is an integral human right and essential to the health and livelihood of people and their environments. However, 2.5 billion people live without adequate sanitation, and in developing regions, 1 in 4 use no form of sanitation (United Nations, 2008). Inadequate sanitation causes diseases and deaths worldwide—about 2 million people die every year from diarrheal diseases (World Health Organization (WHO), 2008). One of the Millennium Development Goals is to improve sustainable access to basic sanitation, a critical step in reducing global poverty. Without basic sanitation, health, social, and economic development cannot advance (WHO, 2008).

The sanitation situation in Panama is commendable with 90% of its population having access to various sanitation systems from latrines to septic tanks to wastewater systems (Autoridad Nacional del Ambiente (ANAM), 2006). Unfortunately, sanitation access within the indigenous reservation, Comarca Ngöbe-Buglé, is not so admirable (Figure 1). Here only 25% of the population has adequate access to basic sanitation (ANAM, 2006). Further complicating matters is the high water table and intermittent flooding from high rainfall in the Caribbean side of the Comarca. This makes simple sanitation solutions like the pit latrine unsuitable in these areas. Therefore, Peace Corps Panama has been promoting the construction of composting latrines (this type of latrine is built above ground) as an acceptable means of sustainable sanitation.

Figure 1: Map of Panama
From: http://en.wikipedia.org/wiki/Image:Countries-Panama-provinces-2005-10-18-en.png.
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The theory of the composting latrine is a safe and effective sanitation method to destroy pathogens in human excrement through aerobic decomposition at high temperature—the composting process. Latrines are designed to separate urine from faeces and the urine may, or may not, be collected for use as a fertilizer. Latrine users add a desiccant (e.g., sawdust and wood ash) to the latrine after defecation, and after some time, seal off the latrine chamber for a 6-month minimum to allow the composting process to take place. It is thought that during this composting process that temperatures are sufficiently elevated for an adequate amount of time to kill pathogens. However, according to several studies (see Chapter 2), the majority of composting latrines in developing countries never reach high enough temperatures for pathogen removal. Instead, studies suggest that desiccation at high pH may be the responsible means of pathogen removal. This leads to the question: is sufficient dry material being added in composting latrines to reduce moisture levels and/or raise the pH high enough to kill pathogens? On the other hand, high pH and low moisture hampers aerobic decomposition, and therefore, the fundamental biochemical processes that produce compost itself.

Accordingly the objectives of this research are to:

1) Evaluate if high pH and desiccation are the responsible means of pathogen destruction by:
    a. Observing the use of desiccant and measuring pH in composting latrines in five indigenous communities,
    b. Analyzing five compost samples from latrines in a laboratory for chemical (i.e., pH and %moisture) and microbiological (i.e., common pathogens found in human faeces) parameters.
2) Assess the properties of the final compost in regards to its value as a pathogen-free, nutrient-rich fertilizer according to the results of a laboratory analysis for various chemical and microbiological parameters (i.e., pH, %moisture, C/N ratio, and presence of various pathogens such as total coliforms, *E. coli, Giardia lamblia,* and *Ascaris lumbricoides*).

Figure 2: Typical composting latrine in rural Panama.

Chapter 2: Previous Work

This research is the continuation of previous studies conducted by colleagues of the author: Danny Hurtado and Josephine Kaiser are Master's International graduates of Michigan Technological University and Returned Peace Corps Volunteers who served in Panama from 2002-2004 and 2004-2006, respectively. Hurtado focused his research on the design and construction of composting latrines in rural Panama, mainly the province of Bocas del Toro. He also evaluated the processes occurring and the factors influencing pathogen removal in composting latrines operating in the developing world. Hurtado concluded that temperatures are not being elevated sufficiently to destroy pathogens and suggests that other means of pathogen removal be assessed, especially the application of desiccant. Kaiser followed-up Hurtado's work with an analysis of the use of desiccant by conducting a survey of composting latrines in the Bocas del Toro province of rural Panama. From her survey results and the discussion of various studies on developing world composting latrines, Kaiser suggested that high pH in conjunction with desiccation is the primary mechanism for pathogen destruction. She recommended that further investigations be undertaken to establish what the chemical and microbiological properties are of the final compost produced from a latrine operated in this manner (high pH and desiccation) to determine if pathogen removal is achieved and if the quality (in terms of decomposition and pH) of the compost is greatly compromised.

2.1 Methods and Results of Hurtado

The first temperature measurements of composting latrines in Panama were taken by a colleague of Hurtado, Peace Corps Volunteer John Spaulding. Spaulding measured the temperature of 97 active chambers and 29 sealed chambers of latrines located in the Bocas del Toro province using a long-stemmed coil compost thermometer. For active chambers, he found that the average temperature was 29.7 C (σ = 4.2 C), which corresponds to the average daytime high of 29 C. Only 30% of latrines measured were above ambient air temperature, see Figure 3. Among the sealed chambers, the average

temperature was 28.1 C and the max was 43.3 C. Hurtado conducted his own temperature measurements on 10 latrines. Using a standard mercury thermometer attached to a stick, he measured 70% of the latrines to be below 35 C and two latrines were approximately 42 C.

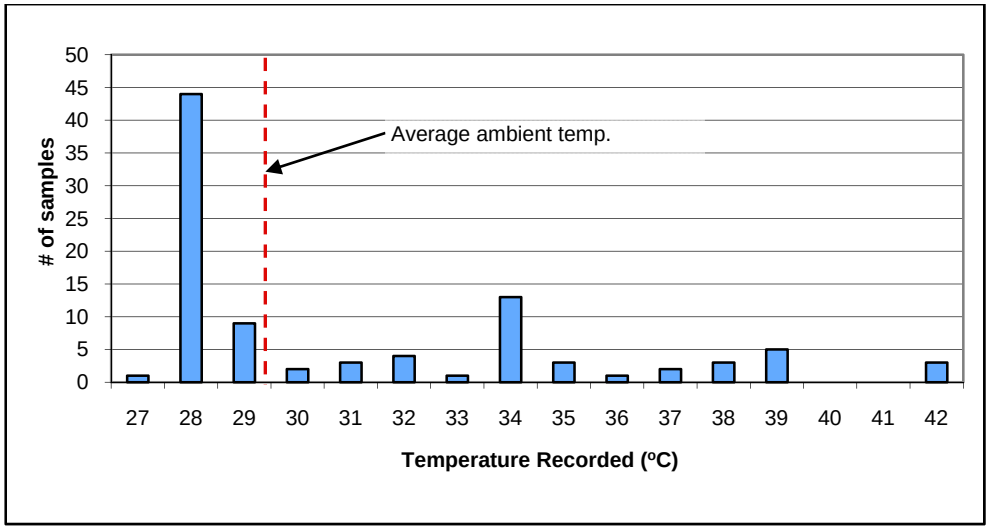

Figure 3: Temperature measurements taken inside the active chamber of 97 composting latrines in Bocas del Toro, Panama. Source: Hurtado, 2005.

Table 1 summarizes Hurtado's review of several studies of composting latrines operating in the developing world. He shows that while the results of each of the studies are site specific, the following general conclusions can be made (Hurtado, 2005):

1. The sole process of aerobic decomposition rarely produces temperatures high enough in a compost latrine for significant acceleration of pathogen destruction.
2. It is possible for high pH to have a detrimental effect on the microbes responsible for aerobic decomposition, hindering the degradation of organic matter and rise in temperature.
3. A synergy of the various mechanisms is likely to be the best method for pathogen destruction.

Table 1: Summary of composting latrine projects reviewed by Hurtado. (NR= not reported). Source: Hurtado, 2005.

Study	Reference	Temperature (compost)	pH	Moisture[1]	Solar Exposure	Soak Material added	Reported Pathogen Destruction	Comments
Mexico	Redlinger et al., 2001	ambient (~28°C)	NR	"Dry" - 54% had Moisture Content < 40%	Latrine affixed with solar collector	Large quantities of sawdust	< 2x106 MPN of fecal coliforms in all samples after 6 months.	Desiccation determined to be mechanism for coliform destruction
Vietnam	Pacey, 1978	2-6°C higher than ambient	NR	NR	NR	Ash 1/3 the weight of the feces was added to reduce odors.	85% reduction in *Ascaris* after 8 weeks. 100% reduction in fecal coliforms	Vegetable yields increased 70%
Based on studies from China, Vietnam and Mexico	Stenstrom, 2002	NR	>9	"Dry"	Mexico (affixed with solar collector) Vietnam and China (NA)	Mexico-Sawdust Vietnam-Ash China-NA	5 to >6 log reduction of Bacteriophages, 100% reduction in *Ascaris* ova	Determined high pH and time were responsible for pathogen destruction
Study of Wet Fecal Sludge	Strauss, 1994	Temperate (10-15°C) and Tropical (20-30°C)	NR	"Wet"	None	None	*Ascaris* eggs viable for 2 - 3 years in temperate climate.	Study was not meant to be a form of treatment.
Guatemala	Strauss and Blumenthal, 1990	NR	up to 12.5	"Relatively dry" (~40%)	Sun-drying	Ash or mixture of soil and ash	Bacterial die-off high at ph >9.	Only sun-dried compost had near zero Ascaris eggs
Panama	Spaulding and Hurtado, 2004	28°C to 42°C	NR	"Dry" to "Wet"	None	Sawdust was main soak material. Ash was added in many latrines.	NR	Samples were being tested for pathogens at the time this report was written.

1. If reported the moisture content is given as a percentage. The terms "dry" or "wet" are expression given by the author. "Dry" and "wet" typically signifies moisture content less than 40% and more than 70%, respectively.

2.2 Methods and Results of Kaiser

Kaiser conducted a literature review (see Table 2) of composting latrine projects in developing countries and found that a high pH seems to be the primary mechanism for accelerated pathogen destruction. The effect of pH on pathogen destruction can decrease if the moisture content is too high; therefore, desiccation also plays an important role (Kaiser, 2006). However, a high pH and low moisture can adversely affect the organisms responsible for aerobic decomposition, compromising the quality of finished compost.

Table 2: Summary of composting latrine studies reviewed by Kaiser. Source: Kaiser, 2006.

Country	Study	Conclusion	Reference
Guatemala	Studies performed by Alvarez on DAFF toilets	The assumption was made that pH and humidity were important factors in removal of fecal coliforms	Peasey, 2000
Guatemala	Studies recorded by Strauss and Blumenthal on DAFF toilets	Measurements showed pH was important factor in pathogen removal Did not appear to affect *Ascaris* eggs	Peasey, 2000
South Africa	Studies performed by Austin	The assumption was made that pH, storage time and humidity impact pathogen removal	Austin,2002
Mexico	Studies performed by the University at Morales on Dry Ecological Toilets	Through measurements pH appeared to be the most important factor in removal of *Ascaris* eggs	Peasey, 2000
Vietnam	Studies recorded by Chien et al on double chamber dry toilets	Measurements showed that pH is the single most influential factor in pathogen removal	Chien et al, 2001
China	Studies recorded by Stenstrom	Measurements showed a higher pH resulted in greater reduction of pathogens	Peasey, 2000
Mexico	Studies performed by Redlinger et al on SIRDO toilets	The assumption was made that desiccation was primary mechanism for removal of fecal coliforms	Redlinger et al, 2001

Kaiser analyzed the use of desiccant by surveying composting latrines in 6 indigenous communities in Bocas del Toro, Panama. Her survey included an inspection portion that

notes use of desiccant, presence of odors, and proper usage and condition of latrine. In an interview portion, she conversed with the latrine caretaker about quantity of users, type and amount of desiccant used, use of finished compost, direct training received, and frequency of illness. Her intent was to determine if the composting latrines were being operated for pathogen removal via desiccation. She observed 76 latrines and interviewed 70 latrine caretakers. Her results show that 94.7% (σ = 12.3%) of latrines had some desiccant visible and 71.0% (σ = 12.8%) of latrines were using a sufficient amount (1-2 cups/use) as was recommended to beneficiaries (Kaiser, 2006).

Kaiser was also interested in the types of desiccant users were adding to their latrines. Wood ash is a desirable desiccant if aiming for a high pH since its pH ranges from 9.4-11.3, whereas sawdust has a low pH of 4.5-7.8 (Kaiser, 2006). Latrine users generally vary the type of desiccant they use depending on what is available. Kaiser found that 95.7% of latrine caretakers reported having used sawdust and 78% have used wood ash as a desiccant. However, 20% of latrine caretakers reported using only sawdust—sawdust will not raise the pH of the latrine contents high enough to kill pathogens; and 4.3% reported using only wood ash, which alone will not be able to absorb enough moisture nor provide sufficient aeration of the latrine contents (Kaiser, 2006).

Chapter 3: Methodology

The results of this study were obtained through a survey conducted between the months of September and November 2007, and through a laboratory analysis performed by the Autonomous University of Chiriquí (UNACHI) in David, Panama. The survey was conducted in five communities in the province of Bocas del Toro in Panama, see Figure 4 and Figure 5. All the communities surveyed had received compost latrines through a project facilitated by various Peace Corps volunteers between the months of June 2003 and February 2004. More importantly, Kaiser (2006) had surveyed these same communities in August and September 2006.

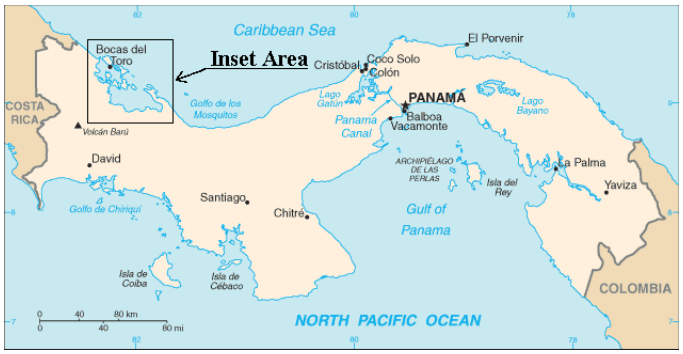

Figure 4: Map of Panama showing inset area detailed in Figure 5. Source: Kaiser, 2006.

Figure 5: Location of the five communities included in the survey. Source: Kaiser, 2006.

3.1 Description of Sample Communities

The sample communities are made up of the indigenous Ngöbe people. The communities are relatively small in size and located either on or fairly close to the main paved highway in the area, see Table 3. The people are mainly poor, subsistence farmers who grow bananas, coffee, cocoa beans, tropical fruits and various starchy root vegetables. Some young men leave the communities to work in the nearby banana company's plantations in order to earn money to support their families at home.

Most families live in either wooden houses on stilts or concrete block houses with corrugated iron or thatched roofs. Running water provided by gravity-flow aqueducts reaches most of the houses. Apart from the families that have compost latrines, many houses have pit latrines. However, these pit latrines are often unsuitable due to flooding and high ground water. Families that do not have any form of sanitation defecate in the streams or rivers.

Table 3: Information on size of communities and distance to highway.

	Community	Dates Surveyed	Approximate Population	Total Number of Houses	Distance from Main Highway
1	Santa Marta	30-Sep-07	300	35	30 min walk
2	Cilico Creek	1-Oct-07	550	34	On highway
3	La Gloria	10-Nov-07	650	80	20 min walk
4	Milla 3	10-Nov-07	400	unknown	20 min walk
5	Valle de Risco	11-13 Nov 07	1,500	126	30 min drive

3.2 Survey Methods

The survey was performed through a series of observations, questions, and measurements. In each sample community, the author made an unannounced visit to many of the houses that had received compost latrines. Sixty-three latrines were visited in total, though not all of them provided useable data—this is explained more in Section 3.3. The closest residing Peace Corps volunteer guided the author through each community. At each house they visited, the author conversed with the family if they were available and then inspected each family's latrine. The natural resources laboratory of UNACHI performed chemical and microbiological analysis on five compost samples collected by the author from latrines in community 5. The survey process and laboratory analysis are detailed below.

3.2.1 Latrine Survey Process

The following steps were followed for the survey:

- Where a family member was at home, the author introduced herself, explained the purpose of the study, and asked for permission to include his/her latrine in the study. The following questions were asked of the latrine owners: Which side is sealed and how long has it been sealed? What types of desiccant are used and which ones are used most?
- The author entered each latrine and made note if a sack/container of desiccant was present, and if so, what type of desiccant it was. Also, the presence of a scoop for applying the desiccant was noted.

- The author then uncovered the sealed chamber and inspected the contents inside with the aid of a flashlight. The presence and type of desiccant inside the latrine box were recorded.
- The moisture level of the latrine contents was visually evaluated using a scale from 1 to 5. Based on the author's observations, a score of 1 signified a very dry latrine and a score of 5 signified a very wet latrine.
- Next, the author noted if the latrine seats were properly covered.
- Also, the odor in the latrine was noted on a scale from 1 to 5. Based on the author's nose, a score of 1 signified no odor or only the odor of the desiccant (e.g., the smell of sawdust) and a score of 5 signified an odor comparable to that of an unkempt pit latrine.
- In a similar fashion, the overall cleanliness of the latrine was noted. In this criterion, a score of 1 signified a well-swept floor and clean latrine seat while a score of 5 signified a dirty floor and a seat fouled by urine and/or excrement.
- Finally, the author inspected the physical condition of the latrine noting any problems, such as broken urine tubes.

The following details the procedure for obtaining the temperature and pH measurements:

- Prior to beginning the survey for the day, the required tools for taking measurements were made. For recording temperatures, a standard mercury thermometer was taped to the end of long stick. To collect grab samples, a metal spoon was bent 90 degrees at the neck and taped to the end of another long stick.
- The ambient air temperature was recorded every four hours and the pH of water carried in a plastic water bottle was measured (water was used to moisten grab samples in order to take field pH measurements of the compost).
- Using a post-digger, a hole was created towards the center of the heap inside the sealed chamber.
- The thermometer was inserted into the heap and left while the grab sample was collected and prepared.

- A sample was grabbed with the spoon (roughly 5 grams) and placed into an empty 200-ml metal can. Then 5 ml of water were added, shaken to mix, and left for the solids to settle.
- The thermometer was removed and the temperature recorded.
- The pH of the supernatant in the metal can was recorded using pH paper. The sample and the used pH paper were then disposed of in the active latrine chamber.

A summary of the inspections made is shown in Table 4. It should be noted that all data recorded, in response to each question, was based purely on the experience of the author and her assistant (the accompanying Peace Corps volunteer). The actual observation sheet used is provided in Appendix 1.

Table 4: Compost latrine inspection criteria.

1	Which side is sealed and for how long has it been sealed?
2	Is there a sack/container of desiccant in the latrine? (Y/N)
	If yes, what type of desiccant is it?
3	Is there a scoop present for the desiccant? (Y/N)
4	Is there a presence of desiccant inside the latrine box? (Y/N)
	If yes, what type of desiccant is present?
5	Do the contents of the latrine box appear (1 dry . . 5 very wet)?
6	Is the latrine seat covered properly? (Y/N)
7	Is there a bad odor? (1 no odor . . . . . 5 bad odor)
8	Is the latrine clean? (1 clean . . . . . 5 dirty)
9	Is the latrine in working condition (seats in place, tubes connected, compost doors in place, no major holes etc.)? (Y/N)
10	Measure the temperature.
11	Measure the pH.

3.2.2 Laboratory Analysis

Five grab samples from five composting latrines located in community 5 were collected and transported to the UNACHI laboratory. Community 5 was chosen because it had the most latrines and easy accessibility to the main highway. The length of time a chamber had been sealed (age of compost), the measured pH, and the observed moisture level

were factors that influenced the author's selection of the five latrines for the laboratory analysis. Latrines were selected to represent a range in these factors—see Table 5 for the characteristics of each latrine sample. These latrines had chambers that had been sealed for approximately 6 months. Latrine owners in the Bocas del Toro region are currently instructed to store their compost for 6-months, and the chambers of the latrines are designed to fill in 6-months for a family of 8.

Table 5: Characteristics of latrines selected for laboratory analysis.

Sample	Age of Compost	pH measured in the field	Moisture Level observed in the field
A	10 months	8.5	4
B	7 months	7.5	3
C	4 months	10	3
D	6 months	6	2
E	6 months	8	2

On the designated day for collection, the author and her assistant worked as quickly as possible to visit the five pre-selected latrines and grab the samples. The post-digger was used to dig towards the center of the compost heap. Using the stick with the attached spoon, the sample was grabbed from 4 spots—front, left, back, right—to result in approximately 150 grams and placed in a plastic jar with lid and promptly labeled. This method of grabbing the sample was repeated in the same manner at each latrine.

It took approximately 40 minutes to collect all the samples and about 5 hours of combined waiting and travel time to reach the laboratory. During transport, the samples were stored in the plastic collection jars with the lids tightly on and kept at ambient temperature or in an air-conditioned environment.

The laboratory performed chemical and microbiological analysis on the compost samples. The chemical properties evaluate the quality of the sample as a nutritious compost to be added to soils. The microbiological analysis tested for common pathogenic bacteria, protozoa, and helminthes found in human feces. Tables 6 and 7 provide information on the specific analytical method of the chemical and microbiological analysis, respectively.

Table 6: Chemical analysis parameters and methodology.

Parameter	Methodology
Dry Material (%)	2 hrs at 135 C
Moisture (%)	2 hrs at 135 C
Organic Material (%)	Walkley-Black
Carbon (%)	Walkley-Black
Carbon/Nitrogen (%)	Walkley-Black/Kjeldahl
Protein (%)	Kjeldahl
Nitrogen (%)	Kjeldahl
Phosphorus (%)	Atomic Absorption
Calcium (%)	Atomic Absorption
Magnesium (%)	Atomic Absorption
Sodium (%)	Atomic Absorption
Potassium (%)	Atomic Absorption
Iron (mg/kg)	Atomic Absorption
Manganese (mg/kg)	Atomic Absorption
Copper (mg/kg)	Atomic Absorption
Zinc (mg/kg)	Atomic Absorption
pH	Orion Research Digital

Table 7: Microbiological analysis.

Bacteria	Helminthes	Protozoa
Total Coliforms	*Taenia solium*	*Entamoeba histolytica*
E. coli	*Taenia saginata*	*Giardia lamblia*
Salmonella	*Ascaris lumbricoides*	
Shiguella	*Strongyloides stercoralis*	
Klebsiella	*Trichuris trichiura*	

3.3 Sample Sizes

In each community surveyed, the number of the latrines visited differs from the sample sizes used in forming the results (see Table 8). This disparity is due to several reasons. In communities 1 and 2, measurements were taken on both the active and the sealed chambers. Therefore, each latrine could potentially yield two data points. However, the objectives of this research focus on what is happening to the latrine contents once left to compost without any other additions. Therefore, measurements were only taken on the sealed chambers of the latrines in communities 3-5. Also, during the course of the

survey, the thermometer was broken and afterwards temperature measurements could not be taken. "Sample Size for Temperature" reflects active and sealed chambers in which the author was able to take a temperature reading. In all communities, if a latrine visited was not being operated correctly in an extreme manner (for example, standing water inside chamber) or the inactive chamber was empty, observations and measurements were not recorded. "Sample size for pH" reflects latrines that had a sealed chamber in which the author was able to take a pH reading. These problems account for the discrepancies between "Number of Latrines Visited," "Total Data Points," "Sample Size for Temperature," and "Sample Size for pH" shown in Table 8.

Table 8: Sample sizes of surveyed communities.

Community Number	Community Name	Number of Latrines Visited	Total Data Points	Sample Size for Temp.	Sample Size for pH
1	Santa Mata	7	8	8	4
2	Cilico Creek	9	16	16	7
3	La Gloria	8	7	7	7
4	Milla 3	6	3	3	3
5	Valle de Risco	33	25	16	25
	Total	**63**	**59**	**50**	**46**

Chapter 4: Results and Discussion

The results of the survey include the field observations, field measurements, and laboratory analysis. The data for each community is included in Appendix 2 and the complete results of the chemical analysis is included in Appendix 3. Table 9 provides the totalled results from the observation portion of the survey. 100% of the latrines had some presence of desiccant. 76% of latrine users keep a sack/container of desiccant inside the latrine and add the desiccant to the latrine box without the aid of a scoop. Wood ash and sawdust are the desiccant materials used: sawdust alone used more frequently by 60%, and an additional 14% of users using a combination of ash and sawdust. Moisture levels in the latrine vary and are discussed in more detail in section 4.3. The latrines generally were well kept and odourless. Urine tubes disconnected or clogged account for the 24% not in perfect condition.

Table 9: Results of the field observations.

1. Is there a sack/container of desiccant in the latrine? (Y/N)	Y - 76%	N - 24%			
If yes, what type of desiccant is it?	Ash - 26%	Sawdust - 60%	Ash & Sawdust - 14%		
2. Is there a scoop present for the desiccant? (Y/N)	Y - 14%	N - 86%			
3. Is there a presence of desiccant inside the latrine box? (Y/N)	Y - 100%	N - 0%			
If yes, what type of desiccant is present?	Ash - 24%	Sawdust - 54%	Ash & Sawdust - 22%		
4. Do the contents of the latrine box appear (1 dry . . .5 very wet)?	1 - 11%	2 - 31%	3 - 41%	4 - 15%	5 - 2%
5. Is the latrine seat covered properly? (Y/N)	Y - 59%	N - 41%			
6. Is there a bad odor? (1 no odor . . . . . .5 bad odor)	1 - 74%	2 - 9%	3 - 11%	4 - 2%	5 - 4%
7. Is the latrine clean? (1 clean . . . . . 5 dirty)	1 -94%	2 - 4%	3 - 2%	4 - 0%	5 - 0%
8. Is the latrine in working condition (seats in place, tubes connected, compost doors in place, no major holes etc)? (Y/N)	Y - 76%	N - 24%			

The factors influencing pathogen destruction and aerobic decomposition that are discussed in the following sections are temperature, pH, moisture, carbon to nitrogen ratio, pathogens, and storage time. The results of the field measurements and laboratory analysis appear in the appropriate sections.

4.1 Temperature

Figure 6 provides the temperature measurements from 50 composting latrines. The average recorded temperature was 26.5 C (σ = 2.8 C), which is comparable to the average ambient air temperature recorded during the study of 25.8 C. However, ambient temperatures in this region are generally around 29 C (Hurtado, 2005), and only 12% of the latrines surveyed exceeded this value. The highest temperature recorded was only 36 C, whereas temperatures greater than 40 C are needed to remove all pathogens within a 1-yr storage time, according to Figure 7, the time and temperature needed to remove certain pathogens. At higher temperatures, >50 C, pathogen destruction proceeds rapidly—one day is sufficient to inactivate all the pathogens of Figure 7. Also, thermophilic (high temperature) composting[1] takes place at these temperatures (Jenkins, 1994; Schönning and Stenström, 2004).

The results support the findings of Hurtado and others, summarized in Table 10, that temperatures in composting latrines operating in developing countries fail to get hot enough to destroy pathogens, nor is thermophilic composting taking place. Pathogen destruction at ambient temperatures (tropical conditions 20-35 C) could occur if the contact time were increased to >12 months (Figure 7). This would require educating latrine users to extend compost storage time and expanding latrine chamber capacity for large families who currently fill a latrine chamber in 6 months.

[1] The term composting refers to aerobic decomposition, and the composting latrine is generally thought to operate under this principle as opposed to anaerobic decomposition, which can occur at mesophilic (10-35 C) or thermophilic (45-80 C) temperatures (Rittmann and McCarty, 2001). The absence of odors in the majority of the latrines surveyed (see Table 9) suggests that anaerobic decomposition is not taking place in the latrines, which corresponds to the latrine design itself in that air enters through the latrine seat and passes through the concrete block walls of the latrine chambers.

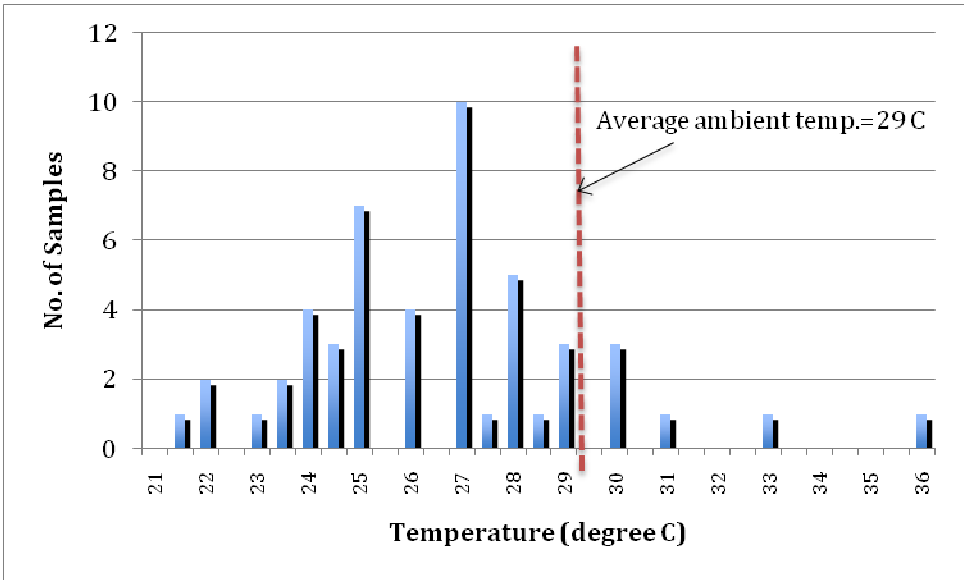

Figure 6: Temperature measurements taken inside 50 composting latrines in the Bocas del Toro region.

Table 10: Summary of temperatures in composting latrines from selected studies.

Country	Study	Results	Reference
Panama	Studies performed by Spaulding and Hurtado on active chambers of 97 composting latrines.	Average temp: 29.7 C (σ = 4.2 C) Highest temp: 42 C Lowest temp: 27 C	Hurtado, 2005
Mexico	Studies performed by Redlinger et al. on 90 composting latrines.	1 toilet at temp of 40 C. The remaining at ambient (28 C).	Redlinger et al., 2001
Vietnam	Studies performed by Chien et al. on 12 composting latrines.	Average temp: 33.9 C Highest temp: 40.1 C	Chien et al., 2001
Panama	Studies performed by the author on 50 composting latrines.	Average temp: 26.5 C (σ = 2.8) Highest temp: 36 C Lowest temp: 21.5 C	Mehl, 2008

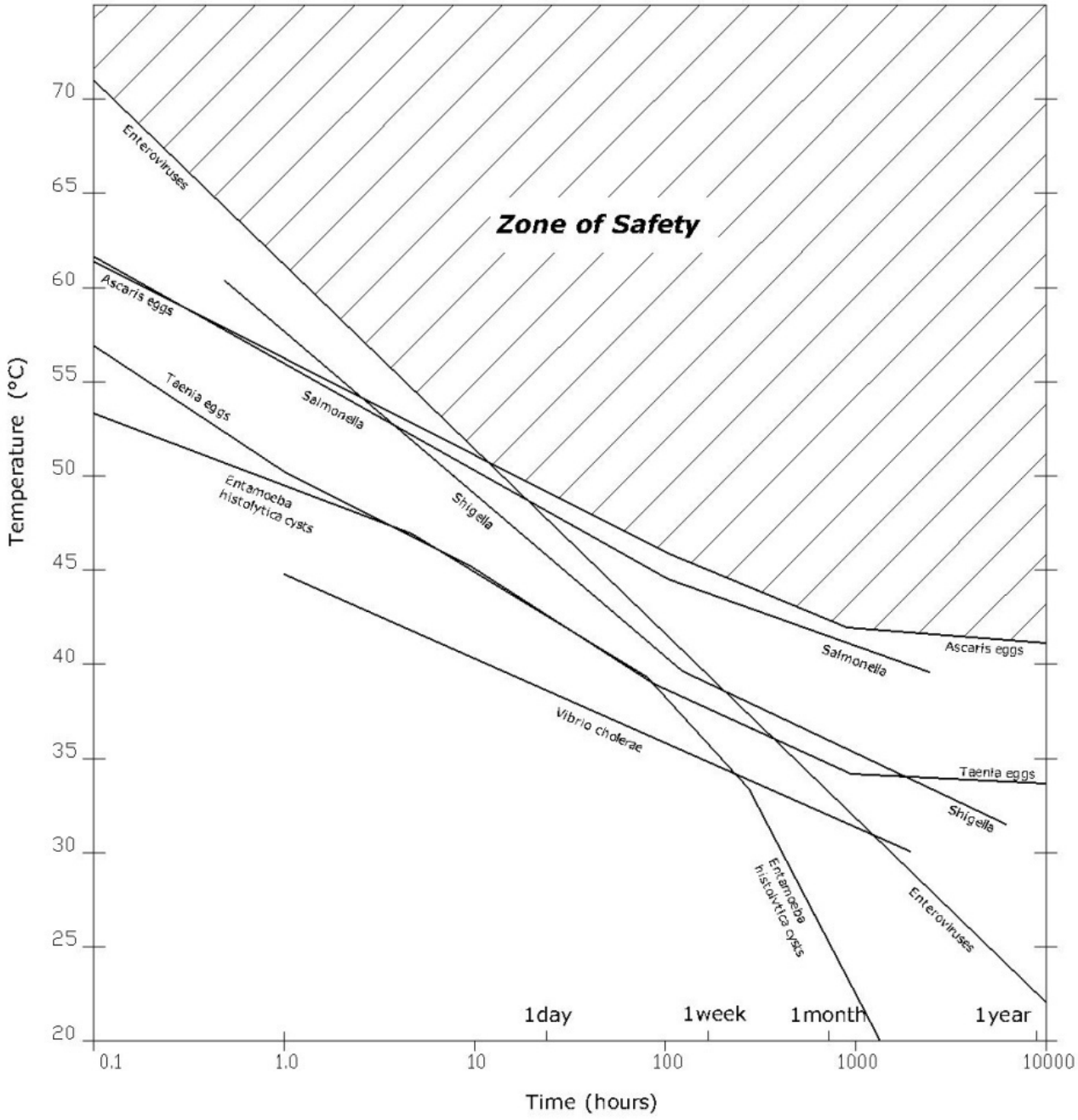

Figure 7: The time and temperature needed to destroy certain pathogens. The lines represent conservative upper boundaries for removal. Source: Cairncross and Feachem, 1993.

4.2 pH

The pH is an important factor in both aerobic decomposition and pathogen destruction. Table 11 shows the optimal pH range for growth for selected pathogens. For aerobic decomposition by thermophilic composting, pH ideally falls within the range 7.5-8.5 (Jenkins, 1994). However, a pH of 9 or greater is desired for pathogen destruction, for it is at this pH that bacterial pathogens, such as fecal coliforms and *E. coli*, begin to die off (Strauss and Blumenthal, 1990; WHO, 2006). Still, pH must be further elevated to remove more resistant pathogens such as *Vibrio cholerae* and *Rotaviruses.* Decomposition is hindered at pH levels greater than 9, presenting a conflict between the breakdown of organic matter and the removal of pathogens by means of high pH (Kaiser, 2006).

Table 11: Minimum and maximum pH for the growth of several pathogens. Source: Kaiser, 2006.

	pH range for growth	
Pathogen	**min**	**max**
Salmonella typhosa	4.5	8.0
E. coli	4.4	9.0
Campylobacter	4.9	9.0
Shigella ssp.	4.8	9.3
Vibrio cholerae	5.0	9.6
Yersinia enterocolitica	4.2	10.0
Rotaviruses	3.0	10.0

The pH of the latrine contents is affected by the pH of the feces and the pH of the desiccant material being added. The pH of human feces is generally neutral, ranging from pH 6.6-7.0 (Dinoto et al., 2006). Table 12 lists the pH values of human feces and the two desiccants used in the latrines surveyed, wood ash and sawdust. Note that wood ash has one of the higher pH values. Adding 1-2 cups of wood ash to the latrine after each use has been suggested to result in a pH of 9 or greater (Mihelcic et al., 2009). Adding just sawdust to the latrine will not raise the pH above 9, and therefore it should always be used in conjunction with wood ash when operating the latrine to destroy pathogens at high pH.

Table 12: pH of human feces, wood ash, and sawdust. Source: Dinoto et al., 2006; Kaiser, 2006.

Material	pH
Human feces	6.6-7.0
Wood ash	9.4-11.3
Sawdust	4.5-7.8

4.2.1 Field pH

Table 13 summarizes the statistics of the field pH data collected from the latrine survey. The data is divided into the measurements taken on active chambers and those taken on sealed chambers. The range of pH values was slightly greater in the active chamber, with a high value of 11. The mean, median, and standard deviation were slightly greater for the active chamber as well. A pH value of 8 was measured most frequently in both active and sealed chambers. Measurements on the active chamber were taken only in community 1 and community 2. Afterwards, the survey was redefined to focus only on sealed chambers as the objectives of this report pertain to finished compost.

Table 13: Summary of field pH measurements.

	Active Chamber	Sealed Chamber
Data Points	13	46
Min	5	6
Max	11	10
Mean	7.9	7.7
Median	8	7.5
Mode	8	8
Standard Deviation	1.4	1.1

Figure 8 shows how many samples taken from the sealed chambers of composting latrines corresponded to each pH value ranging from 6 to 10 (pH was recorded on a 0.5 scale). The average pH value among the 46 samples was 7.7 (95% confidence interval of 0.3)—falling within the ideal range for the process of thermophilic composting. However, only 17% of the samples had a pH of 9 (pH target for pathogen destruction) or

greater. On the other hand, 65% of latrines had a near neutral or slightly alkaline pH ranging from 6.5-8.5. This is the pH range of finished compost (Jenkins, 1994).

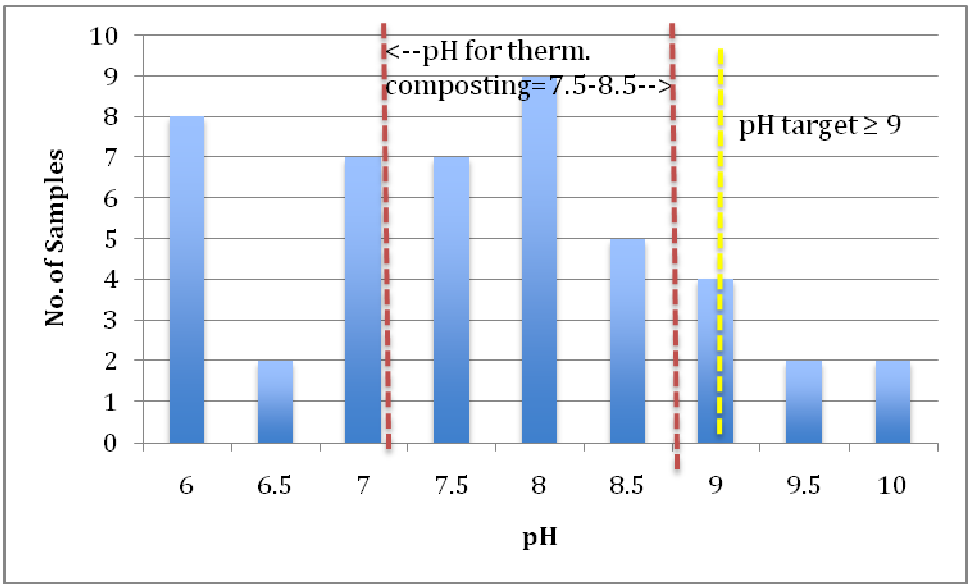

Figure 8: pH measurements taken inside the sealed chamber of 46 composting latrines in the Bocas del Toro region. The pH target to promote thermophillic decomposition is 7.5 to 8.5, and the pH target to achieve pathogen destruction is ≥ 9.

Figure 9 also shows the number of samples corresponding to each pH value, but the samples are categorized according to the type of desiccant observed inside the latrine chamber. The average pH value among the 11 samples using only ash as a desiccant was 8.3 ($\sigma = 0.93$); among the 25 samples using only sawdust, 7.4 ($\sigma = 1.22$); and among the 10 samples using both ash and sawdust, 7.6 ($\sigma = 0.84$). These pH values fall within the ideal range for the process of thermophilic composting. 36% of the samples using ash, 12% of the samples using sawdust, and 10% of the samples using ash and sawdust had a pH of 9 or greater. As expected, more of the samples using ash achieved the target pH than the samples using just sawdust or a combination of sawdust and ash. However, it seems that latrine users are not using a sufficient quantity of high-pH desiccants, like ash, as too few latrines are reaching the target pH.

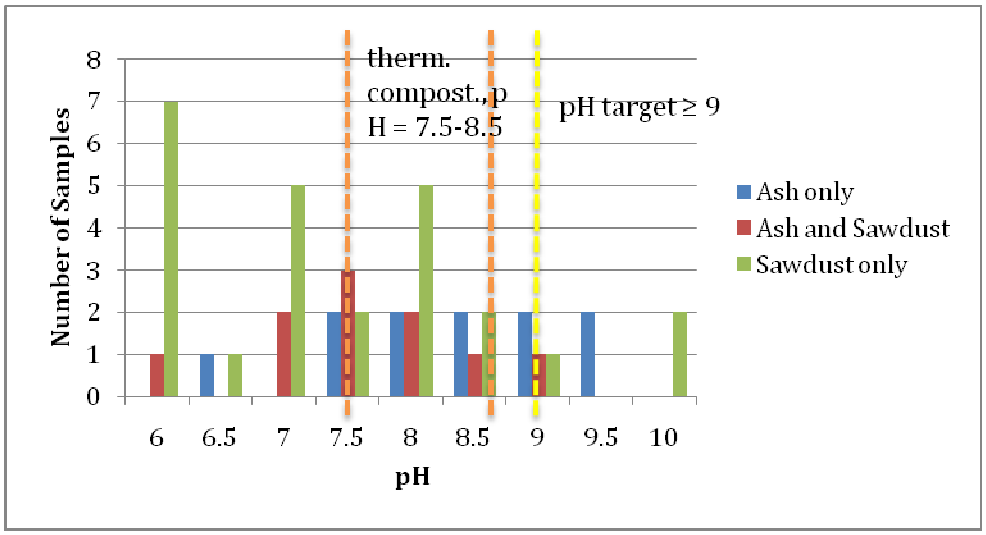

Figure 9: pH measurements taken inside the sealed chamber of 46 composting latrines and categorized according to the type of desiccant observed inside the chamber.

4.2.2 Laboratory pH

Table 14 shows the results of the laboratory analysis for pH compared with the pH values measured in the field. The type of desiccant observed in the latrine box of each respective sample is included in this table, though all the latrine owners reported using both sawdust and ash at some time during the active period of the latrine chamber. The five samples collected for laboratory analysis cover the entire range of pH values measured in the field, 6.0-10.0. The laboratory measurements support the field measurements, with all values falling within 0.5 of one another with the exception of one sample. The latrines using ash nearly reached (pH = 8.45) or exceeded the target pH of 9 (pH = 9.18, 9.45). One latrine using sawdust also exceeded the target pH of 9, while a separate latrine using sawdust remained at a low pH of 6.46. Perhaps this can be attributed to all the owners' claims that both ash and sawdust were used at desiccants. It seems that the owner of latrine C may have used a high enough amount of ash to raise the pH of the compost, while the owner of latrine D used too little.

Table 14: pH values measured in the field versus pH values measured in the laboratory, along with the type of desiccant observed in the latrine box.

Sample ID	Observed desiccant	pH measured in field	pH measured in laboratory
D	Sawdust	6.0	6.46
B	Ash	7.5	9.45
E	Ash	8.0	8.45
A	Ash	8.5	9.18
C	Sawdust	10.0	9.48

4.3 Moisture

For aerobic thermophilic composting, the ideal moisture level of the materials composting is suggested to be 40-60% (Hurtado, 2005). However, to destroy pathogens by means of desiccation, moisture levels should be less than 25% (Schönning and Stenström, 2004; WHO, 2006). Still lower levels of moisture, i.e., 5% or less, are needed to inactivate *Ascaris* eggs if no other pathogen removal mechanisms are employed (Schönning and Stenström, 2004). The starting moisture level of the contents of a composting latrine will be equal to that of raw fecal matter, 66-80% (Jenkins, 1994). Desiccant material must be added to lower this initial moisture level.

To evaluate the moisture level of latrine contents in the field, a scale from 1 to 5 based on visual observation was utilized, see Table 15. As shown in Figure 10, 41% of latrine contents were classified "3", appearing moist, followed by 31% of latrines classified as "2", relatively dry due to the desiccant material. Overall, 87% of latrines had moisture conditions supportive to decomposition (moisture levels 2-4), not being too dry or too wet.

Table 15: Moisture level scale used to make field observations. See Appendix 4 for visual representation.

1	Latrine contents VERY DRY because mostly desiccant material.
2	Latrine contents DRY. Looks like compost, but does not cling together.
3	Latrine contents MOIST. Contents glisten.
4	Latrine contents WET. Contents smear on tools used to take measurements.
5	Latrine contents VERY WET. There is standing water inside latrine chamber.

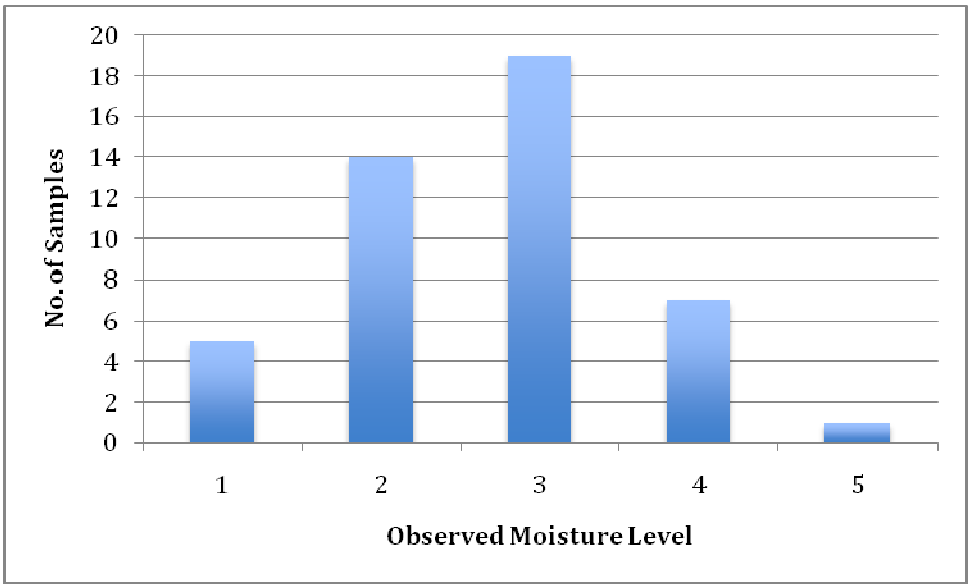

Figure 10: Observed moisture levels in the sealed chamber of 46 composting latrines in the Bocas del Toro region.

The moisture content of the five samples measured by laboratory analyses are provided in Table 16 along with their corresponding "observed moisture level". The values are arranged from driest to wettest. There is some discrepancy between the field observations and the laboratory results. The most probable explanation is that the field observations were based from a top view of the latrine chamber, and the laboratory analyzed samples taken from the center of the compost heap. Moisture filters down through the heap so that the latrine contents towards the bottom of the chamber are generally wetter. Also, latrine caretakers are instructed to add a finishing top layer of desiccant when sealing the chamber, which some caretakers do while others do not. Due to the discrepancy between the field observations and laboratory results, discussion will focus only on the laboratory results.

Table 16: Percent moisture measured in laboratory of 5 samples and their corresponding moisture level observed in the field, along with the type of desiccant observed in the latrine box.

Sample ID	Observed Desiccant	% Moisture measured in Lab	Observed Moisture Level
B	Ash	29.46	3
A	Ash	36.65	4
E	Ash	46.68	2
D	Sawdust	49.62	2
C	Sawdust	66.80	3

The levels of moisture measured in the laboratory support the observation that desiccant materials are used in the latrines—some amount of desiccant material is being added to the latrines in order to lower the initial moisture levels of just human feces (66-80%). In terms of aerobic composting, two samples, D and E, fell within the ideal range of 40-60% moisture, and two others, A and C, came close. However, in terms of pathogen destruction, none of the samples achieve the recommended maximum moisture level of 25%. Accordingly, it appears that the five sampled latrines are not being operated to destroy pathogens by means of desiccation. In order to do this, more desiccant material would have to be added to the latrine to absorb moisture, especially bulky desiccants like sawdust. Interestingly, it was the samples using ash rather than sawdust that reached lower moisture levels. As mentioned previously though, all the latrine owners claimed to use both ash and sawdust in the operation of their respective latrines.

4.4 Carbon to Nitrogen Ratio

The carbon to nitrogen (C/N) ratio is an important parameter in the composting process. Knowing the C/N ratio of the materials to be composted is necessary in determining the amounts of each of the materials to be added. For aerobic decomposition, the C/N ratio of a starting compost pile is 20/1 to 35/1, the ideal being 30/1 (Jenkins, 1994). Table 17 shows the C/N ratios of the materials present in the composting latrines of this survey—human feces + desiccant (sawdust, wood ash, combination of the two). Because human feces have a C/N ratio lower than the ideal 30/1, materials with a high C/N ratio, such as sawdust, must be added to raise the amount of carbon. Notice that adding only wood ash to the feces in the latrine will not provide enough carbon for optimal aerobic decomposition to take place.

Table 17: Carbon/Nitrogen ratio for human feces, sawdust, and wood ash. Source: Composting101, 2006; Kaiser, 2006.

Material	C/N
Human Feces	5-10
Sawdust	200-500
Wood Ash	25

Composting latrine users are currently suggested to add 1-2 handfuls, or roughly 1-2 cups or 200-500 ml) of a desiccant material after defecation in the latrine. Mihelcic et al. (2009) calculate that 0.76 kg of sawdust needs to be added for every 1 kg of human feces to obtain the optimal C/N ratio of 30/1. Considering 135 grams fecal material per person per day (Jenkins, 1994), the *yearly* amount of sawdust needed for *a family of eight* is 1,420 L (see Appendix 5). Obtaining this amount of sawdust may not always be practical in all areas, as deforestation becomes an increasing problem. Additionally, the sawdust needs to be dry to serve as a desiccant, and many regions of Panama experience prolonged rainy seasons. Even if it were feasible to collect a supply of sawdust once a year during the dry season, finding a place to store it and keep it dry becomes an issue. Wood ash is also becoming scarcer as families begin to switch over from cooking with firewood to cooking with a gas stove.

Table 18 is the results of the chemical analysis for C/N ratio. The measured C/N ratio of the five compost samples ranged from 5.4-9.2. This is exactly within the range of the C/N ratio of human feces. While finished compost has a C/N ratio of 10/1 (Richard and Trautmann, 1996), these results along with those of the temperature measurements (all temperatures below temperatures for thermophilic composting) indicate that aerobic decomposition is not taking place. These low C/N ratio values suggest that users need to add more desiccants to the latrine box in order to increase the amount of carbon available to support the decomposition process. Note how the latrines observed using sawdust had slightly higher C/N ratios than those latrines using ash. Sawdust has a higher C/N ratio than ash (refer to Table 4.9), and therefore should be used in greater quantity if aerobic decomposition of the latrine contents is desired. Non-decomposed compost will not provide any benefits to the soil or plants, and may even be harmful. Jenkins says that immature compost can compete with the soil for oxygen and nitrogen, have high levels of organic acids, and produce substances toxic to plants (Jenkins, 1994).

Table 18: Carbon/Nitrogen ratio measured in laboratory of 5 compost samples, along with the type of desiccant observed in the latrine box.

Sample ID	Observed Desiccant	C/N
B	Ash	5.4
A	Ash	5.8
E	Ash	7.0
C	Sawdust	8.5
D	Sawdust	9.2

4.5 Pathogens

The results of the microbiological analysis are shown in Table 19. Several bacteria, helminthes, and protozoa were observed in the five compost samples. For bacteria, total coliforms were observed in all the samples, and *Klebsiella* was found in two samples. However, the largest number of total coliforms observed among the samples is $8x10^4$ CFU/100g or 800 CFU/g, which is less than the maximum allowable amount of just fecal coliforms in EPA class B compost, $2x10^6$ CFU/g[2]. For protozoa, an *Entamoeba coli* cyst was observed in one sample. For helminthes, the eggs of *Taenia solium* (pork tapeworm) were observed in two samples, the eggs of *Strongiloydes* (threadworm) in two samples, and the eggs of *Trichuris trichura* (whipworm) in one sample. One sample even had adult sections of *Taenia solium*. *Ascaris lumbricoides* (roundworm) eggs were observed in all five samples.

[2] Fecal coliforms in EPA class B compost do not exceed $2x10^6$ CFU/g or $2x10^6$ MPN/g. EPA class A compost is only defined by the MPN units--fecal coliforms less than 1,000 MPN/g (Environmental Protection Agency (EPA), 1994).

Table 19: Results of microbiological analysis on the 5 compost samples. N/O = not observed.

BACTERIA					HELMINTHES					PROTOZOA	
Total coliforms (CFU/100g)	*E. coli*	*Salmonella*	*Shiguella*	*Klebsiella* (CFU/100g)	*Taenia solium*	*Taenia saginata*	*Ascaris lumbricoides*	*Strongiloydes*	*Trichuris trichura*	*Entamoebas*	*Giardia lamblia*
8.E+04	N/O	N/O	N/O	N/O	N/O	N/O	infertile egg	N/O	infective egg	Entamoeba coli cyst	N/O
7.E+03	N/O	N/O	N/O	N/O	eggs	N/O	infertile egg	mature and immature eggs	N/O	N/O	N/O
3.E+04	N/O	N/O	N/O	4.E+03	adult sections and eggs	N/O	egg	eggs	N/O	N/O	N/O
3.E+04	N/O	N/O	N/O	6.E+03	N/O	N/O	fertile egg	N/O	N/O	N/O	N/O
7.E+04	N/O	N/O	N/O	N/O	N/O	N/O	infertile egg	N/O	N/O	N/O	N/O

It is not surprising that many pathogens are still present in the compost samples after several months (in the case of the 5 samples, 4-10 months) storage time. As discussed previously, both temperatures and pH are not elevated significantly, and moisture levels are too high to support effective pathogen destruction. Still, by looking at each sample individually, some general observations can be made. The characteristics of the samples (age of compost provided by latrine owner, pH measured in laboratory, moisture measured in laboratory, desiccant observed in the latrine box) are presented in Table 20 along with the pathogens observed in each.

Table 20: The characteristics of the 5 compost samples and the pathogens observed in each.

Sample ID	Age	pH	Moisture	Observed Desiccant	Pathogens
A	10 mo.	9.18	36.65%	Ash	Total coliforms, *Ascaris lumbricoides, Trichuris trichura, Entamoeba*
B	7 mo.	9.45	29.46%	Ash	Total coliforms, *Taenia solium, Ascaris lumbricoides, Strongiloydes*
C	4 mo.	9.48	66.80%	Sawdust	Total coliforms, *Klebsiella, Taenia solium, Ascaris lumbricoides, Strongiloydes*
D	6 mo.	6.46	49.62%	Sawdust	Total coliforms, *Klebsiella, Ascaris lumbricoides*
E	6 mo.	8.45	46.68%	Ash	Total coliforms, *Ascaris lumbricoides*

Sample A had the longest storage time among the samples; yet after 10 months and a pH of 9, many pathogens were still present, including an *Entamoeba coli* cyst. It seems that moisture plays an important role, and since compost dries as it ages, it can be assumed that moisture levels were higher than the final 36% during storage, providing a supportive environment for pathogen growth.

Sample B had the lowest percent moisture among the samples, approaching the recommended maximum of 25%. It had also been stored for more than the recommended 6-month period and had a pH greater than 9. Despite this, pathogens were still present in the compost.

Sample C had the highest pH at 9.5, but also the highest moisture at 67%. More importantly, it only had a storage time of 4 months. It seems that the short storage time and high moisture counteracted the high pH—sample C had the most pathogens with five different types and adult sections of the pork tapeworm, *Taenia solium*.

Samples D and E were similar in that they both had 6-month storage times and moisture levels in the upper 40%. Sample E, however, did have a higher pH by 2 pH units, and the only pathogens present were total coliforms and *Ascaris lumbricoides*. Sample D, at the lower pH of 6.5, had these same pathogens plus *Klebsiella*.

The presence of these pathogens in the samples supports Figure 7, the time and temperature needed to destroy certain pathogens. Six months at ambient temperatures is not sufficient to destroy helminthes such as *Taenia* and *Ascaris* eggs. *Ascaris* eggs are especially resistant and will only be inactivated by high temperatures or extended periods of time. According to Figure 7, one day at 50 C, one month at 45 C, or one year at 42 C is needed to destroy *Ascaris* eggs. Studies by Moe and Izurieta on composting latrines in El Salvador found that temperature is the most reliable predictor for *Ascaris* inactivation, and that pH has minimal effect—*Ascaris* was inactivated after 700 days at pH 9-11 (Moe and Izurieta, 2003).

It follows that those pathogens tested for and not observed (*E. coli, Salmonella, Shiguella, Giardia lamblia, Taenia saginata)* were either destroyed by whatever process or never present at the onset. Since an initial microbiological analysis was not conducted on the compost samples before storage, it is uncertain whether these pathogens were ever present. Interestingly, one pathogen not found in any sample was *Taenia saginata*, beef tapeworm. Beef is rare in the diet of the Ngöbe people living in the Bocas del Toro region, whereas pork is common (and in the samples, so is pork tapeworm, *Taenia solium*).

4.6 Storage Time

Compost should be stored for as long as possible to allow for pathogen removal by means of natural die-off (WHO, 2006). Composting latrine users in Panama have received training that a 6-month storage time is sufficient to produce pathogen-free compost. However, with temperatures remaining approximately at ambient, pH levels below the target of 9.0, and moisture levels well above the recommended 25%, the latrine contents are essentially just being stored. Under these conditions, the compost should be kept for a minimum of 1-yr to eliminate most pathogens and achieve low *Ascaris* egg viability (see Figure 7) (Schonning and Stenstrom, 2004; Strauss and Blumenthal, 1990). Whereas most pathogenic bacteria, viruses, and protozoa generally only survive a few days to a few months in soil, helminthes survive much longer—2 -7 years (Kowal, 1985; Schonning and Stenstrom, 2004). Sun-drying the compost before application may also assist in pathogen inactivation and shorten the storage time necessary by 2-4 months (Strauss and Blumenthal, 1990).

Chapter 5: Conclusions and Recommendations

Pathogens are not being destroyed in composting latrines in rural Panama by means of high temperatures nor desiccation at high pH. Various studies have shown that most composting latrines operating in developing countries never reach high enough temperatures to kill pathogens. The temperature results of this research support this conclusion, as the majority of latrines surveyed measured near ambient temperatures. Also, most latrine users are not adding enough desiccant materials to raise the pH nor lower the moisture level of the latrine contents to the recommended values of pH $\geq$ 9 and moisture < 25% for pathogen destruction. The presence of many pathogens after the currently recommended 6-month storage time suggests this time period is too short, especially when storage appears to be the only form of treatment in the absence of high temperatures, high pH values, and low moisture content.

Many latrines seem to provide a supportive environment for aerobic decomposition—65% of latrines had near neutral pH values, and 87% of latrines had observed moisture levels of 2-4. Yet, the C/N ratio results show that the compost samples had C/N ratios in the range of the C/N ratio of raw human feces, and therefore suggest that the mixture of human excrement with some ash and/or sawdust had not decomposed. During aerobic decomposition, temperatures rise as microorganisms break down organic matter. This temperature rise was not observed in the surveyed latrines, supporting the conclusion that decomposition is not taking place in the composting latrines. Combined with the presence of pathogens, the non-decomposed compost from the latrines would not be an acceptable fertilizer—it presents a risk both to humans and the soil/plants.

Ideally, latrine users would add more desiccant to the latrine box. They could throw in a minimum of 486 ml of sawdust after each use. This amount would provide the latrine contents with an ideal C/N ratio of 30/1 (see Appendix 5 for calculation). Alternatively, a wider variety of high carbon materials such as leaves and straw could be added to reach a C/N ratio between 20/1 and 35/1. This could potentially create the starting environment

for aerobic decomposition at high temperatures. The high temperatures would then safely remove pathogens. Further research should be conducted on what effect adding a variety of materials to the latrine contents, rather than just wood ash and sawdust, has on temperature and decomposition. If the effect were in favor of thermophilic aerobic decomposition, the destruction of pathogens could then evaluated.

Since composting latrines are designed to be a sanitation solution, pathogen destruction is the primary objective. The easiest recommendation for operation towards that objective is to increase the storage time of the compost from 6-months to a minimum of 1-yr. Latrine owners should understand that the longer they store the compost, the lower the risk of pathogen survival. This is especially important when it comes to helminthes like *Ascaris*, proven to be environmentally persistent. Minimum 1-yr storage may present a problem in many cases as the composting latrines have been designed to accommodate 6-month storage periods. The composting latrine design must be adjusted for chambers of larger volume. Education for latrine users should continue to encourage the use of desiccants—both high pH types (ash) and bulky types (sawdust). As far as harvesting and using the final compost, the following recommendations are given:

1. Harvest the aged compost during the dry season, or if there is no marked dry season, during the less rainy time of the year on a clear day.
2. Allow the aged compost to solar-dry for one week. This is best done by spreading the compost on zinc sheets in a thin layer (≤4 inches) under full sunlight.
3. Mix the solar-dried compost with soil and/or bury the compost under a few centimeters of soil when using in agricultural fields.
4. Only use the compost on ornamentals and plants whose fruits are not low-lying or roots. For example, use the compost around the base of banana trees, working it into a few centimeters of soil, but not around lettuce or potato plants.

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Appendix 1: Composting Latrine Survey Form

Community Surveyed:

Surveying by: **Date:**

Community Statistics:

1 Population in the community:

2 Total number of houses in the community:

3 Number of houses with a composting latrine:

4 Number of houses with another type of latrine/septic system:

5 Describe the economic situation of the community:

Ambient Air Temp =

Water pH =

Observations:

1 Is there a sack/container of desiccant in the latrine? (Y/N)

If yes, what type of desiccant is it?

2 Is there a scoop present for the desiccant? (Y/N)

3 Is there a presence of desiccant inside the latrine box? (Y/N)

What type of desiccant is present?

4 Do the contents of the latrine box appear (1 dry . . 5 very wet)?

5 Is the latrine seat covered properly? (Y/N)

6 Is there a bad odor? (1 no odor . . . . . 5 bad odor)

7 Is the latrine clean? (1 clean . . . . . 5 dirty)

8 Is the latrine in working condition (seats in place, tubes

Connected, compost doors in place, no major holes etc.)? (Y/N)

If not, describe the problem below.

Measurements:

Temperature (degree C)

pH

Ask Latrine Owner: Months Sealed?

Latrine Number:

1	2	3	4	5	6	7	8	9

Descriptions (Indicate latrine number):

Figure 11: Composting latrine survey form.

Appendix 2: Survey Data for the 5 Communities

Community 1: Santa Marta

Surveyed by: Jessica Mehl and Lane Olson
Surveyed on: September 30, 2007

Ac=active chamber, Se=sealed chamber

A=ash, S=sawdust

Ambient Air Temp = 31 C

Water pH = 7.0

	Latrine Number:								
Observations:	1Se	2Se	3Ac	4Se	5Ac	6Ac	7Se	7Ac	
1 Is there a sack/container of desiccant in the latrine? (Y/N)	Y	N	N	N	Y	Y	Y	Y	
If yes, what type of desiccant is it?	A	--	--	--	S	A,S	S	S	
2 Is there a scoop present for the desiccant? (Y/N)	Y	N	Y	N	N	N	Y	Y	
3 Is there a presence of desiccant inside the latrine box? (Y/N)	Y	Y	Y	Y	Y	N	Y	Y	
What type of desiccant is present?	A,S	S	S	S	S	A,S	S	S	
4 Do the contents of the latrine box appear (1 dry . . 5 very wet)?	3	3	5	5	5	3	2	2	
5 Is the latrine seat covered properly? (Y/N)	Y	Y	Y	N	N	Y	Y	Y	
6 Is there a bad odor? (1 no odor . . . . . 5 bad odor)	1	1	2	3	1	1	1	1	
7 Is the latrine clean? (1 clean . . . . . 5 dirty)	1	1	1	1	1	1	1	1	
8 Is the latrine in working condition (seats in place, tubes	Y	Y	Y	N	Y	Y	Y	Y	
connected, compost doors in place, no major holes etc.)? (Y/N)									
If not, describe the problem below.									
Measurements:									
Temperature (degree C)	30	27	27	28.5	27	29	25	27	
pH	7.5	10	8	8	8	11	7	7	
Ask Latrine Owner: Months Sealed?	3.5	6+	--	6	--	--	6	--	

Figure 12: Data for community 1, Santa Marta.

Community 2: Cilico Creek

Surveyed by: Jessica Mehl and Lane Olson
Surveyed on: October 1, 2007

Ac=active chamber, Se=sealed chamber
A=ash, S=sawdust

Ambient Air Temp = 26 C

Water pH = 7.0

	Latrine Number:															
Observations:	1Ac	1Se	2Ac	2Se	3Ac	4Se	4Ac	5Se	5Ac	6Ac	7Se	7Ac	8Se	8Ac	9Se	9Ac
1 Is there a sack/container of desiccant in the latrine? (Y/N)	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y
If yes, what type of desiccant is it?	A,S	A,S	A	A	S	A	A	--	--	S	S	S	A	A	S	S
2 Is there a scoop present for the desiccant? (Y/N)	Y	Y	N	N	N	N	N	N	N	N	Y	Y	N	N	N	N
3 Is there a presence of desiccant inside the latrine box? (Y/N)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
What type of desiccant is present?	A	A	A	S	S	S	S	S	A	S	S	S	S	A	S	S
4 Do the contents of the latrine box appear (1 dry . . 5 very wet)?	2	2	4	3	3	3	4	3	2	3	2	3	1	2	1	2
5 Is the latrine seat covered properly? (Y/N)	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
6 Is there a bad odor? (1 no odor . . . . . 5 bad odor)	1	1	3	3	2	1	1	1	1	1	1	1	1	1	1	1
7 Is the latrine clean? (1 clean . . . . . 5 dirty)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8 Is the latrine in working condition (seats in place, tubes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Connected, compost doors in place, no major holes etc.)? (Y/N)																
If not, describe the problem below.																
Measurements:																
Temperature (degree C)	30	29	25	27	27	27.5	28	28	28	26	26	30	27	27	28	36
pH	7.5	9.5	8.5	7.5	8	7	8	8	7.5	7	7	7.5	8.5	10	7	5
Ask Latrine Owner: Months Sealed?	--	2	--	12+	--	6	--	12	--	--	4+	--	5+	--	6	--

Figure 13: Data for community 2, Cilico Creek.

Community 3: La Gloria

Surveyed by: Jessica Mehl and Julie Majkrzak
Surveyed on: November 10, 2007

A=ash, S=sawdust

Ambient Air Temp = 23 C

Water pH = 6.0

	Latrine Number:								
Observations:	1	2	3	4	5	6	7	8	
1 Is there a sack/container of desiccant in the latrine? (Y/N)	Y	Y	Y	Y	Y	N	Y	Y	
If yes, what type of desiccant is it?	S	A	S	S	A,S	--	S	S	
2 Is there a scoop present for the desiccant? (Y/N)									
3 Is there a presence of desiccant inside the latrine box? (Y/N)	Y	Y	Y	Y	Y	Y		Y	
What type of desiccant is present?	A	A,S	S	S	A	S		A,S	
4 Do the contents of the latrine box appear (1 dry . . 5 very wet)?	2	3	3	3	2	3		3	
5 Is the latrine seat covered properly? (Y/N)	N	Y	N	Y	Y	Y		Y	
6 Is there a bad odor? (1 no odor . . . . . 5 bad odor)	1	1	1	1	1	1		1	
7 Is the latrine clean? (1 clean . . . . . 5 dirty)	1	1	1	2	1	1		1	
8 Is the latrine in working condition (seats in place, tubes connected, compost doors in place, no major holes etc.)? (Y/N)	Y	Y	Y	Y	N	Y		Y	
If not, describe the problem below.									
Measurements:									
Temperature (degree C)	23.5	24.5	22	27	25	24		23	
pH	9	7	6	8	8.5	8		7	
Ask Latrine Owner: Months Sealed?	6	6	6	1	4.5	2		12	

Figure 14: Data for community 3, La Gloria.

Community 4: Milla 3
Surveyed by: Jessica Mehl and Julie Majkrzak
Surveyed on: November 10, 2007

A=ash, S=sawdust

Ambient Air Temp = 22 C

Water pH = 6.0

	Latrine Number:								
Observations:	1	2	3	4	5	6			
1 Is there a sack/container of desiccant in the latrine? (Y/N)	Y	Y	N						
If yes, what type of desiccant is it?	S	S	--						
2 Is there a scoop present for the desiccant? (Y/N)									
3 Is there a presence of desiccant inside the latrine box? (Y/N)	Y	Y	Y						
What type of desiccant is present?	S	S	S						
4 Do the contents of the latrine box appear (1 dry . . 5 very wet)?	2	2	3						
5 Is the latrine seat covered properly? (Y/N)	N	N	N						
6 Is there a bad odor? (1 no odor . . . . . 5 bad odor)	1	2	1						
7 Is the latrine clean? (1 clean . . . . . 5 dirty)	1	1	1						
8 Is the latrine in working condition (seats in place, tubes	Y	Y	Y						
connected, compost doors in place, no major holes etc.)? (Y/N)									
If not, describe the problem below.									
Measurements:									
Temperature (degree C)	23.5	21.5	22						
pH	6	6	6						
Ask Latrine Owner: Months Sealed?	6	6	>6						

Figure 15: Data for community 4, Milla 3.

Community 5: Valle de Risco
Surveyed by: Jessica Mehl and Joe Goessling
Surveyed on: November 11-12, 2007
Note: Highlighted latrines were selected for laboratory analysis.

A=ash, S=sawdust

Ambient Air Temp = 28 C
Water pH = 6.0

Ambient Air Temp = 24 C
Water pH = 6.5

	Latrine Number:															
Observations:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 Is there a sack/container of desiccant in the latrine? (Y/N)	Y	Y	Y	Y	Y	N	Y		Y	N	Y	Y	Y		N	N
If yes, what type of desiccant is it?	A	A	A,S	A	A	A,S	A,S			S			S			
2 Is there a scoop present for the desiccant? (Y/N)	Y	N	N	N	N	N	N		N	N	N	N	N		N	
3 Is there a presence of desiccant inside the latrine box? (Y/N)	Y	Y	Y		Y	Y	Y		Y	Y		Y	Y		Y	Y
What type of desiccant is present?	A	A	A,S		A	A	A		S	S	A,S	S	S		S	A,S
4 Do the contents of the latrine box appear (1 dry . . 5 very wet)?	3	3	4		2	4	2		1	1	4	3	2		4	3
5 Is the latrine seat covered properly? (Y/N)	N	Y	Y		Y	N	N		N	N	N	N	N		N	N
6 Is there a bad odor? (1 no odor . . . . . 5 bad odor)	1	1	1		1	2	1		1	1	5	5	1		4	1
7 Is the latrine clean? (1 clean . . . . . 5 dirty)	1	1	1		1	1	1		1	1	1	1	1		1	1
8 Is the latrine in working condition (seats in place, tubes	Y	Y	Y		Y	Y	Y		Y	N	Y	N	N		N	Y
connected, compost doors in place, no major holes etc.)? (Y/N)																
If not, describe the problem below.																
Measurements:																
Temperature (degree C)	28	24	24.5		24	24.5	26		26	25	24	33	25		31	29
pH	9.5	7.5	7.5		9	8.5	8		8.5	7.5	8	7	6		8	8
Ask Latrine Owner: Months Sealed?					6	10	6	3							2.5	2

Figure 16: Data for community 5, Valle de Risco - part 1 of 2.

Community 5 cont.

A=ash, S=sawdust
*Thermometer broke.

Ambient Air Temp = 27.5 C
Water pH = 6.5

Ambient Air Temp =
Water pH = 6.5

Observations:	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1 Is there a sack/container of desiccant in the latrine? (Y/N)	Y	Y	Y	N	N			Y		Y	Y	Y	Y	N		Y	Y
If yes, what type of desiccant is it?	S	S	S	A				S		A	S	S	S			S	S
2 Is there a scoop present for the desiccant? (Y/N)	N	N	N	N	N			N		N	N	N	N	N		N	N
3 Is there a presence of desiccant inside the latrine box? (Y/N)	Y	Y	Y	Y	Y			Y		Y	Y	Y	Y			Y	Y
What type of desiccant is present?	A,S	A	S	A	A			S		A,S	S	S	A,S	A,S		S	A,S
4 Do the contents of the latrine box appear (1 dry . . 5 very wet)?	2	3	2	3	4			1		3	2	2	4	4		3	4
5 Is the latrine seat covered properly? (Y/N)	N	Y	Y	N	Y			N		N	N	N	N	N		N	N
6 Is there a bad odor? (1 no odor . . . . . 5 bad odor)	1	1	1	3	2			1		1	1	2	3	3		1	1
7 Is the latrine clean? (1 clean . . . . . 5 dirty)	1	1	1	3	1			1		1	1	1	1	1		2	1
8 Is the latrine in working condition (seats in place, tubes	N	Y	Y	N	Y			Y		Y	Y	Y	N	N		N	4
connected, compost doors in place, no major holes etc.)? (Y/N)																	
If not, describe the problem below.																	
Measurements:																	
Temperature (degree C)	25	25	27	*	*	*	*	*	*	*	*	*	*	*		*	*
pH	6	7.5	6	6.5	8			6.5		7.5	9	6		9		10	8.5
Ask Latrine Owner: Months Sealed?	7	11	6	5	4			11		7		13	9	16		4	

Figure 17: Data for community 5, Valle de Risco - part 2 of 2.

Appendix 3: Laboratory Results of Chemical Analysis

Table 21: Laboratory results of the chemical analysis on 5 compost samples.

SAMPLE	lab pH	Moisture (%)	Dry Material (%)	Organic Matter (%)	C (%)	C/N (%)	Proteins (%)	N (%)	P (%)	Ca (%)	Mg (%)	Na (%)	K (%)	Fe (mg/Kg)	Mn (mg/Kg)	Cu (mg/Kg)	Zn (mg/Kg)
A	9.18	36.65	63.65	3.5	2.03	5.8	2.19	0.35	0.24	4.5	1.98	0.16	2.79	47603	2289	81.77	388
B	9.45	29.46	70.54	3.32	1.93	5.4	2.25	0.36	0.24	4.24	1.87	0.12	3.62	55444	479	58.46	365
C	9.48	66.8	33.2	34.22	19.85	8.5	14.62	2.34	0.46	2.24	1.56	0.3	3.13	5839	273	38.74	179
D	6.46	49.62	50.38	22.28	12.92	9.2	8.81	1.41	0.41	4.21	1.72	0.16	1.58	21496	397	126.4	260
E	8.45	46.68	53.32	10.68	6.19	7	5.56	0.89	0.41	6.2	2.48	0.24	3.06	29508	606	81.1	282

Appendix 4: Pictures from the Field

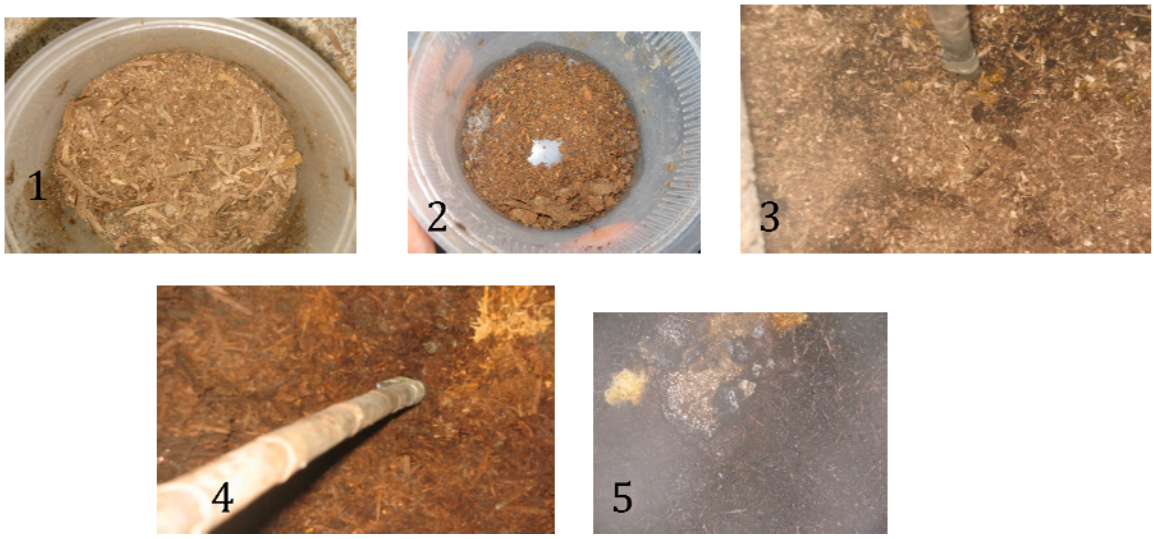

Figure 18: Visual representation of moisture level scale used to make field observations. Left to right, top to bottom: moisture level 1, 2, 3, 4, and 5.

Figure 19: Mixing compost with water to take pH measurement.

Figure 20: Compost whose primary desiccant is ash.

Appendix 5: Calculation of the Amount of Sawdust Needed to Obtain a C/N ratio of 30/1 in the Composting Latrine

Problem: Calculate the amount of sawdust that needs to be added to the composting latrine to obtain the optimal starting C/N ratio of 30/1.

Assumptions (Jenkins, 1994; Mihelcic et al., 2009; SI Metric, 2007):

Fecal matter in latrine (wet weight) = 135 grams/person/day
% N of feces (dry mass basis) = 6.3
C/N of feces = 10
Moisture content of feces = 80%

% N of sawdust (dry mass basis) = 0.1
C/N of sawdust = 400
Moisture content of sawdust = 10%
Density of sawdust = 210 kg/m^3

Solution: Let *Y* equal the grams of sawdust on a dry mass basis. The mass of carbon and nitrogen obtained from each material in the mixture is:

Dry mass nitrogen from feces = 135 g × (1 - 0.8) × 0.063 = 1.701 g

Dry mass carbon from feces = 135 g × (1 - 0.8) × 0.063 × 10 = 17.01 g

Dry mass nitrogen from saw dust = Y × (1 - 0.1) × 0.001 N = 0.0009 × Y g

Dry mass carbon from saw dust = Y × (1 - 0.1) × 0.001 N × 400 g C/ g N = 0.36 × Y g

The desired C/N ratio is:

$$30 = \frac{(\text{mass carbon from feces} + \text{ mass carbon from saw dust})}{(\text{mass nitrogen from feces } + \text{ mass nitrogen from saw dust})}$$

Plugging in the values we determined into this equation results in:

$$30 = \frac{(17.01 + 0.36 * Y)}{(1.701 + 0.0009 * Y)}$$

Solve for Y, which equals 102.2 g. Converting to volume:

$$102.2g \times \frac{1kg}{1000g} \times \frac{1m^3}{210kg} \times \frac{1000L}{1m^3} \times \frac{1000ml}{1L} = 486 \text{ ml}$$

Thus, **486 ml** of sawdust are needed per person per day to obtain a C/N ratio of 30/1 in the composting latrine.

On a yearly basis: 178 L/person

On a yearly basis, for a family of 8: 1,420 L