Compost Latrines in Rural Panama: Design, Construction and Evaluation of Pathogen Removal

By

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A REPORT

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This report “Compost Latrines in Rural Panama: Design, Construction and Evaluation of Pathogen Removal” is hereby approved in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING.

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Preface

While living as a U.S. Peace Corps volunteer in Panama from 2002-2004 I conducted the research, made the observations, gained the experience detailed in this report. For my two-year service I was placed in the town of Kusapin, on the tip of the Peninsula Valiente in the *Comarca* Ngobe-Bugle. While there I worked with local water committees, the ministry of health, and local government officials. In addition to the work performed with compost latrines, I also focused on the design and construction of gravity-fed water supply systems in the area around Kusapin. Due to lack of facilities and long travel necessary to more developed areas that might contain laboratory facilities, research methods were maintained at a level “appropriate” to my location.

Along with two semesters of coursework and research in the field, this report is submitted to complete my Master’s degree in environmental engineering from Michigan Tech. This report is meant to serve as an aid to the development worker interested in implementing compost latrines as a solution to sanitation problems, but is suitable for anyone interested in the idea of recycling human waste.

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Thanks to Diane for being with me, from Rio Mar to Austin to Cuenca. I'll see you soon.

Thanks to my friends and fellow Peninsula people - Iyo, Kweche, Cholita, and Medigo - for all the help and good times out on the *Peninsula Valiente*. Mo ki ño?

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Gracias a la gente de *Sabrikote*, especialmente a Chimi, Huevito y Bocas, por enseñarme el idioma Ngobere y siempre hacerme reír. Chicho siempre les recordará. Gracias a toda la gente Ngobe…que tu lengua siempre viva y que tu *buchu* crezca en cantidad. Jatwaita Kaw Noi.

Abstract

Access to proper sanitation is a basic step towards sustainable development, and crucial to the health of any community. 2.6 billion people in the world lack access to any excreta disposal facility (UNICEF, 2005), with only 49% of the rural population of Latin America and the Caribbean having sanitation coverage (WHO/UNICEF, 2000). As a Peace Corps volunteer living in the rural Ngobe-Bugle Indigenous Territory (*Comarca Ngobe-Bugle*) of Panama, the author of this report assisted in the implementation of several compost latrine projects.

Due to the high water table and copious amount of rainfall found in many coastal areas, standard pit latrines may not be a feasible technology for sanitation problems in the developing world. Because the compost latrine described in this report is constructed above ground with a concrete base, it is feasible for any waterlogged or high-water-table area. This report provides the development worker, who believes compost latrines can be a solution to sanitation problems, with knowledge to successfully implement a compost latrine project. Detailed instruction on the design and construction of a family-sized compost latrine is provided, the various mechanisms responsible for pathogen removal are described in detail, and these mechanisms are incorporated into recommended operational procedures that can then effectively reduce the concentration of fecal pathogens in composted human manure, while producing a nutrient-rich fertilizer.

Thousands of compost latrines have been built worldwide, with the intent of destroying enteric parasites with the high temperatures achieved during thermophilic aerobic decomposition. Though the exposure of compost to temperatures above 45^{o}C for one month has been found to inactivate all gastrointestinal pathogens, studies have shown that few compost latrines implemented in the developing world achieve high enough temperatures to significantly accelerate the destruction of enteric pathogens. Daily addition of local dry organic materials (e.g., rice husks, sawdust) not only provide a source of carbon for carbon-limited fecal material, but also increases the porosity of the compost pile which can accelerate decomposition and subsequently raise the temperature in the compost heap.

In this study, only 30% of the 97 compost latrines evaluated in Panama measured temperatures above ambient conditions (approximately 28^{o}C). These measurements suggest that accelerated aerobic decomposition is not occurring and significant pathogen destruction may not be occurring over the six-month storage timeframe that is recommended to users before the compost material is removed. Nevertheless, there may be other processes taking place inside the compost latrine that effectively destroy pathogens. Daily addition of wood ash can result in pH up to 12.5, and pH levels greater than 9 have been shown to accelerate the destruction of various pathogens. Desiccation (through the addition of wood ash, rice husks, or sawdust) has also been attributed to the removal of fecal coliform bacteria in compost to levels safe enough that the material may be applied on edible food crops. In addition, subsequent sun-drying of the compost has been found to decrease the necessary containment time by 60%. Because studies have shown that a moderate increase in temperature can also shorten the storage period necessary to produce pathogen-free compost, aerobic decomposition is still an important factor, and a synergy of mechanisms (i.e., increased porosity, aerobic decomposition, increased pH, and desiccation) are likely to contribute to pathogen removal.

Chapter 1 - Introduction

The hygienic disposal of human excreta is necessary for the preservation of health, and is one of the most effective measures which any community can undertake to improve their wellbeing (Feachem and Cairncross, 1978).

In 1977, responding to the great need for water and sanitation infrastructure throughout the world, the United Nations announced that the objectives of the decade 1981-1990 would be to "provide safe water and sanitation for all"(UN, 1990). Despite the efforts, 40% of the world's population (2.6 billion people) still lacks access to excreta disposal facilities (UNICEF, 2005). 1.8 million people die every year from diarrhoeal diseases, mainly children under 5 years of age, and 88% of these diseases are attributed to unsafe water supply, inadequate sanitation and hygiene (WHO, 2004). In Latin America and the Caribbean 51% of the rural population lacks sanitation coverage (WHO/UNICEF, 2000).

In Panama, 95% of the indigenous population is poor (<$905/capita/year), as compared to 37% of the non-indigenous population (UNICEF, 2005), and the correlation between poverty and poor health and the lack of sanitation is widely recognized. The author witnessed these conditions first hand while living in the indigenous community of Kusapin in rural Panama.

Because of the high water table and copious amounts of rainfall in this area, the standard pit latrine is not an option for most families. For this reason many Peace Corps volunteers in this area have led compost latrine construction projects. Unlike the pit latrine, the compost latrine detailed in this report is built above ground with a concrete base, making it an appropriate solution to sanitation in coastal and waterlogged areas (Figure 1).

Figure 1. The author’s compost latrine (and house) surrounded by water, after a high tide and heavy rainfall caused the nearby stream to swell. Note – Contents remained dry

In theory compost latrines are a perfect solution to the problem of sanitation in the developing world. Not only do the latrines safely dispose of excrement, improving health, but also provide nutrients in the form of fertilizer, which is greatly needed in many countries. However, when these latrines are put into practice, especially in the developing countries, the results are usually not ideal, with social factors playing a large role in their acceptance. Nevertheless, this technology does have great potential and should not be ignored. Combined with education, compost latrines technology can help improve the health of those who need it the most.

Thousands of compost latrines have been built throughout the world, and it is likely that thousands more will be built in the future. This paper is written for the development worker who believes compost latrines can solve problems of sanitation, and the overall objective is to supply the reader with an “all-in-one” report that provides a detailed manual for the construction of a compost latrine, explains the mechanisms behind the removal of pathogens, details any problems that may arise, and identifies ways to improve results.

Chapter 2 provides background information on the people and the area where the author worked for 2 years, and Peace Corps in Panama. Chapter 3 describes several compost latrine designs and projects that have previously been done in various developing countries. Chapter 4 provides detailed instruction for the construction of a concrete block compost latrine, while introducing the methods of concrete work and providing insights from the field. Chapter 5 describes in detail the biological process of aerobic composting and how it relates to pathogen removal. Chapter 6 is a collection of case studies, including Panama, which explain the true processes and mechanisms for pathogen destruction that occur in composting latrines when implemented in the developing world. Chapter 7 provides a guide for the proper use and maintenance of the compost latrine and incorporates the knowledge of the fundamental processes discussed in earlier chapters. Chapter 8 concludes the report and discusses the aforementioned topics. Appendix A presents the soldier worm, a type of maggot commonly found in compost latrines that can be both undesired and beneficial. Appendix B describes the *Ascaris lumbricoides*, an enteric pathogen whose resistance to chemical and biological stresses make it difficult to eliminate through composting.

Chapter 2 - Background

2.1 Geography

The Republic of Panama is the “S” isthmus located at the bottom of Central America. It runs west to east, and can be considered to be at the division between North and South America, being bordered by Costa Rica to the west and Colombia to the east (See Figure 1). It has been called “the path between the seas”, since it was here, the narrowest landmass between the Pacific and Atlantic Oceans, where the Panama Canal was built. It has a total land area of 78,046 km^2, making it slightly larger than Ireland. Panama is home to around 3 million inhabitants, with the population density being significantly higher as one gets closer to the canal.

Figure 2. Provincial map of Panama showing location of Kusapin. This map was produced before the formation of the Ngobe-Bugle Indigenous Territory. See Figure 3 for an outline of the Ngobe-Bugle Territory.

Reproduced from http://www.lib.utexas.edu/maps/americas/panama.jpg Source: CIA

In 1997, after long negotiations with the government, the Ngobe and Bugle tribes were awarded the rights to 6,673 km^2 of land made up from Veraguas, Chiriqui, and Bocas del Toro provinces. This territory comprises 8.5% of the total land area in Panama. The

Bocas del Toro section of the Ngobe-Bugle indigenous territory, called Ño Kribu, is found in the western part of Panama, on the north side of the mountain range that runs down Panama's spine. Kusapin, the town where the author resided, is located on the tip of the Peninsula Valiente, which separates the Laguna de Chiriqui from the Caribbean Sea (See Figure 2). As is for the majority of the communities located in the Ño Kribu region, Kusapin can only be reached by boat or helicopter, due to the absence of roads. Boat travel to the Kusapin area must be done through the open ocean, while boats must travel up river to reach communities that are further in from the coast. The majority of the work and research detailed in this report was done in the Ño Kribu region.

2.2 Climate and Ecology

For such a small country Panama has a very diverse climate and ecology. In less than a full day one can visit two oceans, passing through coastal mangroves, dry barren hillsides, cool highlands, and dense rainforest. From around mid-December to mid-April most of Panama experiences a dry season, which Panamanians call *verano*, or summer. However, in the area of the Bocas del Toro province, and the other areas on the Caribbean slope, there is rarely a defined dry season. The Bocas del Toro / Ño Kribu region receives around 2,000 – 4,000 mm of rain per year, with some areas measuring 6,000 mm (236 inches) in past years (WWF, 2004).

In Kusapin the author witnessed the abundance of rain, which feeds the densely forested hills and mountains that extend in from the coast. The temperatures in the Kusapin area are typically hot and humid, with yearly average day/night temperatures of around 31°/ 22° C.

The ecosystem of the lowlands of Ño Kribu is a combination of wetland vegetation, and tropical rainforest. In the area of Kusapin the forested hills meet coastal mangrove, brackish water marsh, grasslands and beach. In the other areas of Ño Kribu, which are much further in from the coast, the environment was mainly made up of forested foothills, firm moist grassland, and marsh-like vegetation. In many of these areas the water table is very high, due to the large amount of rain and close proximity to the coast or river planes.

2.3 People and Culture

Along with Afro-Caribbean, European, and mixed Spanish-Indigenous (who make up the majority of the population) decent, there are six main indigenous groups in Panama, comprising about ten percent of the total population. The Ngobe tribe is the largest, with a population of around 170,000 people (*Censos Nacional*, 2000). The Ngobe people mostly inhabit the western part of Panama in the areas that were once part of the Chiriqui and Bocas del Toro provinces (See Figure 3).

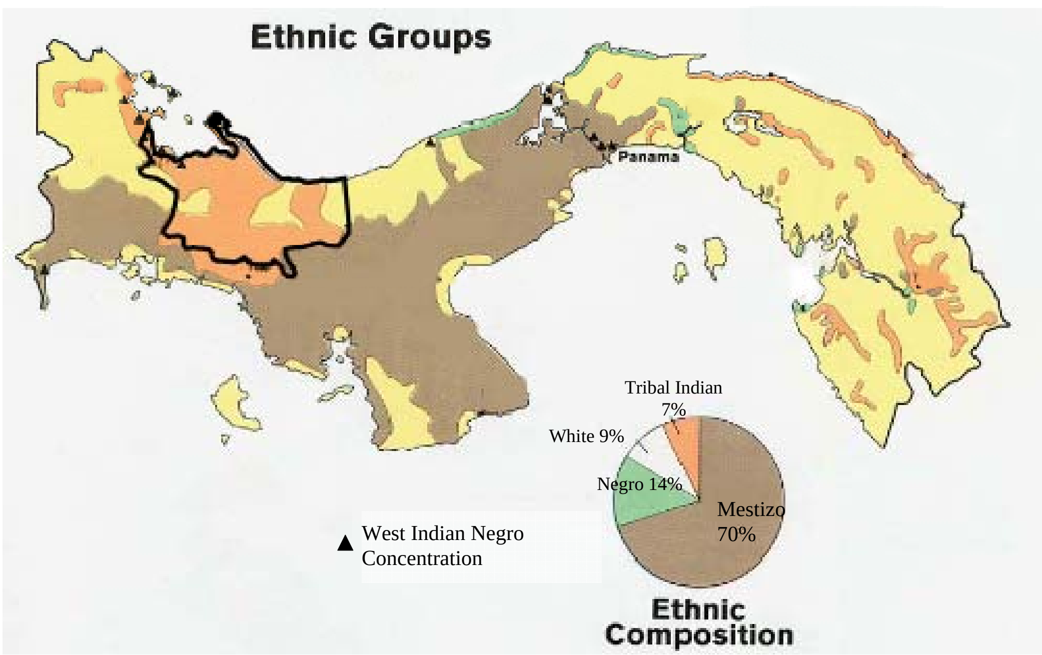

Figure 3. Panama's ethnic composition and outline of the Ngobe-Bugle territory.
Since the time of this map's creation a large number of Mestizo people have moved into the eastern part of Panama, mostly clustered around the Pan-American highway which cuts this part of the country in half. Please excuse any outdated terms that may not be politically correct. Map adapted from: http://www.lib.utexas.edu/maps/americas/panama_ethnic_1981.jpg.

The Ngobe people are mainly subsistence farmers with the majority having no steady income. For the most part, they began as solitary farmers, with families living in spread out clusters close to their farms. Today the Ngobe are more community based, with the construction of schools and clinics bringing them together. Most of the Ngobe people still travel to their farm several times a week to clear the brush, harvest fruits and vegetables, and cut wood for the stove. In larger towns, such as Kusapin, there is a monetary inflow from teachers and visitors who come in from the cities, but the majority of people rely on what can be found in their farms, rivers, or the ocean.

Panama can be considered a “Banana Republic” and the Bocas del Toro area is the capital for bananas (the United Fruit company has large operations in the western part of Bocas del Toro). Needless to say, The Ngobe people eat a lot of bananas, most of which are not eaten ripe, but rather boiled and eaten when green. Please note that when the author writes *banana* he is generalizing (there are several different varieties in the area). Along with bananas, the Ngobe people harvest tubers in large quantities. The types that are eaten most frequently are *yuca*, *ñame*, *ñampi*, *dachin*, and *otoe*. These are usually boiled and eaten with a little bit of salt. To accompany the tuber or banana, the people in the Kusapin area mainly eat fish. If the sea is calm enough for the locals to paddle out in their canoes, fish is usually abundant. The fish is either fried or cooked in coconut milk (Figure 4).

Figure 4. Typical meal in the Kusapin region: fried fish and boiled banana over rice.

2.4 Sanitation in the Ngobe Area

The lack of sanitation in the Ngobe area is a great concern with regards to development work in Panama. The majority of the inhabitants in the Ngobe Territory lack any type of sanitation infrastructure. As any development worker knows, much more is necessary than just finding materials and funding when trying to solve a problem of this magnitude. The customs and ideals of a people should always be viewed with utmost importance. In the Ño Kribu region of the Ngobe territory, most villagers use the local streams and rivers or the ocean to relieve themselves, washing themselves with water immediately afterwards. This has been the custom generation after generation, and for many people changing this custom is awkward and uncomfortable. Many people also view the pit latrine as a smelly breeding ground for mosquitoes that carry malaria.

Along with cultural barriers, the topography and climate of the Ño Kribu region also make it difficult to improve sanitation in the area. With the large amount of rain that consistently falls in the area, the level of the water table in the lowland areas is very close to the surface of the earth. Traditional pit latrines have been known to fill with water, and their walls have been susceptible to collapse due to the soft, porous nature of the earth. This has made the traditional pit latrine impractical and undesirable in many areas.

In the Kusapin area the nearby hills do make it possible for some families to construct pit latrines, but the idea has not spread to the majority of the populous. The author has noted that the families who do construct pit latrines are typically ones who have spent time outside of the communities in larger towns or cities, where they, most likely, had to become accustomed to use latrines or flush toilets. For those families who either do not have land on which to build a pit latrine, or simply find pit latrines undesirable, the small streams that flow through town into the ocean are used as a restroom. Some villagers may have to walk 10 minutes from their homes to find an adequate location. Those who are lucky enough to have a house over the ocean simply build outhouses that drop the excrement anywhere from 1 to 10 meters from shore. On a daily basis these contaminated streams and coastlines are used to collect shrimp and sardines, or simply used as a playground for children (See Figure 5). In other areas of the region whole villages relieve themselves in the same river that is used for drinking water by other villages downstream.

Figure 5. Villagers gathering shrimp in local stream while a young girl uses it as restroom.

In the hospitals of the Ngobe-Bugle territory, diarrhea and gastrointestinal illness make up 15% of all illnesses treated (MINSA, 2002). In addition, the Bocas del Toro region (including Ño Kribu) has the highest mortality rate attributed to diarrhea for children under 5 years old in Panama – 143 per 100,000 inhabitants per year (MINSA, 2000). Needless to say, health education is a dire need in these areas. Along with education, the introduction of an appropriate sanitation technology can help in solving this problem. For this reason Peace Corps Panama has been promoting the composting latrine throughout the Ngobe area.

2.5 Peace Corps Panama

The Peace Corps first worked in Panama from 1963-1971. After an almost 20-year break, it was brought back in 1990. Since then many volunteers have worked in the areas of environmental conservation/education, community economic development, and sustainable agriculture. In January 2002 the first group of Environmental Health volunteers arrived in Panama. The Environmental Health sector was designed to primarily work in the areas of water and sanitation and health education in the most rural parts of Panama. The author was among the second group of Environmental Health volunteers, who came to Panama in September 2002.

During the 2.5 months of training, which took place in a small town an hour outside the capital, the EH volunteers were educated in various aspects of water and sanitation, including basic hydraulic theory, water disinfection, water system construction, and latrine construction. It was here that the idea and design of the composting latrine was introduced to Peace Corps Panama by the EH Assistant Peace Corps Director, Greg (Goyo) Branch.

After the author's group had finished training and was sent to their sites to begin their two years of service, over 20 volunteers were located in the Bocas del Toro / Ño Kribu area. During the next two years dozens of composting latrines were built in and around the communities of these volunteers. Most of these were built with funding awarded to a group initiated by the Peace Corps volunteers in the Bocas del Toro / Ño Kribu area. Other latrines have been and continue to be built in this area, with the aid of both in-country and outside funding.

Chapter 3 - Past Compost Latrine Designs and Projects

The idea of using compost latrines to improve sanitation is not in any way new. This idea has been presented in many countries across the globe and numerous projects have been undertaken. Designs vary and different materials have been used for construction, but the main objective of safely storing human excrement and converting it into a less infectious, highly fertile material is the consistent throughout.

Compost latrines can be divided into two main groups; batch and continuous (Pickford, 1995). A batch system usually has two separate chambers (like the latrine design detailed in this report) that are used alternately, allowing one side to be sealed and the compost to mature. A continuous system has only one chamber that allows matured compost to be removed continuously. This type should be designed so that the compost spends sufficient time inside the chamber to maximize the pathogen killing potential. The success of a composting latrine project is also primarily dependent on cultural factors rather than technical ones. To provide an overview of how the design described in this study relates to other designs used worldwide, several compost latrine designs and projects are described below. The three technologies described in this chapter include the bucket, "Multrum", and the double vault systems.

3.1 The Bucket System

The bucket composting system may be the most low-tech and least material intensive compost latrine system. In Panama several Peace Corps Volunteers used this system with great success, but it must be pointed out that these were usually well-educated, flexible people with hygienic habits that differ greatly from other cultures in the world. With this system, a seat is constructed over a bucket, in which the user relieves themself. The author has used and observed bucket latrines that both have and have not allowed urination into the bucket. After each session, the user typically adds a cupful or two of sawdust or rice husks. When the bucket is filled, it is then placed in a pile where more organic matter can be added. Odors were never a grave problem, and flies were usually not observed. In The Humanure Handbook, a 20+ year user of the sawdust bucket system shows, through lab tests, that with careful composting all pathogens can be killed, while having no odor, fly, or health problems (Jenkins, 1990). Having stated this, it is important to realize that in many cultures it is not acceptable to have such an intimate relationship with your excrement, and although the author does agree with Jenkins in that it could be beneficial to educate the people “about resource recovery, about the human nutrient cycle, and about thermophilic composting”, the author believes that this system is too high-maintenance and fecal-intimate too succeed in most of the world.

3.2 The “Multrum”-type Continuous Compost Toilet

The “Multrum” compost toilet is a single-vault continuous system that was first introduced in Scandinavia (Pacey, 1978). In most designs, the user defecates and urinates in the same chamber and vegetable waste is added periodically (Pickford, 1995). To keep the system aerobic, air ducts or channels are constructed inside the chamber to enhance air circulation (Figure 6). As the organic matter is decomposed, it falls down a sloping floor towards an outlet door.

The average time that the compost remains in the chamber is unclear. However, “Multrum” type latrines without electric heaters in Scandinavia were noted to have a composting cycle of up to 3 to 5 years (Pacey, 1978). Low cost versions have been implemented in the developing world, but a United Nations Center for Human Settlements report (1984) notes that projects initiated in Argentina, Botswana, Dubai, the Philippines, Tanzania and other countries were unsuccessful due to poor maintenance (Pickford, 1995).

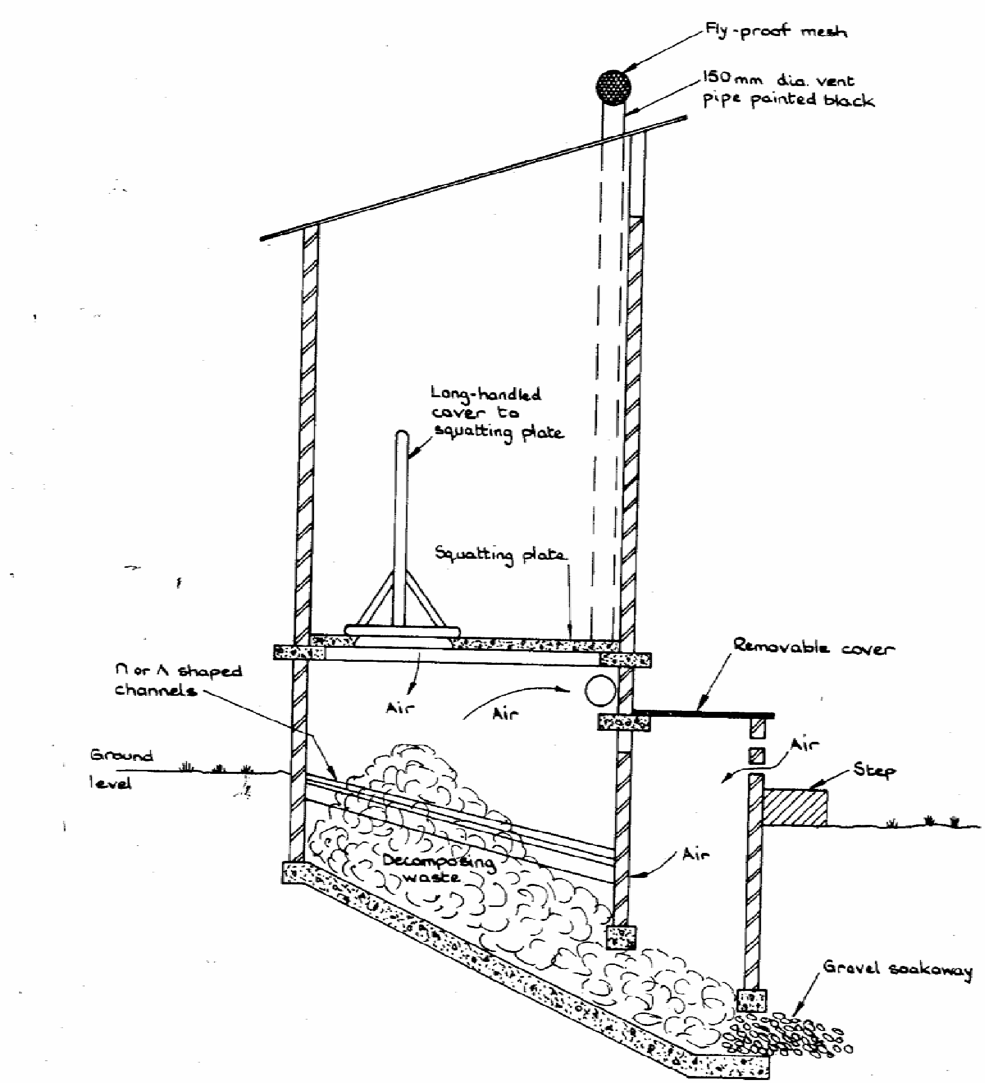

Figure 6. A Prototype Design of a “Multrum”-type Composting Latrine for One Family. (From: Feachem, 1978)

A compost latrine similar to the “Multrum” was introduced in Ciudad Juarez, Mexico and achieved good results. The contents of the latrine were allowed to build up in the chamber below the seat for three months. After this period, the contents were pulled down to the lower chamber, under a solar collector, and remained there until harvest, an additional three months later. This study is discussed further in Chapter 6.

3.3 Double Vault Systems

3.3.1 Vietnamese Double Vault Septic Bin

Compost latrines were first introduced in northern Vietnam around 1954 in the northern area, where hydrologic conditions made other types of latrines unfeasible. The first large push towards widespread use started during the years 1961-65, with the Vietnamese Ministry of Health initiating a “Five-Year Plan” to improve water and sanitation problems (Pacey, 1978). This design closely resembles the design detailed in this report, having two above–ground bins that are used at separate times (Figure 7). However, instead of piping out the urine to leach into the ground, it is collected and used as fertilizer in the fields. By 1972 there was on average one double septic bin for every 1.4 households in the North Vietnam area where the Five-Year Plan was initiated (Pacey, 1978).

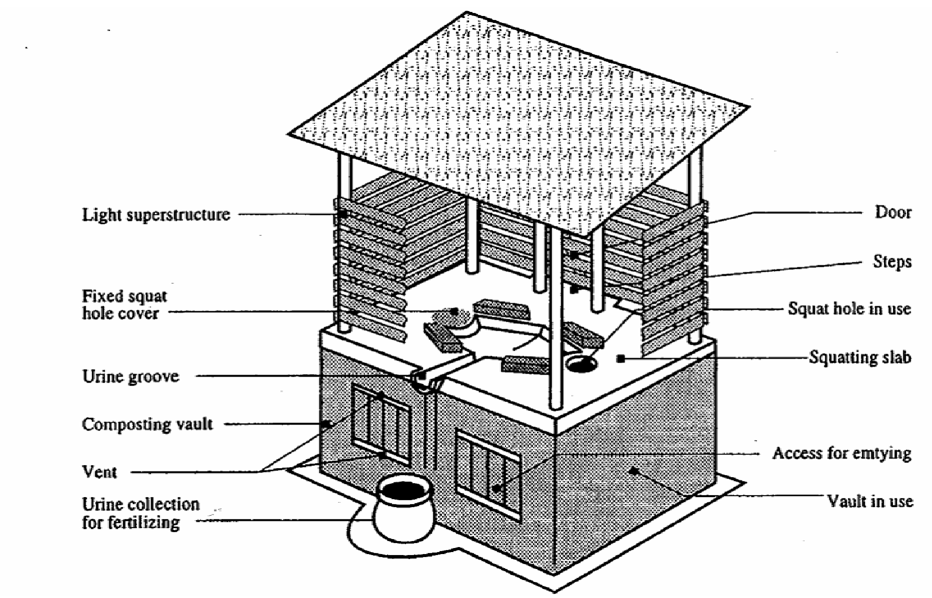

Figure 7. Vietnamese Double Vault Septic Bin with a squatting slab and channels that direct urine into a container. (From: Dahi, 1990)
*Note - In a design provided by the Intermediate Development Group, the urine is allowed to fall into an ornamental plant bed constructed into the wall of the latrine (ITDG, 2005)

With an inner volume of each bin being 0.17m^3, the latrine is suitable for a family of 5-10 people (Pacey, 1978). Before the bin was used the bottom was lined with a layer of powdered earth to absorb moisture. After defecation, the toilet paper was discarded into the bin, and wood ash was sprinkled on top of the feces to reduce odor. Once one chamber was ready to be sealed, the material was left to compost for 2 months.

Pacey (1978) reports that these latrines were a success, and thousands have been built since the time of their introduction. Reports have shown that when everyone used the latrines, there was an 85% reduction in diarrhea and a 50% reduction in worms. In addition, crop yield was noted to have increased by 70% (Pickford, 1995). Culture plays a large role in the success of projects, and one author notes, “This type of latrine is widely used in Vietnam but its use is based on a well-established tradition and it would be difficult to transfer this technology to other communities” (Dahi, 1997).

3.3.2 Guatemala Dry Alkaline Family Fertilizer (DAFF) Latrine

In 1978 the Dry Alkaline Family Fertilizer (DAFF) latrine was introduced to the Lago Atitlan area of Guatemala in hopes to decrease the pollution of the nearby lake. The Guatemalan government first promoted the use of pit latrines, but the people saw no benefit, as they customarily relieved themselves in their fields, providing crops with natural fertilizer (Pickford, 2005).

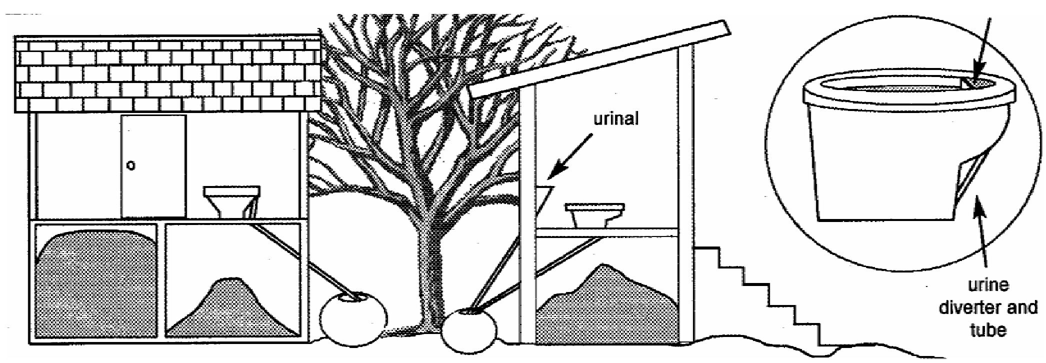

Figure 8. Guatemalan DAFF composting latrine with urine diverter and wall urinal.
Adapted from: Jenkins(1999).

After their introduction these latrines immediately became popular in Guatemala, since the compost could be harvested, instead of lost as in a pit latrine. As in the Vietnamese design, the urine is collected in a container and diluted and used as fertilizer (Figure 8). Ash, or an ash/soil mix is added as a desiccant, which, in effect, raised the pH and reduced odor (Strauss, 1990). The solids were removed after 10 months (8 months more than in Vietnam) and left outside to sun-dry (Pickford, 1995). In a report written by Strauss and Blumenthal (1990) it was noted that in the southern highlands, where yearly temperatures average 17-20^{o}C, viable roundworm egg concentration was greatly reduced after a 12-month incubation time. A further decrease in viable egg concentrations was achieved with subsequent sun-drying, enabling the locals to obtain a fertilizer with "very low" or zero egg viability (See Chapter 6).

3.3.3 Other projects in Central and South America

The latrine design detailed in this report was brought to Panama from El Salvador. Hundreds of these latrines have been built and various national and international organizations have promoted compost latrine projects in El Salvador with success (Branch, 2003). Similar latrines have been reported to have been built in Honduras and Nicaragua.

Family sized dry composting latrines (LASF) have also been promoted in Bolivia. A well-put-together education/design manual, titled *La Letrina Abonera Seca Familiar (LASF.): Manual de Capacitation Para Facilitadores y Visitadores*, was arranged by the Bolivian Ministry of Housing and Basic Services, The Development Institute – Bibosi, and Peace Corps / Bolivia. Information on the success of any projects could not be found. The manual details the construction of the latrine using brick.

3.3.4 Panama Design – Family-Sized Dry Compost Toilet

The compost latrine detailed in this report can be described as a family-sized dry composting latrine (Figure 9). The design is very similar to the Vietnamese double vault latrine, and the Guatemalan DAFF. This design was brought to Panama by an Assistant Peace Corps Director, who had led many composting latrine projects in El Salvador, while serving as a Peace Corps Volunteer. Each latrine is designed to service one household, with up to 8-10 users with one chamber having an inner volume of around 900 cm^3. It is built above ground with a base floor of concrete. The latrine contains two chambers, each with their own seat and access door in the rear. The specially designed seat separates the urine, which is taken out with PVC pipe, from the feces by collecting it with a receptacle attached to the front. In Panama, several male and female Peace Corps volunteers designed a fiberglass mold (See Chapter 4), so that an ergonomic concrete composting latrine seats could be reproduced.

Figure 9. Typical compost latrine in the Bocas del Toro area of Panama.
Note – PVC tubes (emerging from wall) transport urine from the seat to a soak pit next to latrine.

Only one side (chamber) of the latrine is used at a time. After every use, some type of dry organic material (e.g. sawdust, rice husks) must be thrown into the latrine. This will absorb moisture and aid the compost process, while reducing the production of unwanted odors (See in Chapter 5 & 9)). Wood ash should also be thrown in to reduce odors, and raise the pH (See Chapter 5). The design presented in this report allows the family to use one side of the latrine for approximately six months. Of course, if there are less family members the chamber will take longer to fill, or vice versa.

After the first chamber has been used for six months the seat should be covered (typically with a plastic or burlap sack), and the second chambers should be used. Once an additional six months has passed, the contents of the first chamber can be removed, and the chamber can be put into service again. This process can be continued indefinitely, with lifetime of the latrine almost solely dependent on the lifetime of the construction materials.

Chapter 4 - Design and Construction of Family-Sized Dry Compost Latrine

4.1 Materials

The Recommended materials for the concrete structure of one compost latrine that can serve up to 8-10 people are:

- 70 – 4-inch concrete blocks (add 10 more if a staircase is to be made from block)
- 5 – 49.5-kg sacks of cement
- 23 – 5-gallon buckets of sand/rock mixture
- 18 – 5-gallon buckets of sifted sand
- 32 meters - 3/8-inch rebar
- 4 meters– ½ or ¾ inch PVC tube
- 4- PVC elbows corresponding to the tube size
- 1 – small can PVC glue
- 10 meters– 2x4 pieces of wood (for the forms)

4.1.1 Concrete Blocks

In Panama, 4-inch (the block's width) concrete blocks come in two different sizes – 40 cm and 45 cm long. The design in this report (See Figure 10) is for the 45-cm blocks. 40-cm blocks have been used with the same design layout. The shorter blocks will change the storage capacity, but not significantly. In projects with which the author was involved, the blocks were either made on-site or purchased commercially. In Kusapin, where good quality sand was plentiful and free, all the blocks were made in town with a block-pressing machine. The quality of the concrete blocks can be better assured by making them on-site. The author has noted that many times pre-made blocks bought from local stores have been much weaker than those made in-site. This may be due to the manufacturer saving money by using less cement, the poor quality of the sand, or the insufficient time allowed for the blocks to cure. In the author's experience, stronger blocks could be made on-site for a lower cost (including labor), while providing work and income to the local block presser and assistants.

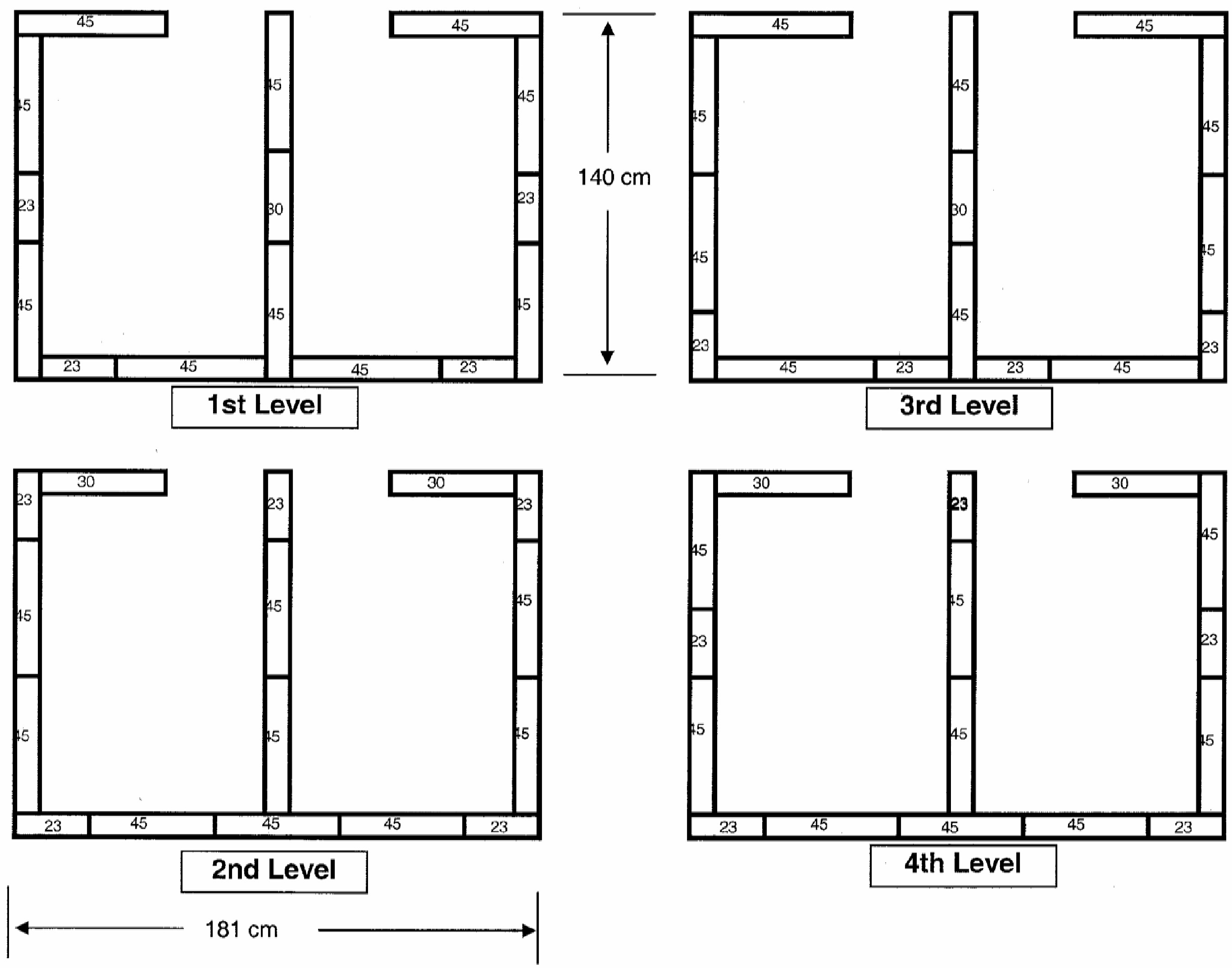

Figure 10. Block layout using 45cm long concrete blocks. Note – the partial blocks (23 and 30 cm) will be need broken with machete or hammer.

4.1.2 Cement

Cement in Panama is primarily sold in 49.5-kg sacks. It is important to keep cement as dry as possible, since the cement can harden by absorbing moisture from the air. In the Ño Kribu region, much of the material transport needs to be done by boat in rivers or the ocean. For this reason, each sack of cement was sealed in a large plastic garbage bag. Not only does this prevent the cement from getting splashed in the boat, but it also prevents the sacks from getting torn, and helps contain the cement if a sack does burst. In Kusapin, where the humidity can be unbearable, sacks tied up with a plastic bag have been kept for several months without hardening.

4.1.3 Aggregate

Aggregate is the general term for the material mixed with cement and water to form concrete. Sand is considered a fine aggregate, and gravel and crushed rock are considered as coarse aggregate. The quality of the aggregates is very important to the strength of the concrete. For example, sand containing clay, silt, salt, mica, organic material may weaken the strength of the concrete (Jordan, 1996). Having said this, the author will note that, many times, one can only deal with the resources found locally. In the areas where the author worked almost all concrete structures (school, hospitals, water tanks) were constructed with locally available aggregate. In many instances this aggregate may be considered low quality. However the local masons have used the materials all their lives and believe it is suitable. It is the job of the development worker to educate the people on the problems that may arise and how to improve on what they have. However, sometimes it is impossible or monetarily unfeasible to have the materials be “grade A” quality.

The tools that are recommended for construction are:

- 1 – shovel with rounded tip (author found it good for mixing concrete)
- 1 – shovel with square tip and flat head (good for leveling earth)
- 3 – 5-gallon buckets (for carrying and measuring water, sand, and concrete mix)
- 1 – regular foot long level
- 1 – level (a line level that can be hung on thread)

1 – measuring tape

1 – saw (to cut wood)

1 - flat metal mason's trowels

1 - flat wooden mason's trowels

2 – triangular mason's trowels

1 – hack saw (to cut rebar and PVC pipe)

1 – square (to measure 90^o angles)

4.2 Mixing Concrete and Mortar

Mixing concrete is a skill that usually takes some time to master. In the developing world, volume of materials is more likely measured in buckets, wheelbarrows, donkey carts or shovel-fulls, than in cubic meters or feet. Sometimes locals only feel comfortable using an entire bag of cement at a time, or their only tool of measurement is the trained eye. It is always important to include the local opinion and be flexible in the way things are done.

The majority of the time the author used 5-gallon buckets to measure materials, as they were widely available. Having a standard volume helps when managing the construction of several latrines. Measurement using sacks is not recommended, because of the personal discrepancy as to what is "full". Wheelbarrows were often used, and seemed to work well, although they do vary in sizes. Table 1 shows typical mix concentrations for concrete. The larger the mix ratio between cement and aggregate, the stronger the concrete will be.

Table 1 Proportion of Concrete Using 1 Sack (50kg) as Basis (From: Longland, 1998)

Mix	Cement sack	Sand (m^3)	Stone (m^3)
1:2:4	1	0.07	0.14
1:3:6	1	0.10	0.20
1:4:8	1	0.14	0.28

The size and quality of aggregate is an important issue when mixing concrete. In the Kusapin area, all stone is derived from the ocean, and many times, it was larger than desired. This makes it difficult to add the correct proportion of stone because large stones can prevent a thin slab from being adequately smoothed out (See Section 4.4). For this reason, the mix used in this area usually had a 1:6 to 1:8 ratio of cement to mixed aggregate, but had substantially less stone than found in traditional mixes. In many locations in Panama mixed aggregate was gathered from riverbeds. Many times locals would pay no attention to the ratio of sand to rock, with this mixed aggregate usually containing a much lower portion of stone than the traditional mix. This riverbed aggregate may also contain much organic matter, which can decrease the strength of the concrete. The author has noticed that concrete made with riverbed aggregate was more brittle than concrete made with beach sand and stones. However, salt can also decrease the strength of reinforced concrete by breaking down the rebar, so precautions should be taken (Van Dam, 2005).

Mortar is a mixture of cement and sand, and is used for laying block, and parging (See Section 4.6) the walls. The sand must be sifted through a fine screen (mesh of at least 0.5 cm), to remove any larger particles (Figure 11). The ratio of cement to sand used in Panama to produce mortar was around 1:3 to 1:4. This is a typical mix for masonry work (Jordan, 1996).

Figure 11. Sifting sand to use for mortar.

A good style of mixing concrete or mortar is the “volcano.” This is where the dry aggregate is mixed with cement to form a mound with a crater in the middle where the water is then added (Figure 12). The dry mix from around the edges can be shoveled up and into the water, while the worker moves around the pile in a circle. As the concrete absorbs the water, the crater can be widened and more water can be added. Water should be added slowly, and the crater should not be filled to the top, as this may cause a wall to collapse and cement to be lost. When most of the mix has absorbed water, it can be turned over several times to ensure a uniform consistency. Enough water has been added when the concrete can hold itself up in large clumps when placed on the floor. Adding too much water decreases the strength of concrete. In Panama, the author has noted that, many times, locals prefer to add excess water in order to facilitate its transport and placement.

Figure 12. The “volcano” style of mixing of concrete

Within 4 hours of adding water to cement it has finished setting and can no longer be worked. As Table 2 shows, the chemical hardening process of cement is most rapid for the first few days, but will continue for at least a year. Moisture is essential in the hardening process, and therefore the concrete should be kept wet. If possible, newly placed concrete should be covered to prevent excess evaporation.

Table 2 - Strength of Portland Cement Concrete (From: Jordan, 1996)

(percent of ultimate strength at various stages)

3 days	……..	approx.	20%
7 days	……..	"	45%
28 days	……..	"	60%
3 months	……..	"	85%
6 months	……..	"	95%
1 year	……..	"	100%

4.3 Site Selection/Preparation

The importance of the placement of the composing latrine should not be overlooked. The location should facilitate the construction, and the distance away from the house should be acceptable for everyone in the family.

Before the construction of the latrine the ground should be totally level. Unleveled ground can cause the walls of the latrine to be structurally unsound. If the area is hilly, picks and shovels can be used to dig out and flatten a slope (See Figure 13). The levelness of the ground can be measured by placing a level on a straight piece of wood that is laid widthwise, lengthwise, and diagonally on the surface. For the author it was easiest to "fine tune" the levelness using a flat-headed shovel to scrape off sheets of dirt from the surface. It is important to leave at least an extra 1-foot leveled border around the area where the floor will be placed, to make room to work and lay the concrete block walls.

Figure 13. Leveled hillside with concrete floor of latrine showing

Before choosing a final location for construction, it is always best to consult with the household members. The author experienced situations where the ideas of the head of the household were in conflict with the rest of the family members. After learning that the composting latrine does not release bad odors, one head decided to construct it very close to the house, which the author agreed was a good idea. However, even before the latrine was finished, family members expressed their discontent about the proximity, lowering enthusiasm towards the project and slowing down the construction progress. For this reason, it is important to analyze any potential conflicts the latrine location may pose on family members or neighbors in the vicinity.

4.4 Laying the Floor

After the construction area is completely level, a form is placed around the border using pieces of wood with a 2-inch width. The area enclosed by the form should be 2 meters by 1.5 meters. This leaves about a 5-cm border along the floor in between the edge and where the block wall will begin. The wood should be laid so that the thickness of the floor will be 2 inches. Unlike 2 x 4's that are purchased in the U.S. (which are actually 1.5" x 3.5"), the 2 x 4's used by the author actually had 4-inch and 2-inch sides, since they were usually rough sawn by locals and hauled down from the neighboring jungle. If nails are unavailable, stakes can be implanted around the outside of the wood to hold the form in place.

Although two inches is a sufficient thickness for the base slab, it is relatively thin compared to most structures. Typically, large aggregate should be no larger that 1/3 the thickness of a slab (Van Dam, 2005). If aggregate is too large, the placing of concrete can be very difficult and tedious. For this reason, the mix ratios can be altered from those shown in Table 1. To facilitate a smooth placement of concrete, equal parts of sand and rock can be added to the concrete. As stated earlier, many masons will be used to working with a concrete mix with far less large aggregate than shown in Table 1. This, however, will not be detrimental to the strength of the structure (Fritz, 2005).

For the 1.5 m x 2 m slab, the rebar should be cut to have three bars running lengthwise and four bars widthwise (See Figure 14). The rebar should then be tied at the intersections with wire to hold it in place. The rebar should be lifted about 1 inch above the ground at several points by inserting small stones underneath the bars. This enables the fresh concrete to seep under the rebar, suspending it in the middle of the floor as it hardens. If the rebar is not raised, the full strength of the rebar would be lost, weakening the structure.

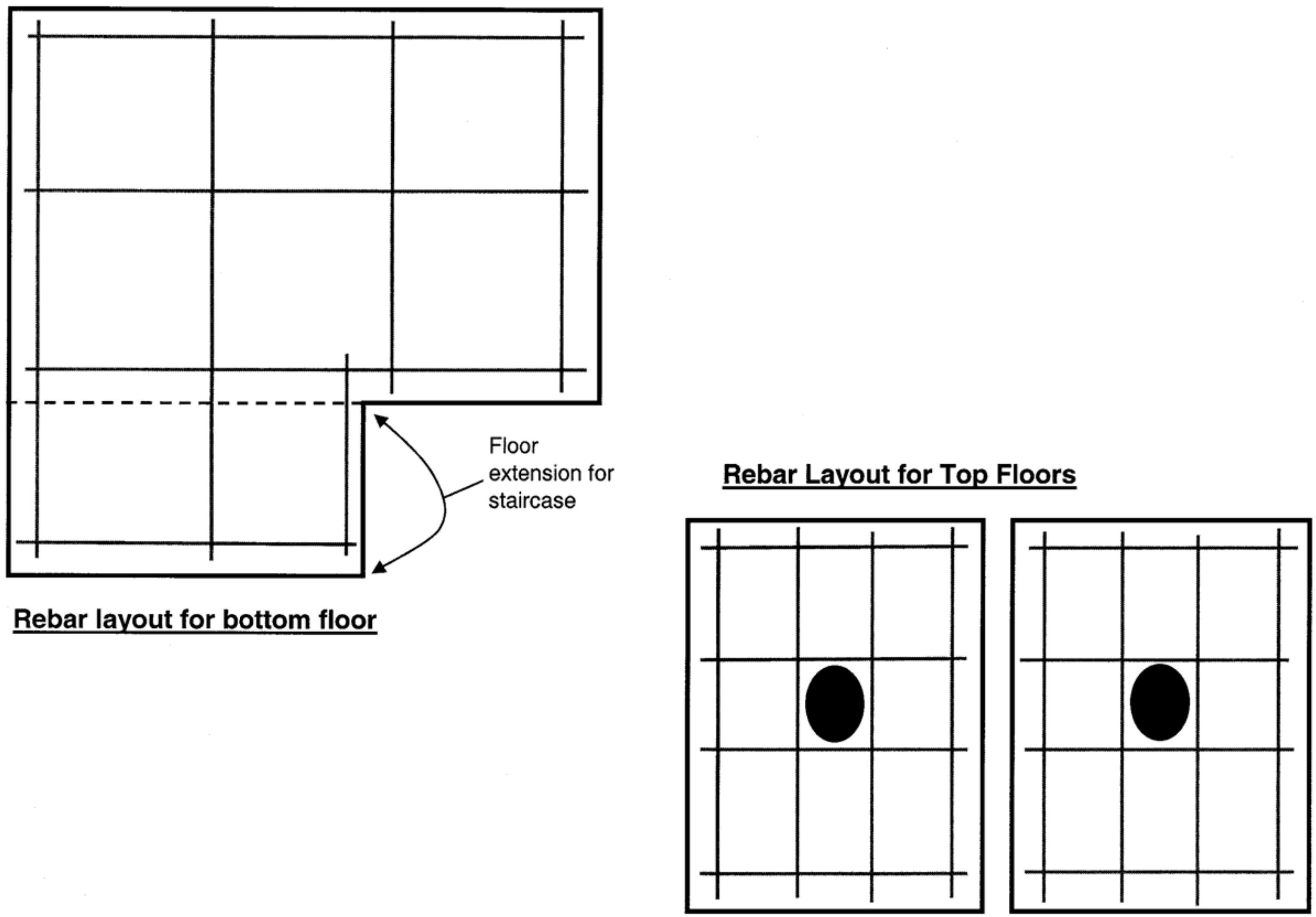

Figure 14. Rebar layout for the base and top floors of the compost latrine. Note the holes left for the seat. Extension of the concrete base is not necessary if staircase is made from wood. All rebar is 3/8-inch.

The floor requires about one sack of cement. Once the concrete is mixed, it can be placed into the form with shovels, buckets, or wheelbarrows. The author recommends starting with the far corners of the form, to ease the evening-out process. With a flat trowel the concrete can be smoothed into place with a circular vibrating motion (See Figure 15). This will release any air bubbles and cause water to rise to the top making it easier to smooth out with the flat trowel. Protruding stones can be pushed in, but it is better to throw out any stones that are difficult to smooth into place. It is important the concrete meets up with the top of the form on all sides, and that there are no lips on the edges, as this may inhibit the laying of blocks.

Figure 15. Smoothing out concrete with flat mason's trowel
Note that people in photo are working on the top floors, but the technique is the same for the all concrete slabs.

Once the floor is placed, it should be covered to prevent damage and drying-out, as moisture is crucial in the proper curing of concrete. If the conditions are very dry, it may be best to periodically cover the floor with water to keep it moist at all times. The first few days are most critical in the curing of concrete. From the author's experience, the floor does, however, become strong enough after one day to begin the construction of the block walls.

4.5 Construction of Chamber Walls

The construction of the latrine walls is the most time consuming step, and most technically difficult. Two or three skilled masons can easily block the four necessary levels in one day. If the workers are novice block layers, it may be best to split the work between two days, to ensure that the blocks are placed correctly.

For laying block, one should use mortar (a mix of sand and cement only). The author found it useful to have a flat trowel, in addition to a triangular masons trowel. The mason can carry a mound of mortar with the flat trowel in one hand and place it with the trowel in the other.

Following the layout (Figure 10), it is best to start aligning the blocks at the four corners, leaving a 5cm border along the edges. It is helpful to first line up all the blocks in their respective locations (See Figure 16) then begin to mortar the blocks in place at the corners. A square can be used to ensure 90-degree angles at the corners.

Figure 16 – Aligning concrete blocks before placing with mortar.

Enough mortar should be placed below the block as to enable the block to be leveled by tapping down either side. Once the blocks are in line and level, the corner holes can be filled with mortar for strength. With the four corners in place, string can be strung around the blocks, to use as a guide to place the rest of the first-level blocks in a straight line.

Gaps in between blocks can be about 2-5 cm wide, and must be filled with mortar (See Figure 17). The following three block levels should be done in the same fashion, moving the string up as you proceed. It is of the utmost importance that two or more gaps never line up vertically, as this is structurally unsound.

NOTE - Two gaps, one on each side, should be left for the PVC outlet tube that will be connected to the seat.

There is no need for rebar in the block walls, since the structure is interlocking. If people involved in the project are skeptical or uneasy about not using rebar in the walls, a bar can be placed in the middle of each of the three main walls. If one decides to use the rebar, it must be placed before the floor hardens.

Figure 17. Erected Walls With 2-5 cm Filled-in Gaps Between Blocks

4.6 Parging the Inner Walls

Parging is the term used for the application of mortar on to surfaces in relatively thin even layers. Since concrete blocks are porous, it is necessary to parge the inner walls of the latrine. This keeps the moisture of the compost contained, as well as prevents outside water from seeping in.

Using a 1:4 or 1:3 cement:sand mixture, the mortar should be applied with a flat trowel. The author found it useful to, first, roughly apply mortar to a large area in long continuous upward strokes. After allowing this to set for a few minutes, a wooden flat trowel (preferably wet) can be used to even it out, using circular strokes. Once the surface is even, it can be smoothed out with a wet trowel, giving it an almost shiny look. Appearance may very important to the locals, an this should be taken into account. Many times there will be extra cement in a project, which can be used to parge the outside walls, covering up the naked block.

4.7 Top Floor Slabs

The easiest and least resource-demanding way to construct the top floor of the latrine is to pour two separate slabs on the floor and place them on top of the block walls once they harden. The top floors can be poured in place, which was done for many latrines in Panama and worked very well. However, this process requires several wood planks, and support beams for the form, which may be expensive and difficult to obtain in other developing countries with fewer resources than Panama.

The first step in pouring the top floors on the ground is the same for pouring the base floor. The ground should be level and flat, although any low cut grass can be left in place. As with the bottom floors, the outside form can be made with 2 x 4's, using the 2-inch side as the thickness. The top floor should be split into two slabs with a piece of wood or metal, so they can be more easily lifted. The area of the slabs can be made to fit exactly over the block walls, but one must be sure to exclude the area of the middle divide. Once the rebar is in place and lifted with small rocks, sheets of paper of cloth should be placed underneath so the concrete does not adhere to the ground. Newspaper or left over cement bags work well. To make a hole for the seat, a form can be made of wood, or a sack can be filled with small stones to fill the desired area (See Figure 18). The concrete mix should be the same as that for the bottom floor, as well as the smoothing out process. To provide the floor with an extra smooth, shinny appearance, pure cement can be sprinkled on top of the wet concrete and spread over with a flat trowel.

Figure 18. Construction of top floors of latrine showing wood forms to make seat holes
*NOTE – Pieces or rebar, protruding upwards, can be placed in the floors at the corners to facilitate the construction of the housing structure later on (See Section 4.12).

4.8 Access Door for Removal of Compost

The access door can be constructed of many local materials. If wood is used, it should be durable and not easily rot. A good design is to make frame with 2x4's that fit snug inside the doorway with wood planks nailed on to entirely cover the doorway and any spaces.

A reinforced concrete door can also be made. However, depending on the size of the opening the door may be very heavy. Concrete blocks can also be used to cover the doorway, but are easily susceptible to breaking if continuously moved. A sheet of corrugated metal can be used by cutting squares from the corners of the metal can be used and folding in the sides with a 2-inch lip, the door can be made to fit snuggly into the opening (Bingley, 2004).

A weak mix of mortar can be used to fill in any gaps between the opening and the door. However, this may be impractical if the locals will not be able to get cement continuously in the future. As always, it is important to use local materials as frequently as possible. In the author's experience, sometimes there is the belief that a certain outside material is necessary for the successful completion of a project, when in reality that certain material can be easily substituted with one found locally. For example, locally-found clay may be a good substitute.

4.9 Compost Latrine Seat

Thanks to a group of Peace Corps Volunteers in Panama, a good compost latrine seat mold was designed and manufactured. Up until this time only regular pit latrine seats could be obtained in Panama. The basic design for a dry compost latrine seat includes a receptacle to collect urine and a large area to allow excrement to drop into the bins. If a pre-made compost latrine seat cannot be obtained, a regular pit latrine seat can be fitted with a receptacle to collect urine. A large plastic bottle can be cut and inverted to serve as a good receptacle (Figure 19a). Other seats have been hand made from wood or concrete block. Three main problems that may arise with a seat are: 1) the urine receptacle is too high and touches the user, 2) the space for the excrement is too small, making it difficult to aim properly, and 3) the location of the receptacle makes it hard for the users, especially women, to keep the urine and excrement separate. The compost latrine seat now used in Panama (Figure 19b) was ergonomically designed with special insight from female volunteers. A latrine seat can also be made from wood (Figure 19c).


a

b


c

Figures 19a, b, c. Examples of dry composting latrine seats. The seat shown in19a is a standard pit latrine seat fitted with a cut Clorox bottle to serve as urine receptacle. Figure19b shows a concrete seat designed by a group of Peace Corps / Panama volunteers. The seat shown in 19c is made from wood, and a plastic bottle functions as the urine receptacle (Note the screen place inside the receptacle to prevent material from clogging PVC tubes).

4.10 Urine Removal Piping

Urine is a nutrient rich waste that can be either collected and used as fertilizer or leached out into the soil outside the latrine. With one 90-degree elbow the PVC tube can be led away from the urine receptacle towards the side wall of the latrine, through the gap in the top level of block. With another elbow the tube can be led straight down into the drainage pit.

From the author's experience the drainage pit did not need to be more than a hole in the ground filled with small to medium sized rocks. The hole should be at least 1.5 feet in diameter and 2.5 feet deep. If the geology causes a difficulty in digging, or inhibits drainage, the urine can be collected in a container and disposed (or diluted and used for fertilizer) of later. One must be aware that urine can contain pathogens, although incomparable to that of feces.

4.11 Staircase

A staircase can be constructed from concrete blocks, as shown in Figure 20, and may be a good idea if extra concrete blocks are available. This can be done by filling rectangular levels of block with compacted dirt and covering the exposed area with mortar, forming steps by decreasing the size of the block rectangle as you work up. It is best to have an extension of the concrete base on which to build the staircase. However, money can be saved, and community participation can be gained if a staircase is made from wood, or some other local material. The need for a staircase can also be eliminated if the latrine is built into the side of a hill (See Figure 13).

Figure 20. Staircase for compost latrine made from concrete block.

4.12 Housing Structure

The construction of the house that will cover the chamber should be made from local materials. Concrete nails can be used to hammer the wood beams at the base to concrete floor of the latrine. If small lengths of rebar were incorporated into the top floor, small holes can be drilled into the wood, and the beam can be hammered in place. The housing structure should be left up to the locals, who will have a better idea of what to do than an outside development worker. Figure 21 shows a basic housing structure design that can be built over the chambers.

Figure 21 – Housing structure built over latrine chambers in Vanuatu, South Pacific.
Concrete nails were used to connect the bottom wood beams to concrete floor.
Source: Eric Tawney, PCV / Vanuatu and Master’s International student

Chapter 5 - Aerobic Composting

There are some discrepancies as to what the term *composting* means in regard to the presence of oxygen. Some sources state that the "composting process can be aerobic, i.e., oxygen is required to support the biodegradation process or anaerobic, i.e., oxygen is not required to support the biodegradation process" (Hickman, 1999). Others distinguish aerobic conversion (composting) from anaerobic fermentation (Peavy et al., 1985). Composting has also been defined more strictly as aerobic decomposition that only occurs at high temperatures, in-contrast to low-temperature aerobic decomposition or any anaerobic process (Dahi, 1997).

No one definite process is occurring inside the compost latrine, and this topic will be discussed later on. To avoid confusion in this report, the term *compost* (or *composting*), as used by Hickman (1999) in the previous paragraph, will be used to describe both the aerobic and anaerobic decomposition processes. The author will try to clarify whether a certain process is taking place in the presence, or absence, of oxygen. In both processes the organic matter is broken down but the time this takes, the byproducts that are formed, and the temperature that is reached during the process can vary greatly.

5.1 Stabilization and Maturing

When discussing high-temperature aerobic decomposition of organic waste, a distinction is made between the *stabilization* and *maturing* of compost. Stabilization is the decomposition of easily degradable matter causing a rapid temperature increase over a few days. Maturing is the decomposition of the slowly degradable organic matter, resulting in a gradual temperature decrease over a period of approximately three months.

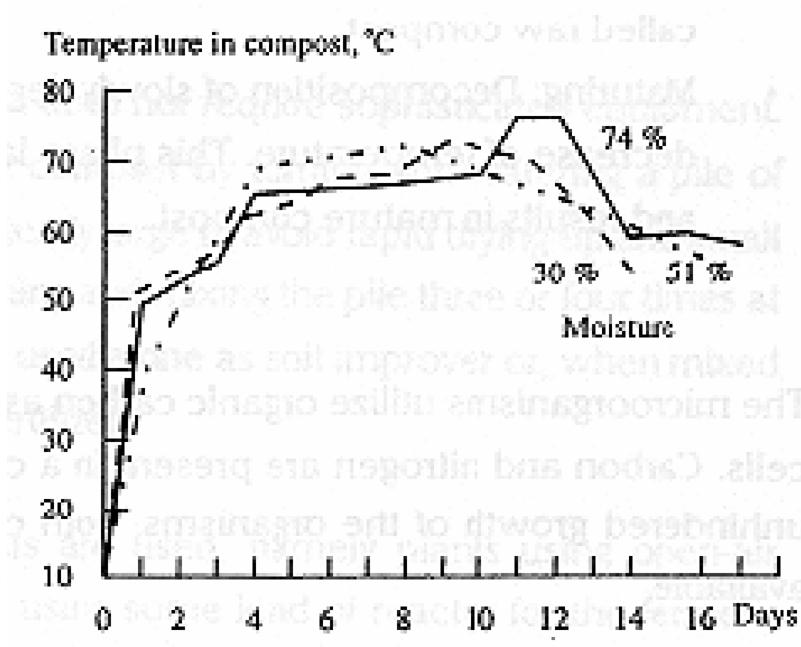

Figure 22. Temperature increase during the composting of organic waste.
From: (Dahi, 1997)

As shown in Figure 22, the rapid increase of temperature after the first few days (stabilization) is followed by a leveling out and gradual decrease (maturing), where a maximum temperature of 70°C is reached. At temperatures higher than 40°C thermophilic (heat-loving) organisms become dominant in the decomposition process. As will be discussed in this chapter, to achieve these high temperatures certain parameters must be met. The likelihood of this occurring in composting latrines of the developing world will be discussed later in this report.

5.2 Parameters for Aerobic Composting

In the aerobic decomposition process organic matter (including human waste) is broken down by oxygen-utilizing microorganisms. During this reaction, a large amount of chemical energy is released as heat (Dahi, 1997). There are several parameters that control the extent of the process. Many studies have been performed to optimize these parameters in order to create conditions that maximize the growth rate of the microbes responsible for the decomposition of organic matter. When dealing with projects in the developing world, these conditions will, most likely, not be ideal. However, conditions such as moisture, oxygen, and the carbon/nitrogen ratio can be manipulated in order to increase the rate of decomposition, and, as a result, raise the temperature of the compost.

5.21 Temperature

As stated earlier, aerobic decomposition is an exothermic process, capable of releasing a large amount of heat. It is this heat that is most responsible for the destruction of pathogens in the compost (Bitton, 1999).

Figure 23 illustrates the effect temperature and exposure time has on pathogens. The "Zone of Safety" indicates the amount of time the compost must maintain a certain temperature to kill all pathogens. As shown in Figure 22, where temperatures exceed 60^{o}C, all the pathogens specified in this figure will be killed off in about an hour. In the case where temperatures are considerably lower, an extended period of exposure is needed. This is the scenario that will, most likely, be found in composting latrines in the developing world. For this reason, special attention must be paid to the survival of heat-resistant pathogens, such as the *Ascaris* worm, which is the most resilient in temperatures below 50 degrees C if exposed for longer than one day.

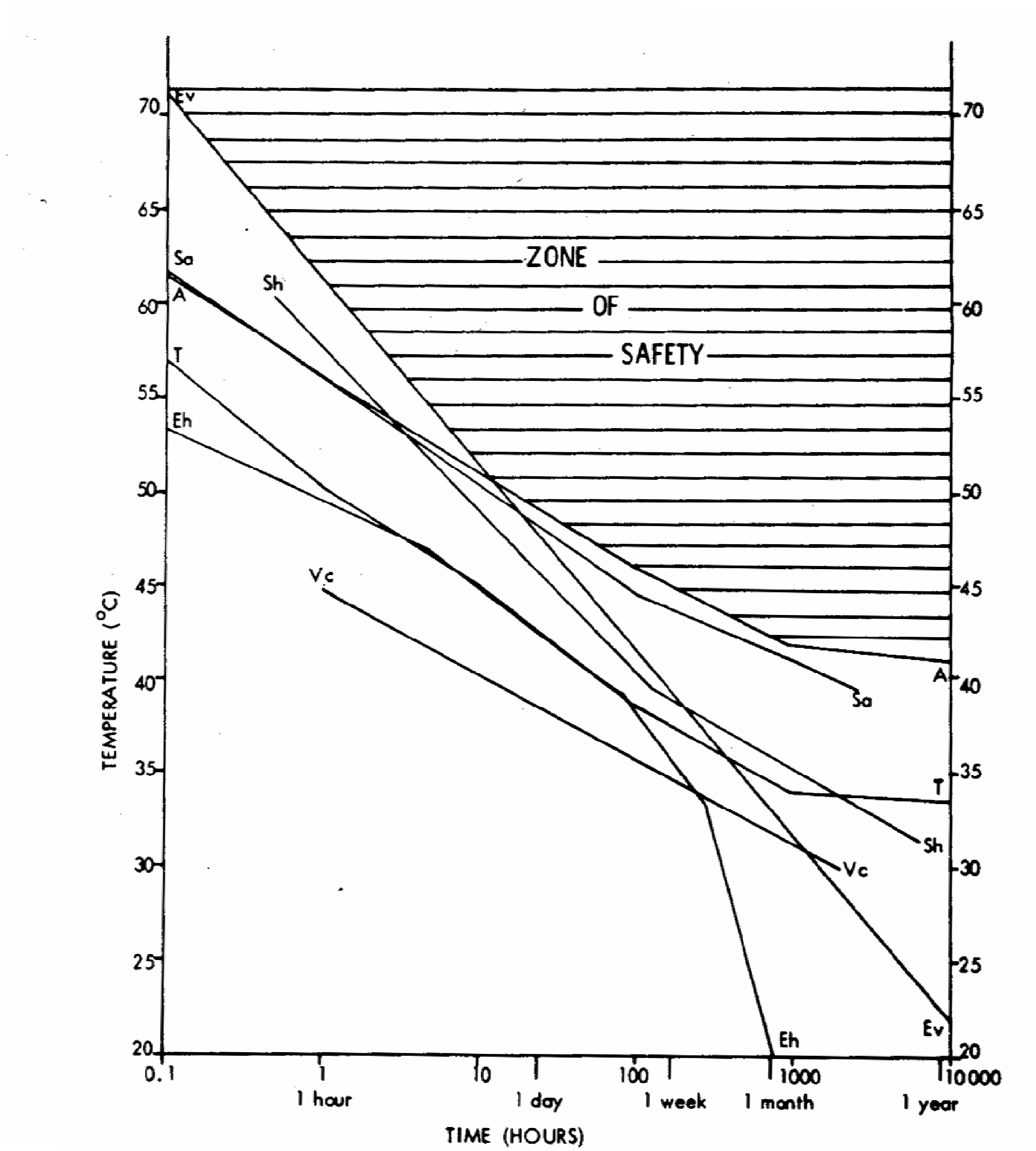

Figure 23. The influence of time and temperature on a variety of excreted pathogens. A process with time-temperature characteristics lying within the "Zone of Safety" should guarantee the inactivation of all excreted pathogens.

The lines drawn represent very conservative upper boundaries for death for specific pathogens.

Ev Enteroviruses
Sa *Salmonella*
Sh *Shigella*
Vc *Vibrio cholerae*
Eh *Entamoeba histolytica* cysts
A *Ascaris* eggs
T *Taenia* eggs

(From: Cairncross & Feachem, 1999)

5.22 Carbon / Nitrogen Ratio

The microorganisms that are responsible for the exothermic decomposition process are comprised of several elements, including relatively large amounts of carbon and nitrogen. Consequently, these elements are crucial to microbe reproduction, and a balance of the two is needed for optimum microbial activity. At the beginning of the stabilization phase a carbon to nitrogen of 30:1 is ideal (Hickman, 1999). If excess nitrogen is present during the composting process, it can be released to the air in the form of ammonia, giving off an unpleasant odor. Conversely, the lack of carbon can hinder microbial activity, permitting high temperatures from being reached.

Table 3. Carbon / Nitrogen Ratios of Typical Composting Substrates
(From: Jenkins, 1999; Dahi, 1997; Cairncross & Feachmem, 1999)

Feces	8	Raw Sawdust	500	Grass	12
Urine	0.8	Rice Husks	121	Vegetable refuse	25
Feces/Urine mix	2.5	Wheat straw	128	Leaves	54

Table 3 shows the Carbon/Nitrogen (C/N) ratio for various materials. Since feces has a relatively low C/N ratio of 8, it should be composted with materials having a higher C/N in order to raise the percentage of carbon. It is important to realize that the system may not be well mixed, causing the area in close proximity to the feces to have a much lower C/N ratio than expected with the addition of material with high carbon content.

In Panama, the author observed latrines that used sawdust, grass or rice husks and found them all beneficial in the decomposition process. These dry organic materials also serve the purpose of absorbing moisture in the latrine. The addition of these “soak” materials and the effects of desiccation will be discussed more in depth later in this report.

5.23 Aeration

A general reaction that describes the aerobic decomposition of organic matter can be written as:

Organics ($C_aH_bO_cN_dS_e$) + $O_2 \rightarrow CO_2 + H_2O + NH_3 + SO_4^{2-}$ (Dahi, 1997)

As the microorganisms break down the organic material, oxygen is consumed and carbon dioxide and water are produced. Without sufficient oxygen the reaction rate will be slowed and high temperatures required for pathogen destruction will not be attained. For this reason, it is important that the compost pile be aerated thoroughly. Composting facilities in more developed areas typically form windrows, or long mounds, which are turned every few days, manually or mechanically, to ensure the compost is kept aerobic (Cairncross & Feachem, 1999). The compost in a latrine can also be aerated by turning with a wood pole or shovel twice a week.

In addition to manually aerating the pile, the infiltration of oxygen can be achieved by adding dry porous organic material. Organic material (e.g. rice husks, grass and sawdust) also provides voids of air space throughout the compost heap, assisting air circulation.

A lack of aeration can cause the formation of odors. As shown in the general reaction, organic nitrogen is first converted to ammonia (NH_3), whose unpleasant odor can be associated with an unkept urinal. If the compost is aerated sufficiently, this ammonia can be converted to NO_3^-, which is not odorous.

Similarly, organic sulfu can be released as hydrogen sulfide (H_2S) if oxygen levels become too low in the compost heap (Bitton, 1999) . Hydrogen sulfide emits an odor that is usually associated with rotten eggs. Fortunately, in compost the sulfur levels are typically very low, so hydrogen sulfide is typically not a major nuisance odor.

5.24 Moisture

Moisture content is another factor that can be crucial in maintaining aerobic conditions and can determine the extent of temperature increase. Moisture content should be in the range between 40 and 60 percent during the composting process (Cairncross & Feachem, 1999). To achieve this level in a composting latrine drier material must be added to balance out the 66-83% moisture level of feces (Jenkins, 1999). The moisture content of a feces and urine mixture is 93% (Dahi, 1997), which is one reason urine is typically separated from feces in a compost latrine.

If the compost becomes too wet, air circulation throughout the compost can be impeded, preventing oxygen to be transferred to the microbes that carry out the decomposition process. At the same time, the compost cannot become too dry, as this also has an adverse effect on the microbial process (Hickman, 1999).

It must be pointed out that the compost in a latrine will most likely not be a completely mixed system, as may be obtained in a laboratory setting. Therefore, when discussing the moisture content required for optimum decomposition, it is important to look at the moisture in the localized area where the composting process is most essential – the interface where the feces and other organic material are in direct contact. Consequently, if a considerable amount dry organic matter is added, the compost heap as a whole may seem drier than optimum, while the area where the decomposition process is most active may be at the correct level.

Chapter 6 – Processes Occurring and Factors Influencing Pathogen Removal in Compost Latrines of the Developing World

As always, it is of the utmost importance to realize that there are several factors influencing the success of a technology in the developing world. In theory, the composting of human waste seems to be an excellent solution to sanitation problems. However, the fundamental processes that are actually occurring in the compost and the exact mechanisms that are responsible for pathogen removal are not always clear. If the adoption of compost latrines in the developing world to increase, it is necessary to understand more about the processes taking place and how basic operational procedures can improve the end result.

For one to evaluate the effectiveness of a compost latrine, they must first understand how different pathogens survive in the environment. All pathogens will eventually die of "old age" (Stenstrom, 2002). However, as shown in Table 3, the survival of pathogens is different in temperate and tropical climates, indicating that temperature is a key factor even if thermophilic levels are not reached.

Table 4. Pathogen Survival in Wet Fecal Sludge at Ambient Temperature
(From: Strauss, 1994)

Pathogen	Temp 10 - 15^{o}C days	Temp 20-30^{o}C days
Virus	< 100	< 20
<u>Bacteria</u>		
Salmonella	< 100	< 30
Cholera	< 30	< 5
Fecal Coliforms	< 150	< 50
<u>Protozoa</u>		
Amoebic cysts	< 30	< 15
<u>Helminths</u>		
Ascaris eggs	2 - 3 years	10 - 12 months
Tapeworm eggs	12 months	6 months

While in Panama the author observed many compost latrines in use. Although many villagers maintained their latrines well, others were not so diligent. The type, as well as the amount, of a soak material added to the chambers after defecation varied greatly amongst the latrine users. While some latrines were filled with organic matter and ash, and kept relatively dry, others appeared excessively moist, due to the lack of sufficient desiccant material. These factors greatly influence the conditions inside the latrine, and, in effect, the potential for pathogen removal and aerobic decomposition.

Through observation, temperature measurements, and research of past compost latrine projects, the author has shed light on the processes occurring and what steps can be taken to increase the potential for pathogen destruction.

6.1 Methods of Temperature Measurement

During the months of October through December 2004, PCV John Spaulding measured the temperature of 97 latrines in the Ño Kribu / Bocas del Toro area using a long-stemmed coil compost thermometer. Measurements were taken of the compost heap inside the chamber in use, as well as a chamber that had been sealed off after 6-months of use, when possible.

Similarly, at different times during 2004, the author of this study attached a standard mercury thermometer to a stick to obtain temperature in the chambers of 10 latrines located in the Ño Kribu region, by placing the thermometer towards the middle of the compost heap.

6.2 Composting and Mouldering

To further clarify the processes that are taking place in a compost heap a distinction can be made between *composting* and *mouldering*. In this sense, composting is the relatively fast process of decomposition of organic that achieves a relatively high temperature during the process, while mouldering is a slower, mainly aerobic process that takes place at room temperatures. The high-temperature aerobic decomposition process, called composting in this case, may take only two to three months to produce a pathogen-free compost (Pacey, 1978).

6.3 Temperatures Inside Latrines

As shown in Figure 24, the conditions present inside most of the composting latrines that were tested by Spaulding resembled that of the mouldering process. An average temperature of 29.7^{o}C (σ = 4.2^{o}C) was measured in the active chambers of 97 latrines, which is close to the average daytime highs (29^{o}C) for this area during the months when measurements were taken (Doggett, 2001).

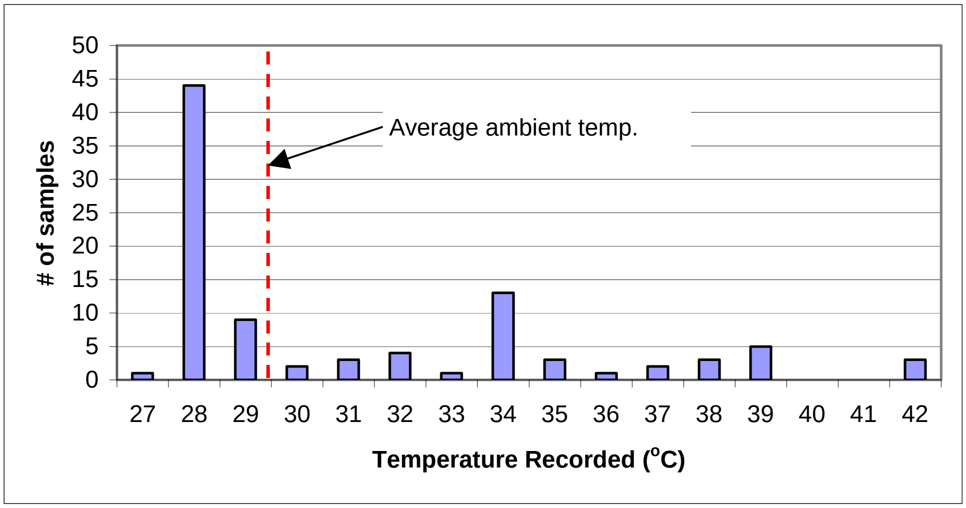

Figure 24. Temperatures measurements taken inside the active chamber of 97 compost latrines in the Ño Kribu / Bocas del Toro area of Panama.

However, approximately 30% of the latrines recorded temperatures above the average ambient temperature. For the 29 latrines where measurements were taken in the sealed-off chamber, the average temperature was 28.1^{o}C. Interestingly, temperatures well above average ambient levels were also measured here, with a maximum measurement of 43.3^{o}C (Spaulding, 2004). The amount of time that the chamber had been sealed is uncertain.

The author of this study recorded similar measurements in the 10 latrines tested. While 70% of the temperatures recorded were below 35^{o}C, two latrines recorded temperatures around 42^{o}C, with the highest measurement of 41.8^{o}C being taken in a latrine chamber that had been sealed for eight days. As indicated in Figure 23, one week at a temperature of 41.8^{o}C is capable of killing off most types of pathogens. However, other pathogens such as *Salmonella* bacteria and the *Ascaris* worm, can survive for much longer at this temperature (See Figure 23).

Temperature alone cannot be responsible for the accelerated destruction of pathogens in most compost latrines. However its relationship with other factors can increase the rate of pathogen destruction. This will be presented in later in this chapter.

6.4 Comparison of Moisture Content and its Relationship to Temperature

In all the latrines that recorded temperatures above the ambient, a dry soak material (e.g. sawdust, dry grass) was being added after defecation. In some cases ash was also added periodically. The amount, and moisture content, of the added soak material varied amongst the latrines. The author observed that this plays a large role in determining the conditions inside the latrine, and can affect the temperature attained, as well as the dispersion of the heat. By comparing two individual latrines with very different observed moisture contents the process of aerobic degradation and heat dissipation in a compost latrine can be better understood.

In the case of the two latrines in which the author recorded the highest temperatures, the conditions inside were very different. In the first latrine, located in Kusapin, a mixture of sawdust and wood ash was used as a soak material. The sawdust collected was slightly damp from rainfall, since it was collected in the nearby hills after a tree had been chainsawed. The owner of the latrine would add about two cupfuls of sawdust after defecation, as well as a cupful of ash a few times a week. While helping the owner seal off this side of the latrine after six months of use, the author noticed that a large amount of heat being expelled from the chamber. After sticking his hand into the chamber, above the compost, the author would describe the conditions as “hot and steamy.” After placing the thermometer in the center of the pile, the author recorded temperatures at several locations in the compost heap. The owner of the latrine had been instructed to periodically turn the compost with a wood pole, and the heap appeared very moist and well mixed. All locations registered temperatures above 40^{o}C, with a maximum temperature reading of 41.6^{o}C. After two months of being sealed, no temperatures above 29^{o}C could be measured.

In the second latrine, the conditions of the compost were very different. The owner, a resident of the town of Cilico Creek, added a large amount of dry grass to the latrine after defecation. The author observed the latrine chamber seven days after it had been sealed. The contents were kept very dry, and a significant amount of grass was placed on top of the compost heap before sealing. The heap was visibly porous, and no heat could be felt leaving the latrine. In the top portion of the latrine, which was mostly grass, no significant temperature could be measured. However, to measure the temperature in the middle of the heap, the author moved the top portion of grass, and placed the thermometer about 1.5 ft below the top. At this point a temperature of 41.8^{o}C was recorded.

These examples are provided, not to conclude that high heat is the primary mechanism for pathogen removal, but rather to explain what processes are possibly occurring inside a composting latrine. In the case of the first latrine the compost was relatively well mixed to provide oxygen, carbonaceous material was added, and the moisture content was relatively high. This system most resembles the optimal conditions described in Chapter 5. In the case of the second latrine, the contents were far dryer and much more porous. In contrast to the first latrine, high temperatures could not be measured in all areas of the compost, but rather confined to the inner area. This suggests that both mixing and moisture content are key in the containment of heat in the compost.

Also, the fact that high temperatures were reached in certain areas, even though the system the system was drier than optimum (See Chapter 5) and not sufficiently mixed, shows that the reaction taking place may have much more to do with the conditions found in close proximity to the excrement, which will remain moist, rather than the conditions of the heap as a whole.

6.5 Other Factors Influencing Pathogen Destruction

Since it has been has been shown that the majority of the latrines do not reach temperatures that kill pathogens at an accelerated rate (thermophilic conditions), other factors that can assist in the destruction of pathogens must be must be taken into account. Studies have shown that desiccation, high pH levels, and solar exposure are all mechanisms capable of pathogen inactivation. Each will be discussed in sections that follow.

6.5.1 Effects of Desiccation

Like all forms of life, pathogens require water to survive. When moisture levels become too low, the cells of a microorganism will dehydrate and be unable to function. For this reason, desiccation has been noted as a successful mechanism for pathogen destruction. In some areas, achieving very dry compost inside a latrine is very feasible, and may be the most suitable method to kill pathogens.

In a study performed by Redlinger et al. (2001) in Ciudad Juarez, Mexico, 90 dry composting latrines were analyzed to determine the reduction of fecal coliforms and the mechanism most responsible for this. The latrines were of the continuous design (See Chapter 3), where the users pull down the “forming pile”, which collects below the seat, to the “composting pile”, situated in a lower compartment of the same chamber. A “solar collector” was positioned over this compartment to absorb heat. The material was contained in each area for 3 months. Almost all users deposited toilet paper and sawdust in the latrine after use.

The results of this study showed that after six months in the latrine 60.5% of samples could be classified as EPA class B compost (<1,000 MPN fecal coliforms / gm) and 35.8% as class A compost (< 2×10^6 MPN fecal coliforms / gm). After analyzing data of temperature, moisture content, and aeration (mixing by user), the report concludes that the primary mechanism for the reduction of fecal coliforms was desiccation. While class A compost is acceptable for food and nonfood plants, the EPA recommends that class B compost be used for ornamentals.

Analysis performed after only three months resulted in 16% decrease in the number of samples qualifying as Class A compost, showing that time is also a key factor. In addition, 95% of the latrines whose solar collector was exposed to the sun were of class A rating, indicating that solar exposure also plays a role. Unfortunately, pH was not measured.

6.5.2 Effects of pH

In many areas in the developing world food is cooked over open wood fires. These fires produce a large amount of ash, which can be added to the composting latrine to absorb moisture and control odors. Because of the alkaline nature of ash, its addition can increase the pH levels in the compost up to 12.5. A pH around 9 has been shown to enhance the die off of bacterial pathogens, such as fecal coliforms (Strauss and Blumenthal, 1990).

In Guatemala the double vault latrine with urine separation described in Chapter 3 was designated the “DAFF” (dry alkaline family fertilizer) latrine. The users were instructed to keep the contents dry by adding ash, or a mixture of ash and soil, or lime and soil. The destruction of bacterial pathogens was found to be high at a pH of 9, but the effect decreased in latrines where moisture content was above 60% (Strauss and Blumenthal, 1990).

The *Ascaris* egg was found to be much less affected by a high pH, and is used, along with fecal coliforms as hygienic quality parameters in Guatemala. In this case temperature does play a role in the potential for *Ascaris* egg destruction in the DAFF latrine. In the lowland tropical area of Guatemala (average ambient temperature of 28-30^{o}C), it was found that a storage period 10-12 months could produce a fertilizer with "very low" or zero egg viability. However, in the cooler highlands the storage period needed to be 18 months to achieve the same result (Strauss and Blumenthal, 1990). Subsequent sun-drying decreased the time necessary to obtain a pathogen free compost, and will be discussed later in this report.

Contrary to the findings in Guatemala, a study from the Swedish Institute for Infectious Disease shows that for a dry composting latrine a storage period of 6 months is sufficient to produce pathogen-free compost. The findings, summarized in Table 5, show a 100% reduction of *Ascaris* egg viability and more than a 6-log reduction in fecal coliforms. Time and high pH are stated as the governing factors in the destruction of pathogens in the material of the latrine (Stenstrom, 2002).

Table 5. Reduction efficiency in dry latrines, with a storage time of 6 months and a pH value in the material of 9 or greater. Based on, and in some cases extrapolated from, experiments from China, Vietnam, and Mexico. (Stenstrom, 2002)

Parameters	Reduction efficiency
Bacteria (coliforms)	>6 log
Bacteria (fecal enterococci)	4-6 log
Bacteriophages (index virus)	5 - >6 log
Ascaris ova (index parasite)	100% reduction of viability

High pH may not only be detrimental to the survival of pathogenic organisms, but also to the microorganisms responsible for aerobic decomposition. This is because enteric pathogens are more accustomed to the low pH environment found in the human digestive system (pH around 2). Although the matured compost may be pathogen free, it may not be fully decomposed, decreasing its effect as a soil conditioner while preventing high temperatures from being reached.

However, in compost latrines in Vietnam where ash was added as the main soak material, temperatures in the compost reached $50^{o}C$, indicating aerobic decomposition was taking place. Furthermore, crop yields were reported to have increased by 70% after the addition of the matured fertilizer (Pacey, 1978).

6.5.3 Effects of Sun Drying

Sun drying can effectively destroy pathogens in three ways: 1) by drying out the compost (desiccation), 2) by raising the temperature, and 3) by ultraviolet (UV) radiation. The first two mechanisms have been discussed previously. Although UV light is effective in destroying microbial DNA (Bitton, 1999), the probability that pathogens in the compost will be sufficiently exposed to the sun may be small.

Redlinger et al. (2001) concluded that exposure of the solar collector to the sun was critical for a large reduction of fecal coliforms (See Section 6.5.1). Since no high temperatures were recorded, it is presumed that the correlation of die-off of coliforms to solar exposure was mainly due to an increase of desiccation, rather than an increase of temperature. Since temperatures of the compost were not measured consistently, the possibility that high temperatures played large role in coliform die-off cannot be ignored.

In Guatemala sun drying has proved to effective in reducing the number of viable *Ascaris* worm eggs. After a 10-month storage time in the chamber the “fertilizer” is left out under the sun to dry. In the warm lowlands this storage period proves to be sufficient time to produce a fertilizer with very low or zero egg viability. As Table 6 indicates, more time is needed to produce a hygienically safe fertilizer in the cooler highlands. However sun-drying significantly decreases the necessary storage time by 6 months (Strauss & Blumenthal, 1990).

Table 6. Required chamber storage period, with and without subsequent sun-drying to achieve very low to zero *Ascaris* egg viability (Strauss and Blumenthal, 1990)

Average Temperatures	Without subsequent sun-drying	With subsequent sun-drying
17 - 20°C (highlands)	18 months	12 months
28 - 30°C (lowlands)	10 - 12 months	8-10 months

6.6 Comparative Discussion

Table 7 summarizes the studies discussed in this report by detailing the maintenance procedures performed, the conditions found inside the latrine chambers, and the extent of pathogen removal for each for each situation.

By comparing the data presented in this section one can infer that compost latrines are capable of significantly reducing pathogen levels, and are capable of being implemented in the developing world. However, most of these studies are site specific, with factors such as climate and available natural resources playing a key role in the extent of pathogen destruction. While desiccation can be an effective method to kill pathogens in the hot dry atmosphere of northern Mexico where sawdust is plentiful, high pH and sun-drying has been found to be the primary mechanisms for pathogen removal in the humid lands of Guatemala, where wood ash is easily attained.

From observations made by the author, and results from various studies (e.g. Guatemala, Mexico), it can be concluded that the sole process of aerobic decomposition rarely produces temperatures high enough in a compost latrine for a significant acceleration of pathogen destruction. However, it has been found that aerobic decomposition has raised the temperature of the compost well above ambient temperature in many latrines. As seen in the data from both the warm lowlands and cool highlands of Guatemala (Table 5), even when a high pH is thought to be the governing factor in the destruction of pathogens, a higher temperature does increase the rate of pathogen destruction, reducing the required storage time by 40% (before subsequent sun drying). However, as stated previously, 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.

Desiccation works by killing the pathogens via dehydration and aerobic decomposition is an important factor that can aid this process. The low moisture content and, consequently, the large amount of void space in the soak material allow oxygen to penetrate the compost heap driving the aerobic process. Although the compost may be too dry to contain a significant amount of heat, the exothermic process is still occurring and will further enhance desiccation.

A synergy of the various mechanisms is likely to be the best method for pathogen destruction. As stated previously, a moderate temperature increase achieved by aerobic decomposition can shorten the storage period necessary for the removal of pathogens. The addition of a carbon-rich porous soak material (e.g. sawdust, rice husks, grass) aids the decomposition process by allowing oxygen to enter the system and raising the C/N ratio, while absorbing much moisture and promoting desiccation. Wood ash should be added to the compost to raise the pH and aid desiccation. The addition of a soak material can also enhance the effects of high pH, since the rate of pathogen die-off decreases if moisture content is too high. However, more important than any chemical, biological, or physical factor dealing with compost latrines, is the social aspect involving the acceptance of this theory by the local people, and the effects the introduction of a project may have on the community.

Table 7. Description and Results From Several Compost Latrine Studies (NR = Not Reported)

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.

Chapter 7 - Correct Use and Maintenance of the Compost Latrine

Education is key for the success of a compost latrine project. The user must be aware of the processes occurring inside the latrine, what steps should be taken to maintain it, and, most importantly, the health benefits of safely disposing their waste. As a development worker one should be most concerned, not with the construction of a new technology, but rather with its acceptance by the locals and its potential in the long run, long after its implementers have left.

A joint effort between Peace Corps and U.S.AID developed a poster to aid users in the maintenance of their compost latrines. The poster was based on a design used to promote good maintenance of dry composting latrines in El Salvador (Branch, 2005). Each picture explains an important procedure for the success of a compost latrine. Below the picture are boxes that a latrine inspector can check off according to whether or not the procedure has been carried out correctly. This poster is shown as Figure 25, and the steps that should be taken to maintain a compost latrine, in accordance with the poster are as follows:

1) Dry organic material should be collected and always be available. In Panama latrine users use sawdust, rice husks, dry dirt or wood ash. Many times this soak material will run out and not be replenished due to the lack of free time or bad weather. Wet conditions inside the latrine promote foul odors, and provide a habitat for flies. Before using the first chamber, the floor should be covered with the soak material to absorb any excess moisture.

2) The separation of urine and feces is important in keeping the contents dry. This is more difficult for women and children. Users should be educated on the effects of excess urine entering the chambers.

Figure 25. Poster Detailing Steps for Proper Use of a Composting Latrine. Language used is Ngobere and Spanish

3) After each use the excrement should be completely covered with the desiccant material.

The fecal material should be covered with a carbonaceous soak material (e.g. sawdust, rice husks). As discussed in Chapter 6, this will aid in the aerobic decomposition process by raising the C/N ratio and increasing airflow through void spaces, while accelerating the desiccation of the fecal material. Wood ash weighing about one third the weight of the feces should be added to raise the pH, which is effective in deactivating many pathogens. Wood ash will also aid in desiccation.

The seat of the latrine should always be covered when not in use. As shown in Figure 26, a good cover can be made from wood, and the stones can be used to create a tight seal.

Figure 26. Example of a tight fitting cover for a latrine seat, using wood and heavy stones. Note the bag of sawdust (left of seat) that is used as a soak material.

4) The users should be encouraged to wash their hands, preferably with soap. Hygiene interventions including hygiene education and the promotion of hand washing can lead to a reduction or diarrhoeal cases by up to 45% (WHO, 2005). As discussed in Chapter 2,

the majority of the Ngobe people are accustomed to wash their anal region with water after defecation. In some latrines in Panama, a water tap was constructed in or around the compost latrine, in order to make the users more comfortable. In this case, extra attention should be given to the sanitary conditions around the latrine, and the users should be educated accordingly.

5) The compost pile should be pushed down with a wood pole, preferably twice a week. The users should be encouraged to turn the complete pile twice a week. This will provide the oxygen necessary for the biodegradation of the fecal material, and prevent the formation of odors such as ammonia and hydrogen sulfide.

6) All family members should be educated and encouraged to use the latrine. The author has observed that, on average, women were more hesitant to use the latrine. When asked no definite reason was given.

7) Cleanliness around the latrine is very important. Stagnant water and garbage can become breeding grounds for mosquitoes and flies.

8) After the six-month period of usage is complete, the seat from that chamber should be sealed off, preferably with a plastic or burlap sack. The bottom of the new chamber should then be covered with the soak material to absorb moisture that settles to the bottom.

9) After six months of storage, the compost can be removed and applied to the land. Matured compost should be a non-odorous humus-like product that is a good conditioning soil (See Figure 27). Since the extent of pathogen removal will be uncertain it is best to the compost to fruit trees or ornamental plants. The compost should not be applied to foods that are eaten raw, and application to tubers, such as potatoes and cassava, is not recommended. When applied as fertilizer, the compost should be buried under at least 6 inches of soil.

Figure 27. A sample of matured compost taken from the author's composting latrine in Kusapin, Panama. Note the humus-like appearance. The compost had no distinct odor.

As discussed in Chapter 6, sun-drying the compost after the storage period can greatly reduce the number of pathogens that may still exist in the compost. After sun-drying, the compost can be stored in sacks for later use. If a user is hesitant to apply the compost directly to crops, it can be dug into the ground where crops will be grown in the future. Although the harvest will not utilize the nutrients from the compost, the goal of hygienically disposing of human waste is still achieved.

Chapter 8 - Conclusion

Since the late 1960's compost latrines have been implemented across the globe with the intention of solving problems of sanitation. Despite the fact that the fundamental processes that are actually occurring in the compost and the exact mechanisms that are responsible for pathogen removal are not always clear, studies have shown that, compost latrines can be effective in the reduction of enteric parasites Though the exposure of compost to temperatures above 45^{o}C for one month guarantees the inactivation of all pathogens, studies have shown that few compost latrines implemented in the developing world reach high enough (thermophilic) temperatures to significantly accelerate the destruction of enteric pathogens. However, moderate temperature increases were recorded in compost latrines and this does assist in the removal of pathogens. High pH, desiccation, and solar exposure are also mechanisms of pathogen destruction, and combining these with an elevated temperature, a synergistic effect increasing the destruction of pathogens may be achieved. Since it is likely that many more compost latrines will be built in the future, it should be of great interest to further research the mechanisms responsible for pathogen removal, how they can work together, and what additional operational procedures can be followed to maximize their potential.

This report has provided detailed instruction in the construction of a family-sized compost latrine, explained the actual processes that may take place within the chambers, and provided recommendations for maximizing the potential for pathogen destruction. Compost latrines can be a solution to the problems of sanitation in developing countries. However, as with any project, acceptance by the local people may be the largest obstacle. Therefore it is of the utmost importance to accompany education with the introduction of this technology to ensure its sustainable implementation.

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Appendix A - The Soldier Worm

Decaying organic matter is the natural habitat of many types of insect larvae. Fly larvae, or “maggots”, are no exception and were present in many composting latrines in Panama. Although maggots are a very undesired sight and adult flies can aid oral contact with fecal pathogens, they are good decomposers of organic matter, and are commonly found in compost (Happy D Ranch, 2005). These larvae have also been used on a large scale for the biodegradation of animal manure (NCSU, 2005).

The Ministry of Agricultural Development (MIDA) in the Bocas del Toro Province of Panama identified the maggots inhabiting one compost latrine as the *gusano soldado*, or soldier worm (Watkins, 2004). This “worm” is actually the larvae (*Diptera Stratiomyidae*) of the Black Soldier Fly (*Hermetia Illucens*), non-disease-carrying, non-biting fly that resembles a small wasp (Figure 28). Unlike houseflies, the soldier fly rarely enters dwellings (Newton et al., 1995).

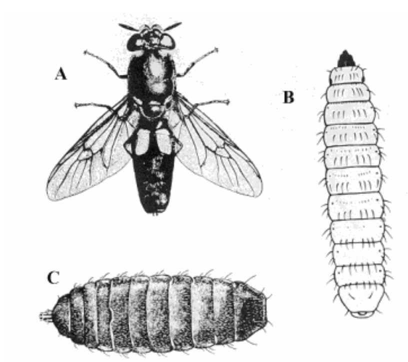

Figure 28. Black Soldier Fly (Source: NCSU, 2005)
A. Adult Female B. Larva C. Puparium

The author observed large quantities of these larvae in various latrines, including his own (Figure 29). The larvae were not always visible, but would come to the surface soon after latrine use. However, very few adult flies were seen. This is most likely due to the fact that the “maggots need a cooler, dryer place in order to pupate” (Frankel, 2005).

Figure 29. Soldier Fly larvae observed feeding on fresh excrement in a composting latrine in the Ño Kribu region of Panama. Note: Rice shells used as soak material

Many studies have been performed on the benefits of soldier fly larvae in animal manure volume reduction and manure nutrient recycling, and have even been used in large scale processing plants for the biodegradation of chicken and hog manure (Newton et al., 1995). The digestion of swine manure by soldier fly larvae has been shown to reduce the mass of the manure by half (Sheppard et al., 2005).

Despite the benefits, most latrine users would like to eliminate any type of “worm” in their latrine. Soldier flies are attracted by smells produced by excess nitrogen in the compost, so adding a carbon-rich soak material can reduce the likelihood of the breeding of maggots. Several latrine users in the Ño Kribu region informed the author that a reduction in maggots could be achieved by adding a few cupfuls of ash. This is most likely due to the increase in pH that creates unsuitable conditions for larvae survival.

Appendix B - The *Ascaris* Worm

Ascaris lumbricoides, commonly known as the roundworm, is classified as a helminth parasite. Because of its high resistance to chemical and environmental stresses, compared to other enteric pathogens, the *Ascaris* worm has been used as a hygienic quality parameter in various countries when dealing with the reuse of treated excreta (Strauss, 1994). In 1999 it was estimated that close to 1,5 billion people were infected with the *ascaris* worm worldwide, with 23% of these cases causing significant morbidity (Crompton, 2005). In children the *ascaris* worm is in constant competition for food and steals the nutrients and calories necessary for their development. In severe cases adult worms can obstruct the bowel, bile duct or pancreatic duct becoming fatal in children (Dahi, 1990).

Ascaris infection is very common in the Ño Kribu / Bocas del Toro area of Panama, which is most likely due to improper disposal of human waste (e.g. defecation in streams). The presence of worms inside their bodies is well known by the locals, since the majority of them have seen them excreted. Jokes such as “I need to feed my worms”, when hungry, are commonplace. The author and several other Peace Corps Volunteers have also been infected with *ascaris* worm, with one volunteer reported to have excreted a foot-long adult. While infected, the author experienced diarrhoea, nausea and abdominal pain. As seen in Figure 30, *ascaris* infection in children can cause distended bellies, mainly due to the large mass of worms inside (Mara, 1996).

The *ascaris* worm lives in the small intestine of humans, and can produce 200,000 eggs per day (Bitton, 1999). Once excreted into soil the eggs take 1-2 weeks to become infectious and can be viable for years. The parasite is transmitted to humans when the infectious eggs are ingested (Cairncross and Feachman, 1999). Figure 31 describes the life cycle of the ascaris worm.

Figure 30. Child with distended belly, most likely due to *ascaris* worm infection**.**

Since the matured contents of a compost latrine will be applied on land, the ascaris worm should be of great concern. However, as one international sanitation study points out, there is a difference between the infection by helminths (*ascaris*) and other pathogens. If infected with a virus, protozoa or bacteria, the infected person will either get sick or not. With helminths, however, an infected person will exhibit various degrees of disease intensities depending on the number of worms he/she carries in its intestines. In addition, in relation to treatment of fecal material for land application, a reduction of ascaris worm eggs by 80-90% already is a major public health effect (Strauss, 1994). It has been shown that compost latrines are capable of significantly reducing the number of *ascaris* eggs, and therefore capable of improving public health (Stenstrom, 2002).

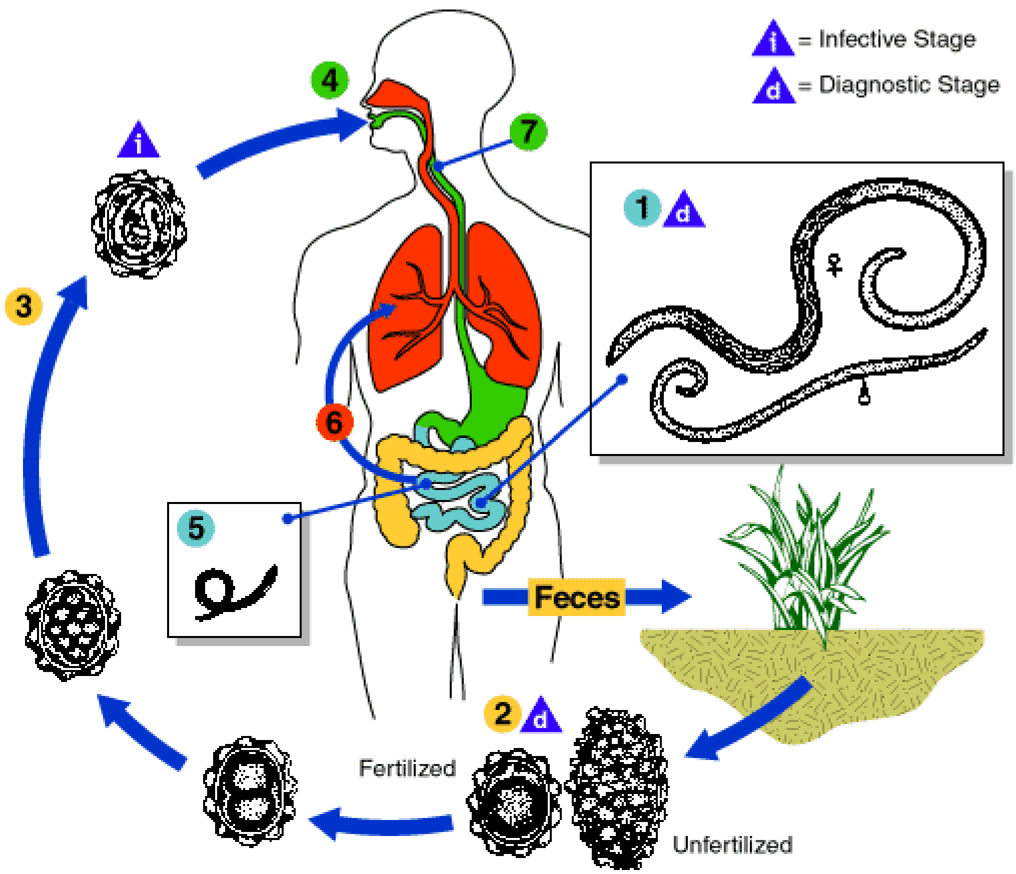

Figure 31. Life cycle of the a*scaris lumbricoides* (Source: CDC - U.S. Government, 2005)

Adult worms ❶live in the lumen of the small intestine. A female may produce approximately 200,000 eggs per day, which are passed with the feces ❷. Unfertilized eggs may be ingested but are not infective. Fertile eggs embryonate and become infective after 18 days to several weeks ❸, depending on the environmental conditions (optimum: moist, warm, shaded soil). After infective eggs are swallowed ❹, the larvae hatch ❺, invade the intestinal mucosa, and are carried via the portal, then systemic circulation to the lungs ❻. The larvae mature further in the lungs (10 to 14 days), penetrate the alveolar walls, ascend the bronchial tree to the throat, and are swallowed ❼. Upon reaching the small intestine, they develop into adult worms ❶. Between 2 and 3 months are required from ingestion of the infective eggs to oviposition by the adult female. Adult worms can live 1 to 2 years.