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DOUBLE VAULT COMPOSTING LATRINES IN RURAL PARAGUAY : FEASIBLE CONSTRUCTION AND OPTIMAL USE

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DOUBLE VAULT COMPOSTING LATRINES IN RURAL PARAGUAY : FEASIBLE CONSTRUCTION AND OPTIMAL USE

By

Paul T. Pebler

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

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This thesis has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Civil Engineering.

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Preface

The report is based on the work I did during my Peace Corps service in Paraguay from 2012 to 2014. I worked as a rural health volunteer in Santa Elena, Guairá, Paraguay, where I collaborated with community members to develop and complete the double vault composting latrine project presented in this report.

This report is submitted to complete the requirements for my Master's Degree in Civil Engineering from the Master's International Program in Civil Engineering at Michigan Technological University. This report is intended to be used as a case study, showing the optimal use of a double vault composting latrine, and the results to expect. This report can also be used as resource when building a double vault composting latrine, as it contains extensive construction directions in Chapter 3.

Acknowledgments

I would initially like to give many thanks to my advisor Dr. Brian Barkdoll. He has helped me immensely before, during, and after my Peace Corps Service. Through his Peace Corps stories from Nepal, to his deep knowledge of research, my report would not have been possible without his help.

I would also like to thank my committee members, Dr. Yue Li and Dr. David Shonnard. Thank you for dedicating your time and energy to help me with this report.

Second, I would like to give many thanks to my parents. During my service they were nothing but interested and supportive, which has continued during this process of completing this report. They reminded me many times that my work in Paraguay was worthwhile, and a unique experience that will continue to influence my life for years to come. I also need to thank them for bringing me a camera and thermometer during their visit to Paraguay. Without either of these this report would not have been possible.

Thirdly, thank you to all the community members of Santa Elena, Guairá for putting up with me during this project. I know how strange of a concept it must have been to want to store your human waste above ground close to your homes. But, I hope now through our hard work and collaboration you can see the advantages of these latrines.

Lastly, I would like to acknowledge all that my Paraguayan neighbors (Io, Celia, Wilson, Walter, William) did for me during my time in their country. Not only did they spend months patiently teaching me their native language Guarani, but were also more than happy and interested in being my guinea pigs during the design and testing phase of our shared composting latrine. I need to give a special thanks to Celia, as she was my primary cultural and language teacher during my service. She is one of the strongest and committed people I have ever met. Also, I want to give many thanks to Io for teaching me the construction methods and skills used in Paraguay, along with teaching me to laugh at myself along the way. Most of all I need to thank them for the friendship and love they showed to this strange *Ameriguayo*.

Abstract

Water resource depletion and sanitation are growing problems around the world. A solution to both of these problems is the use of composting latrines, as it requires no water and has been recommended by the World Health Organization as an improved sanitation technology. However, little analysis has been done on the decomposition process occurring inside the latrine, including what temperatures are reached and what variables most affect the composting process. Having better knowledge of how outside variables affect composting latrines can aid development workers on the choice of implementing such technology, and to better educate the users on the appropriate methods of maintenance.

This report presents a full, detailed construction manual and temperature data analysis of a double vault composting latrine. During the author's two year Peace Corps service in rural Paraguay he was involved with building twenty one composting latrines, and took detailed temperature readings and visual observations of his personal latrine for ten months. The author also took limited temperature readings of fourteen community member's latrines over a three month period. These data points were analyzed to find correlations between compost temperatures and several variables.

The two main variables found to affect the compost temperatures were the seasonal trends of the outside temperatures, and the mixing and addition of moisture to the compost. Outside seasonal temperature changes were compared to those of the compost and a linear regression was performed resulting in a R^2-value of 0.89. Mixing the compost and adding water, or a water/urine mixture, resulted in temperature increases of the compost 100% of the time, with seasonal temperatures determining the rate and duration of the temperature increases.

The temperature readings were also used to find events when certain temperatures were held for sufficient amounts of time to reach total pathogen destruction in the compost. Four different events were recorded when a temperature of 122^0F (50^0C) was held for at least 24 hours, ensuring total pathogen destruction in that area of the compost. One event of 114.8^0F (46^0C) held for one week was also recorded, again ensuring total pathogen destruction.

Through the analysis of the temperature data, however, it was found that the compost only reached total pathogen destruction levels during ten percent of the data points. Because of this the storage time recommendation outlined by the World Health Organization should be complied with. The WHO recommends storing compost for 1.5-2 years in climates with ambient temperatures of 2-20^0C (35-68^0F), and for at least 1 year with ambient temperatures of 20-35^0C (68-95^0F). If these storage durations are obtainable the use of the double vault composting latrine is an economical and achievable solution to sanitation while conserving water resources.

Chapter 1: Introduction

Growing human populations and increasing water consumption rates are creating unprecedented strains of the world's resources. Water shortages are a large problem in many parts of the world and "[have] become the single greatest threat to food security, human health and natural ecosystems" (Seckler, Barker et al. 1999, p.29). There is no end in sight with an estimated 1.4 billion people (25% of the world's population) expected to live in severe water scarcity during the first quarter of the 21st century (Seckler, Barker et al. 1999). The problem is also compounded by the complex situation of a growing middle class. Although this growth in developing countries can be a positive signal, as it elevates people into a higher standard of living and education, it also pushes them into a higher rate of water consumption. With an estimated 1.8 billion people expected to join the middle class by 2020, pushing the percentage of middle class families to 52% of the world's population (Naím 2008), water resource over-use will become an increasingly pressing issue in many regions of the world.

Despite these projections many societies continue to defecate into their clean water sources, causing pollution of this precious resource and adding to the water shortage problem. It is obvious from these statistics that the western solution of flushed toilets and expensive wastewater treatment plants are not going to be a viable solution to the growing population and consumption rates of the world. With an expected 500 km^3 of additional irrigation water needed to grow enough food to sustain the world's population in 2025 (Postel 2000), it is clear we should be looking for solutions to sanitation that do not waste or soil water resources, as most westerns countries do. In the United States alone, five billion gallons of drinking water are flushed down the toilet each day (Jenkins 2005), water that could be used for agriculture or kept in its natural surroundings to protect the health of ecosystems we depend on for life on earth. Groundwater withdrawal rates are already exceeding re-charge levels in many places around the world, including China and India with 40% of the world's population, surely leading to environmental and social problems down the road (Postel 2000).

There are also many sanitation and pollution problems associated with flushed toilet systems. Many sewage systems in the United States are combined waste water and storm water systems, making them susceptible to overloading during storms. Because of this, billions of gallons of untreated sewage water are released into the environment each year during such storm events. An estimated 3-10 billion gallons of untreated wastewater are released each year in the US, leading to thousands of beach closings and documented health related problems (EPA 2004). Clearly the model of flushed toilets is not a promising solution to sanitation needs in a world of growing population and water scarcity.

Composting latrines are a viable solution to the world's sanitation problems and are beginning to become more popular in many developing countries. Not only are they considered an improved sanitation facility by the World Health Organization by "ensuring hygienic separation of human excreta from human contact" (UNICEF 2014), but do so without depleting or polluting water resources. Their benefits of sanitation also come at a much smaller capital cost than flushed toilets, as there is significantly less infrastructure needed to build and maintain them. Composting latrines also produce a valuable product, humus, which can be used as a fertilizer and soil amendment to increase the productivity of the land.

Composting latrines use a four phase aerobic decomposition process to safely biodegrade human waste and convert it into humus. The four phases include: 1) Mesophilic phase; 2) Thermophilic phase; 3) Cooling phase; 4) Curing phase. Each phase will be described in detail in Chapter 4. A main advantage of using composting latrines is the lack of noxious fumes, such as ammonia, and hydrogen sulfide, resulting in a near odor free sanitation solution.

There are many models of composting latrines seen around the world. This report will focus on a double vault composting latrine design used during the author's Peace Corps service in rural Paraguay from April 2012-April 2014.

The main objective of this report is to present and promote the use of composting latrines as a proven alternative to western-style human waste management systems which depend on and deplete water resources. Methods of construction and maintenance used to construct and use a double vault composting latrine will be presented to aid in the design and development of composting latrine projects. This report can also be used as a case study to help determine if the use of composting latrines is the correct choice when choosing alternative sanitation methods in climates, cultures, and demographics similar to the ones found in rural Paraguay. Through detailed temperature data analysis in Chapters 6-10, the reader will also be exposed to the process of aerobic decomposition and how to best use this technology to produce a safe and beneficial product.

Chapter 2: Background of Community and Project

2.1: Community Background

Figure 1: Author pictured on top of hill in community with farm fields shown in back ground. Photo by author.

Santa Elena is an agricultural community consisting of approximately four hundred residents and one hundred homes. Located in the department of Guairá, Santa Elena is roughly two hundred kilometers southeast of the capital city of Asuncion. Within Guairá, Santa Elena is located on the southern edge of *Parque Nacional Yvytyruzu*, containing the tallest range of hills in Paraguay with many steep slopes and thick forest. The climate is sub-tropical with very hot summers reaching temperatures of 115^0F and cold winters reaching freezing temperatures during the night. Rainfall is fairly well distributed throughout the year, with the lowest rainfalls occurring between June and August and the highest in November through February.

Figure 2: Map of Paraguay (http://www.state.gov/p/wha/ci/pa/) accessed on 1/5/2015.

The primary language used in Santa Elena is Guarani, or rather a mixture of Spanish and Guarani called *Jopara*, meaning "mixture." While most community members can understand and speak basic Spanish, Guarani is much preferred and easier for them.

Figure 3: A typical breakfast of Mbeju, made from corn flour, madioca flour and cheese, usually served with fresh warm milk. Photo by author.

The community is economically dependent on agriculture through the cultivation and selling of crops such as cotton, corn, beans, sugar cane, peanuts, and to a very small extent, cattle. The majority of the residents subsidize their income through subsistent cultivation of corn, bean, chickens, cattle and pigs. Corn is a major part of their diet along with red meat, beans, and mandioca, a starchy root similar to yucca or cassava. The herbal tea called *Ka'ay* or *Yerba Mate* is a very culturally important drink. Paraguayans drink it both hot and cold depending on the time of day and the outside temperatures.

The majority of the community lives in traditional Paraguayan houses using thatched roofs and wooden planked walls. Many times all the materials for the house are found and produced from inside the community, with only cement, nails and bricks being purchased from outside sources.

Figure 4: Authors house pictured above. This was is a very typical house in the community. Photo by author.

2.2: Sanitation and Water Sources in Santa Elena

2.2a: Sanitation

The majority of households use open pit latrines as their main form of human waste disposal (Figure 5). These latrines use either a concrete or wooden top and are usually uncovered and open to the elements, creating a pungent smelling haven for flies and other insects that can spread disease. Because of the smell and flies, most households place their latrines far from their homes, making them uninviting in the dark and during rain storms. It is common to use a latrine for roughly two years until it fills up, then top it with dirt and dig another pit close by.

Figure 5: Typical pit latrine found in Santa Elena. Photo by author.

Some families do have *Modern Bathrooms*, which are a western style bathroom consisting of a shower, toilet, and sink inside the same room. These are expensive to build, hindering many families from building them at their houses. The waste water is drained into a *pozo siego*, a large soak pit dug into the earth near the bathroom, where it slowly seeps into the ground. According to the locals these pits usually fill up after a few years and need to be re-dug in another location. Most pits are equipped with a ventilation tube and a concrete cover, greatly reducing smells and fly populations.

2.2b: Water Sources

Many families still use hand dug wells as a daily source of water. However, Santa Elena installed a running water system roughly eight years ago with the help of the governmental water and sanitation organization named SENASA. There is a central ninety-meter-deep well with an electric pump that pumps the water to a tower on the highest point of the community. Unfortunately, the water tower is located 1.8km away from the tower with an elevation difference of one hundred meters, adding unnecessary stress to the small electric pump and causing it to burn out on a fairly regular basis. Because of this the modern bathrooms in the community become unusable at these times unless the household has its own pump and tank using water from shallow hand dug wells. The frequent burnouts have also added a lot of cost to the community's water commission. The monthly cost of water doubled during the author's time in the community, causing many households to reduce their water use or return to using their shallow hand dug wells as a main source of water.

2.3: Project Background/Story

Prior to the arrival of the author to Santa Elena, a Peace Corps Volunteer lived and worked there during 2010-2012, where he started a commission of twenty two families to improve latrines and sanitation in the community. The commission was started in late 2011 and primarily focused on raising money while talking briefly about the types of latrines that could be implemented to reach the goals of reducing flies and smells of the latrines. In April 2012 the author moved to the community and entered the commission. During his first year of service the author participated in the bi-weekly fundraising events and began to talk in more depth about the types of latrines the commission could implement. Through several presentations (Figure 6) and many personal conversations with commission members, a consensus was reached that they would build composting latrines since they could achieve the goals of fly and smell reduction at an affordable price. The author also emphasized the conservation and protection of water resources that is achieved by the use of composting latrines. This was well accepted in the community since potable water is of significant cost to community members and many households still use shallow hand dug wells as a water source, which are at risk of pollution from pit latrines.

Figure 6: Presentation given in the local language of Guarani to commission members to introduce the advantages and disadvantages of a composting latrine. Photo by author.

Although many illnesses and diseases found in developing countries can be attributed to the lack of proper sanitation (Montgomery and Elimelech 2007), this was not a problem in Santa Elena. Almost every household was already equipped with pit latrines and seemed to have at least heard of the need to wash your hands after the use of the latrines. Because of this, the composting latrine project presented in the report was more of a way to improve the latrine experience by reducing flies and smells. It was also aimed to show a viable alternative to the wasteful and unnecessary practice of using flushed toilets as a main method of sanitation.

2.4: Pilot Latrine-PCV's Personal Composting Latrine

Figure 7: Author pouring latrine tops with neighbors and commission members. Photo by author.

The author started the construction of his personal composting latrine eight months into his service with the help of his neighbors and several commission members (Figure 7). The goals of building his personal composting latrine were: 1) to learn how to build a composting latrine with locally available materials and tools, 2) to learn vocabulary in the local language of Guarani to help him direct the construction of the commission members latrines, 3) to prove the benefits of using a composting latrine (no smell or flies), 4) to create an accurate materials list and cost to build each latrine, and 5) to conserve and protect local water resources while living in the community. The construction of the author's personal latrine turned out to be an invaluable experience, since he not only learned how to build and price a composting latrine, but also learned how community members were more than likely going to use them, since he shared his latrine with his neighbors (Figure 8). Hearing and answering common questions early on from his neighbors was very helpful throughout the project. The author was also able to learn the appropriate words and ways of explaining how a composting latrine works to other commission members through his practice with his neighbors.

Figure 8: Author with his neighbor Io on completion of bottom of vaults of latrine. Photo by author.

Whenever it was possible community members were hired out to help complete the author's latrine (Figures 9 below). The finished latrine is shown in Figure 10 below.

Figure 9: Local sawyer cutting lumber for author's latrine. Photo by author.

Figure 10: Author's completed latrine. Photo by author.

2.5: Construction of Commission Member's Latrines

The construction phase of the project started in June 2013 (Figure 11), with the pouring of forty-four *lozas* (concrete latrine tops) by the commission member in a single location. Once the *lozas* had cured the commission members transported them with all other materials to their house and started the construction of their personal latrines. The author personally worked on fourteen of the twenty-two planned latrines, six were constructed by their owners or contracted out to local masons, and two were sadly not constructed because of the misuse of funds and/or materials. All twenty of the commission members latrines were built within nine months of the start date, with the final one completed in mid-March 2014.A group of several community members worked together on the first commission member's latrine to learn how to build their own (Figures 12 and 13). The author also helped commission members build latrines when help was needed (Figures 14 & 15).

Figure 11: Tying rebar during loza construction. Photo by author.

Figure 12: Construction of first commission latrine. Photo by author.

Figure 13: Completion of first commission latrine. The stairs were added later by the owner. Photo by author.

Figure 14: Author and two of his best friends in the community working on a latrine. Photo by author.

Figure 15: Completion day of this family's latrine. This latrine was built without help from the author. Photo by author.

2.6: Project Funding

The project was funded both locally and internationally. Locally, the commission member rose over $1000 USD through bi-weekly raffles and several other community events. Each family was also responsible for helping in the construction of their latrine, by either working with the author or hiring a local mason to work with him. This labor cost came out to be roughly $125 USD per family. Each household was also responsible for supplying a tree for the fabrication of the latrine, which in the community represents a value of $30 USD. Internationally, the project was funded by an Energy and Climate Partners of the Americas (ECPA) grant through the US State Department with an amount of roughly $3200 USD. This money was used to purchase the materials to build the *lozas* and bottom vaults of the latrines. In the final calculation the community members contributed over 50% of the project (Table 1).

Table 1: Breakdown of international and local funds for composting latrine project.

Local Funds		International Funds	
Item	**Cost**	**Item**	**Cost**
Raised money	$47	ECPA Grant divided between 22 families	$145
Mason labor cost	$125		
Value of tree	$30		
Total contribution from each family=	$202		
Total funding for each latrine	$202 + $145=$347		
Percentage of funds given locally	**$202/$347=58%**		
Percentage of funds given internationally	$145/$347=42%		

2.7: Affordability of Project

The affordability of the project was very important for the author, not only to enable completion of the commission member's latrines, but also to make this design usable in the community to other residents who may want to construct a latrine on their own. From Table 1 shown above, the total cost of one latrine is roughly $347 USD, which is roughly 120% of the monthly minimum wage of $290 USD. This minimum wage is not significantly relevant for rural Paraguayans, however, as few earn the minimum wage. However, if community members commit themselves to saving and have access to outside help in the form of remittance from family members in Argentina, which many families do, this latrine design would be achievable within the community.

2.8: Materials Chosen

The materials chosen were all locally available in the nearest city of Villarrica, and most in the small town called Ñumi. Projects done in the community were often completed by purchasing materials from these two locations, so it was felt by the author that this would not be a burden or unachievable to complete the project.

It is highly recommended by the author to use as locally sourced material as possible to complete latrine projects such as the one presented in this thesis. Not only will buying local products benefit the local community financially, but it will be much easier to get and orders, and change orders if the business is done locally.

Chapter 3: Construction Manual of Double Vault Composting Latrine

The construction of the following double vault composting design should take two to three weeks to complete, if all the materials are acquired before the start of the construction process. A complete list of materials needed for each latrine can be found in Appendix A.

3.1: Construction Schedule

The construction of the double vault design described in this report was constructed in several distinct steps. The steps are as follows:

1. Pour *lozas* (concrete tops of vaults) at least 15 days before expected placement days of *lozas* on vaults. (0.5-1day)
2. Construct double vault base, including stuccoing inside and outside of vaults, and placing the *lozas* on top of vaults. (2-3days)
3. Construct housing structure on top of vaults (2-3 days)
4. Construct stairs (1-3days)
5. Build seat (0.5-1day)
6. Prepare and close vaults and place urine diversion tubing into soak pit (2 hours)

3.2: Loza Construction (0.5-1day)

- Equipment needed: shovel, hoe, hand level, 2 meter long ruler (wood or metal), 2 masonry buckets, tape measure, pliers, wood handsaw, metal handsaw, masonry trowel
- Materials needed:
    - Bricks or scrap wood to make forms
    - Banana leafs, tarp, old bags
    - 24m of 6mm rebar
    - Water
    - 10 cm of 20mm tubing
    - 2/3 of 50kg bag of cement(4 masonry buckets)
    - 16 masonry buckets of crushed rock aggregate
    - 8 masonry buckets of clean sand
    - 1.5 meters of ½” threaded bars
    - 22- ½” nuts
    - 22- ½” washers

Figure 16: Tying of rebar during loza construction. Photo by author.

3.2a: Construction Steps

1. Decide on area to build the *lozas*. Search for a convenient area to work that is relatively level, shaded, and close to a water source, with dimension of 2.5m X 1.5m.
2. Level ground using shovel, hoe, metal ruler, and hand level.
3. Using scrap wood or bricks, construct the formwork for each of the two *lozas* being built. The dimensions of each *loza* should be 90cm X 110cm, with a diagonal dimension of 142cm.
4. Use scrap wood or bricks to construct the small formwork for the center hole of each *loza*. Dimensions of each hole should be at least 15cm X 30cm. Holes can be larger or smaller depending on the desire of the user. Place the center hole formwork 25cm from the back or the *loza*, and centered widthwise (Figure 17).

Figure 17: Completed rebar cage. Photo by author.

5. Lay down old cement bags, plastic, or banana leaves under each form to create a barrier between the ground and concrete.
6. Cut rebar to specified lengths.
    - 6mm rebar
        - 12 bars @ 100cm
        - 10 bars @ 80cm
        - 2 bars @ 50 cm
        - 8 bars @ 30cm
        - 2 bars @ 20cm
7. Lay out rebar and tie each intersection using wire and pliers (Figure 18).

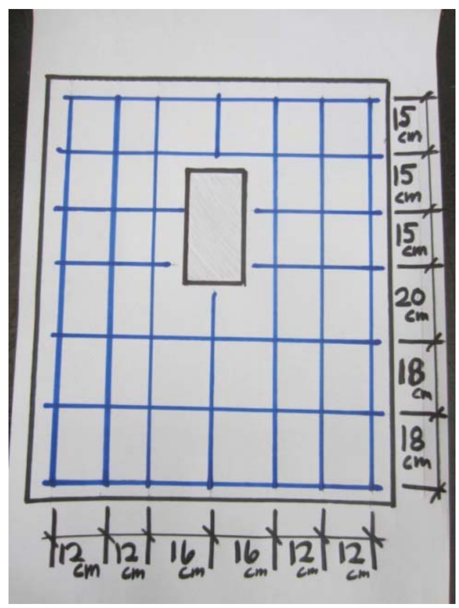


Figure 18: Rebar placement in loza. Photo and schematic by author.

8. Place pieces of rock or broken bricks under rebar in various locations to raise the bars above the ground surface. This will allow for the concrete to go underneath the rebar and completely surround each bar.

Figure 19: Placement of 20mm tubing in relation to loza opening. Photo by author.

9. Place 10cm length of 20mm PVC tubing in front of center hole by pushing it into the ground (Figure 19). Make sure the tubing is higher than the *loza's* finished level will be so concrete won't fill it.

10. Cut 10 threaded bars, each at a length of 15cm.

11. Place one nut and one washer at the end of each threaded bar.

12. Prepare concrete by mixing dry materials together until a uniform color and consistency is reached. Prepare mix for each *loza* separately to ensure proper mixing. The concrete mix design for each *loza* is the following:
    - 8 buckets crushed rock aggregate
    - 4 buckets clean sand
    - 2 buckets cement

13. Slowly add water to the mix until a workable consistency is reached. A workable consistency is one that is liquid enough to go under rebar but still holds its shape on a trowel. Avoid adding excess water as this will weaken the *loza*.

Figure 20: Threaded bolts placed 5cm from edge of loza. Photo by author.

14. Pour concrete into each form, slowly working the concrete with a trowel under the rebar. While pouring, place the 10 threaded bars roughly 5cm from edge of *loza* (Figures 20 and 21).

15. Smooth the top of each *loza* with trowel to the desired finish.

16. Thoroughly wet *lozas* at least once a day for at least 15 days. Also, cover *lozas* with old cement bags, banana leaves, plastic, or scrap wood to keep sun off of them.

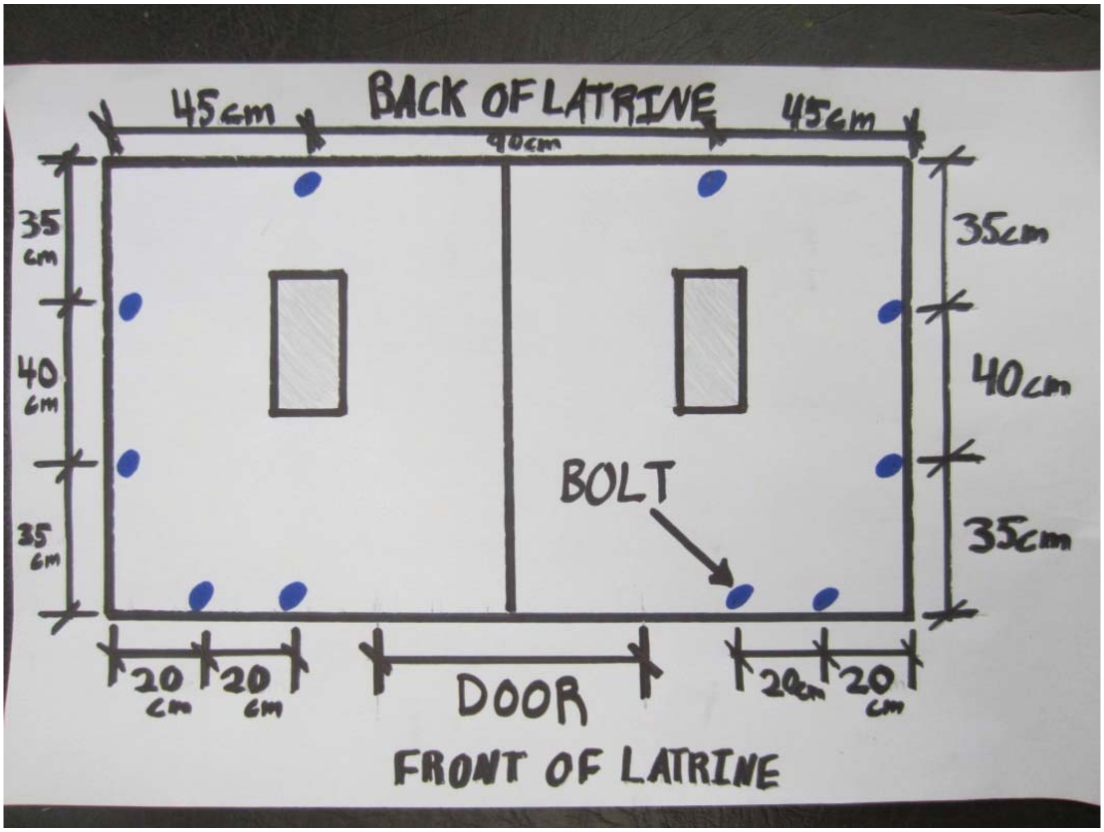


Figure 21: Placement of threaded bolts in loza. Photo and schematic by author.

17. Wait at least 15 days before placing *lozas* on the vaults of the latrine.

<u>3.3: Vault Construction (2-3days)</u>

- Equipment needed: masonry trowel, two masonry buckets, one large bucket (5gal), string, tape measure, two-meter long ruler (metal or wood), hand level, plumb bob, hoe, shovel, wooden stucco trowel, wood handsaw, metal handsaw.
- Materials needed:
    - 8 mm rebar
        - 8 @ 75cm
    - 48 masonry buckets of clean sand
    - 8 masonry buckets of cement
    - 8 masonry buckets of hydrated lime
    - 80 common bricks
    - 115 *hueco* bricks
    - Water
    - 1m of 20mm plastic tubing
    - 2 plastic 20mm elbows
    - Scrap wood

3.3b: Construction steps

1) Choose a location for the latrine, one that is on high ground to ensure protection from rainwater runoff. Also choose a location that is convenient for use. Keep in mind ease of access when it is raining, night time, and ease of extracting resulting compost.

2) Level ground using a shovel, hoe, metal ruler and hand level (Figure 22). Level an area of 2m X 2.5m. Dig slightly under surrounding dirt level to place common bricks slightly under ground. This will add protection from erosion caused from rainwater runoff.

Figure 22: Level ground using shovel, hoe, rake, and long ruler. Photo by author.

3) Mix mortar with mix design of six parts sand – one part cement – one part hydrated lime. First mix sand, cement, and hydrated lime together without water until a uniform color is reached. Next form a "volcano" and add a small amount water into the "mouth" of the volcano (Figure 23). Mix thoroughly, being careful not to let water spill over and drain away from mix. Once thoroughly mixed create another "volcano" and add another small amount of water and mix thoroughly. Repeat this process until the mortar is sufficiently wet and will smoothly fall off a trowel but holds its shape. Adding too much water will significantly weaken the strength of the

Figure 23: "Volcano" method of mixing concrete. Photo by author.

mortar. Also, keep an eye on the time. Each batch of mortar should be used within 2 hours. If the mortar gets dry from the heat during this time a SMALL amount of water can be added to make it workable again.

4) Pull a string line using small stakes to create a rectangle with the dimensions of 197cm X 127cm (Figure 24). The diagonal should measure 234cm. Next lay each corner brick with mortar and a trowel, and level in between each brick using the 2m long metal ruler and hand level to ensure all bricks are on the same level. Next reposition the string line to follow the level of each corner brick to create a level line between each brick.

Figure 24: String strung between stakes to show placement of base level of bricks. Photo by author.

**Note: These dimensions are specific to the bricks and size of lozas used. Latrines using other sized bricks or lozas will take other dimensions for the base. These dimensions were calculated to allow 2cm of freedom in each direction, to compensate for variations in loza size.*

5) Lay common bricks using the mortar and trowel following the string line previously strung (Figure 25). Also lay a line of bricks in the center of the rectangle to form a base for the center divisional wall. Try to make each brick as level as possible in each direction. Remember to continue to check the dimensions of the string line during this process to ensure that the base will be square when finished (Figure 26).

Figure 25: Base level of bricks being laid using string lines. Photo by author.

Figure 26: Completed base level of bricks. Photo by author.

6) Mark corner bricks with a pencil to position the first layer of *hueco* bricks (Figure 27). Measure in from the outside of each brick 7.5cm from each direction. Measure the distances between these marks to check dimensions. The final dimensions should be 182cm X 112cm with a diagonal measurement of 214cm.
**Note: The added 2cm widthwise is to add a small amount of mortar between the two lozas once they are placed on top of the vaults.*

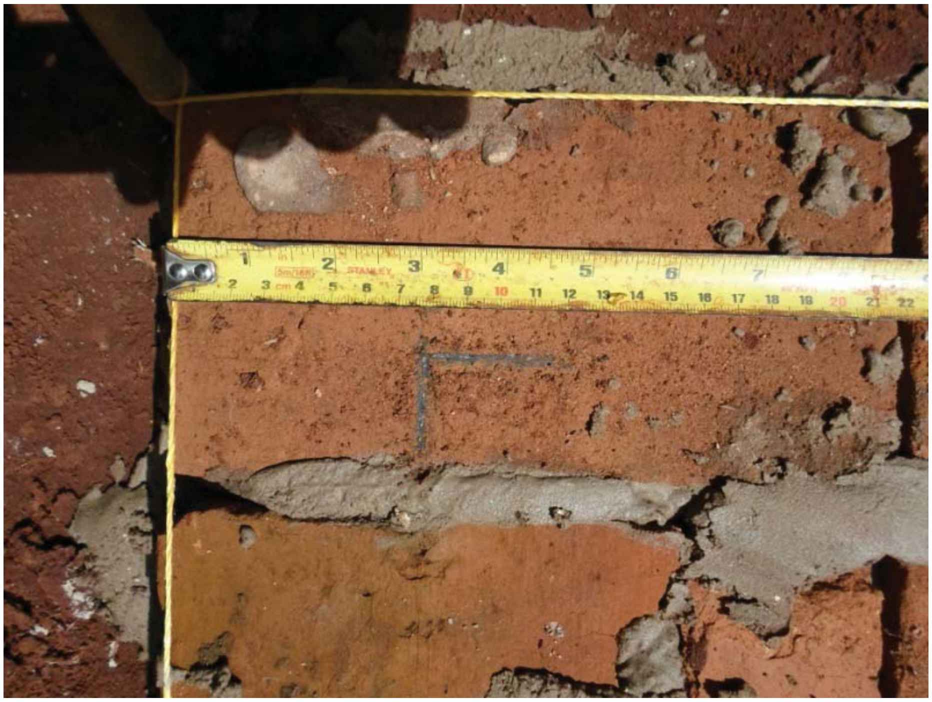


Figure 27: Corner brick placement marked 7.5cm from each side. Photo by author.

7) Lay corner bricks using the pencil marks made in step 6 (Figure 28). Place roughly 3cm of mortar under the first corner brick using the trowel and level the brick in each direction using the hand level. Next lay another corner brick and level it to the first corner brick using the 2m long metal ruler and hand level. Lay the remaining two corner bricks by leveling them to the first corner brick laid. Once the bricks are level between each other, the hand level can be used to individually level the corner bricks in each direction to ensure they are lying flat on the base.

Figure 28: Corner bricks laid on first level. Photo by author.

8) Once all four corner bricks are laid string lines can be pulled between each brick, and the first level of bricks can be laid (Figures 29 and 30). Remember to leave an opening in each vault to create the doors where the resulting compost will be taken out of. The doors can either be on the sides or the back of each vault.

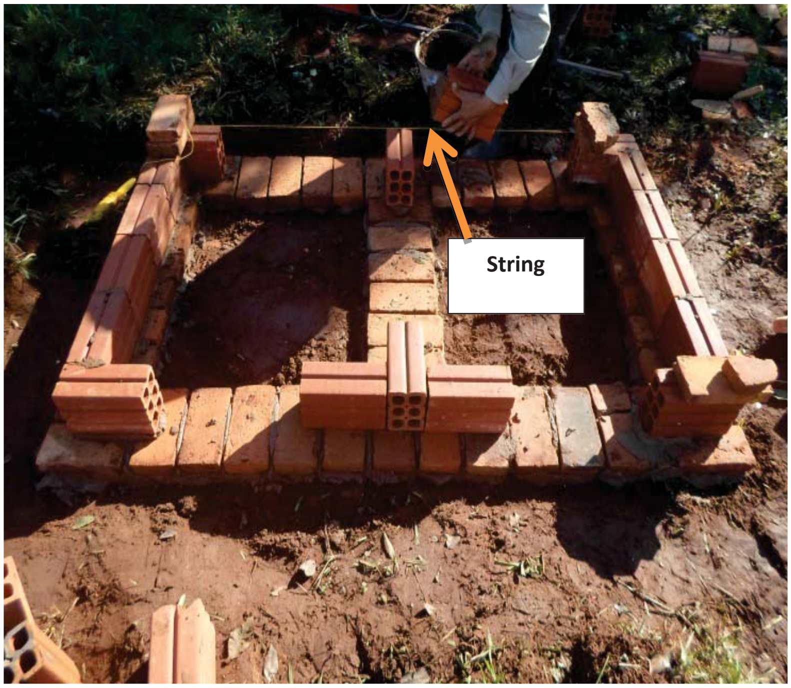


Figure 29: String strung between corner bricks to aid in the laying of brick layer. Photo by author.

Common bricks can be used where half pieces of *hueco* bricks are needed. One can try to break the *hueco* bricks in half, but this usually results in ruining the entire brick. Because of this it is recommended to use common bricks to fill these gaps.

Figure 30: Center bricks of bottom layer being laid. Photo by author.

9) Start and finish the next three levels in the same fashion as the first level, by placing and leveling the corner bricks and running a string line between them to lay the remaining bricks. A plumb bob can be used while placing each corner brick to make sure the vaults are rising up straight. Remember to stagger the joints of the bricks to make a stronger structure.

10) After completing the first 3 levels you will need to place rebar over the openings to create a small bridge to lay the remaining two levels of *heuco* bricks (Figure 31). A form can be made with scrap wood to support the bridge while the mortar cures (Figure 33). Cut eight 8mm rebar at 75cm, and place four on top of each doorway (Figures 32). Use rocks or pieces of brick to lift the rebar off the formwork to allow mortar to completely encapsulate the rebar. Place mortar on top of the formwork, and then place the rebar into the mortar making sure they are sitting on top of the stones or pieces of brick (Figure 34). Next lay the *hueco* bricks across the rebar and mortar.**Note: A mixture or three parts sand and one part cement should be prepared to place the hueco brick on the rebar. No hydrated lime should be used with the rebar as it will cause them to corrode.*

Figure 31: Completed first three levels of bricks. Three lengths of rebar are laid over the door openings to add support to the structure. Photo by author.

Figure 32: Rebar placed over door opening before bricks were laid. Photo by author.

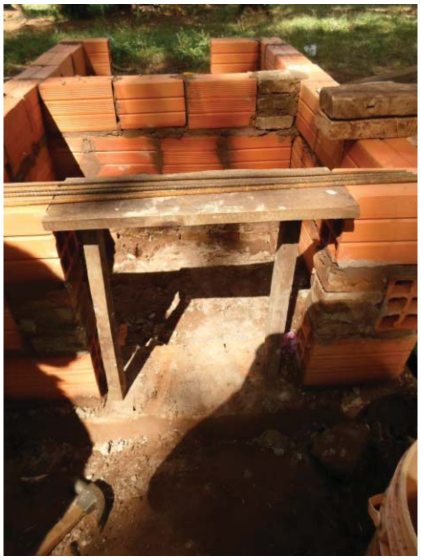


Figure 33: Formwork made from scrape wood used to support bricks over door opening. Photo by author.

Figure 34: Placement of mortar in-between and below rebar. Photo by author.

11) Finish laying the 4th level of *hueco* bricks using original mortar mix design of six parts sand -one part cement - one part hydrated lime (Figures 35).

Figure 35: Completed 'bridge' over door opening. Photo by author.

12) Next lay the final layer of *hueco* bricks. Leave a space in the back of both vaults on this level (Figure 37) to place the ventilation tubes, along with a space 50cm from the back of each vault (Figure 36) to allow for the urine diversion tube to exit each vault.

Figure 37: Openings in back for ventilation tubes on the final layer of bricks. Photo by author.

Figure 36: Opening on side of top layer of bricks for urine diversion tubing. Photo by author.

13) The floor of each vault can now be poured. First place rocks or broken bricks on the floor of each vault, up to the level of the common bricks used to make the base (Figure 38). Next make a mixture of five masonry buckets of sand with one masonry bucket of cement with more water than was used for the mortar. Pour each floor and smooth out with a trowel (Figure 39).

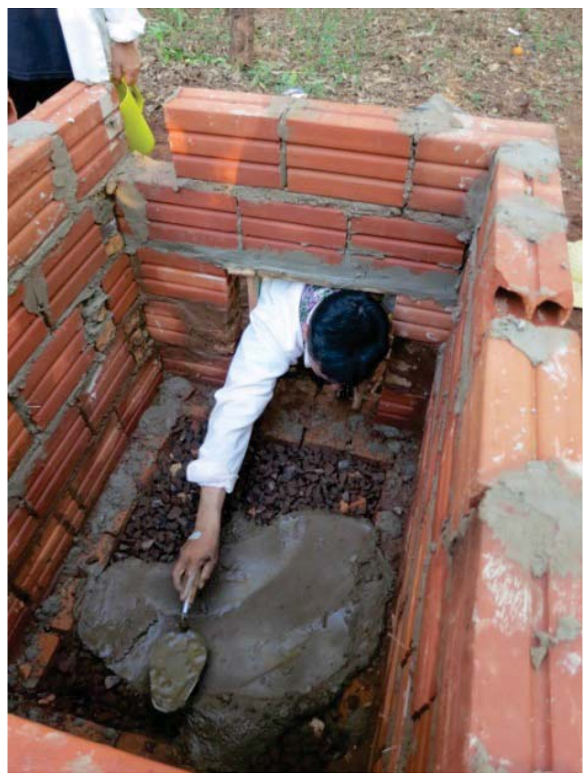


Figure 38: Vault floor bring poured. Photo by author.

Figure 39: Completed floor of vault. Photo by author.

14) Next a layer of stucco (*revoke)* needs to be placed on the inside of each vault (Figure 40). This needs to be done after the floors have had enough time to cure, roughly one day. Prepare a mixture of six parts sand - one part cement - one part hydrated lime to use as your stucco. Next, using a trowel, cover the inside walls of each vault with a thin layer of stucco. A technique of lightly “throwing” the mortar on the wall then smoothing it with the backside of the trowel works well to apply a uniform layer of stucco on all four walls.

Figure 40: Ignacio putting layer of stucco on inside walls of vault. Photo by author.

15) Next, the *lozas* can be placed on top of each vault. First prepare each *loza* by attaching a 0.5m long 20mm PVC tube to the existing 20mm PVC tube that was placed in the *loza* when it was poured (Figure 41). Use a 20mm PVC elbow to connect both tubes, and position the 0.5m long PVC tube to pass out of the side of each vault where the holes were left when the 5th layer of bricks were laid (Figures 42). Next place a layer of mortar (six parts sand - one part cement - one part hydrated lime) on top of each wall and hoist each *loza* onto each vault. Level each *loza* using the hand level (Figurs 43 and 44).

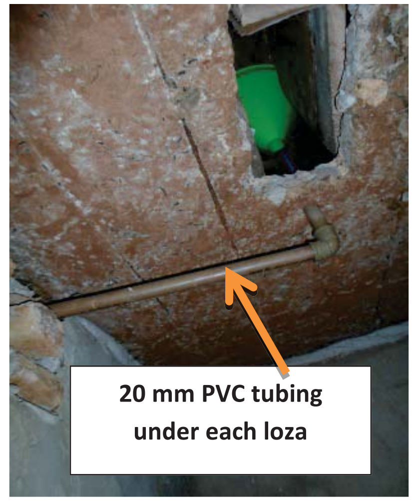


Figure 41: Picture of 20mm urine diversion tubing passing under loza to exit latrine. Photo by author.

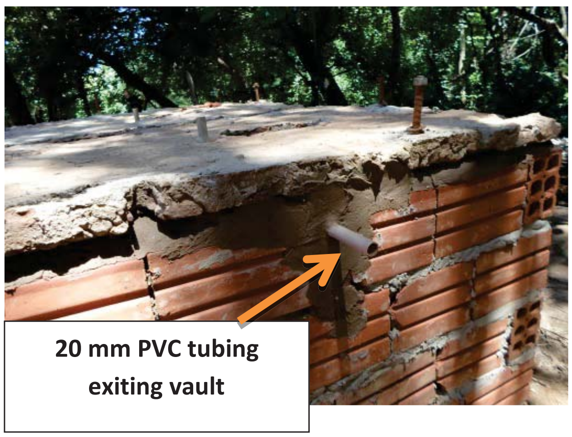


Figure 42: 20mm urine diversion tubing exiting latrine vault. Photo by author.

Figure 43: Preparing top of vault with mortar for placement of left loza. The right loza has already been placed. Photo by author.

Figure 44: Completed latrine base without stucco on outside walls. Photo by author.

3.3b: Stucco (Revoke)

1) Place thickness guides at each corner of the vaults (Figure 45). Scrap wood with the uniform thickness can be used to make these guides. Metal c-clamps made by bending scrap pieces of rebar can be used to hold thickness guides tightly to the vault walls. The thickness should be roughly 2cm.

Figure 45: Stucco thickness guide attached to outside corner of vault. Photo by author.

2) Prepare the stucco mix by using a mix design of six parts sand - one part cement - one part hydrated lime. Use same mixing technique as before when preparing mortar mix; however make stucco mix slightly more liquid than the mortar mix.

3) Cover one wall of the latrine with the stucco, in between the thickness guides (Figure 46). The technique of coving the walls with stucco is slightly tricky at the beginning and requires much practice, but can be achieve by anyone if practiced. To place the stucco on the wall use a masonry trowel to lightly, but with a quick snap action of the wrist, "throw" the stucco onto the wall. If the mix is to wet it will fall of the wall, and if it is too dry it will crumble into pieces when "thrown" at the wall. Next use the back or the trowel to smooth out the stucco and push it into the cracks of the wall. This will also help push out any air bubbles that might be in the mix. Try to match the thickness of the guides at each corner, but do not spend too much time at this point making sure it the correct thickness.

Figure 46: Author's neighbor Io 'throwing' stucco on to outside walls of vaults. Photo by author.

4) Once the wall is completely covered, use the 2m long metal ruler to smooth out the stucco on the wall (Figure 47). Using the thickness guides on the corners lightly push the ruler back and forth slowly smoothing out the stucco. While planning out the surface, stucco can be added to the areas that are too thin by using the same technique of "throwing" and smoothing. Continue placing and smoothing the stucco until a relatively uniform thickness is obtained.

Figure 47: Author's neighbor Io smoothing stucco with long metal ruler. Photo by author.

5) Next use a wooden finishing trowel to smooth out the stucco (Figures 48). First wet the trowel then lightly press it on the stucco surface and move in a circular motion, making circles with a diameter of roughly 3-4 inches. Add stucco where needed. The finished result should be a smooth uniform surface with a slightly rough texture (Figure 49). Adding the stucco inside and out of each vault helps to make it waterproof, along with adding strength to the entire structure.

Figure 48: Final smoothing of latrine outside walls. Photo by author.

Figure 49: Completed base of latrine. Photo by author.

3.4: Housing Structure Construction (2-3 days)

- Equipment needed: wood handsaw, chainsaw (if available), machete, carpenter's square, adjustable wrench, hammer, ladder, chair, table, tape measure, hand level, pencil
- Materials needed:
    - 4x6cm board (footers and beams)
        - 9 @ 2m long
        - 6 @ 1.5m long
    - 7x7cm corner post
        - 4 @ 2m long
    - 2x4cm lathes
        - 5 @ 2m long
    - 5.8m width of 2m long planks (boards to make walls, the housing structure has a perimeter 5.8m)
    - 0.5 kilo three inches nails
    - 0.5 kilo 2" nails
    - 25 rubber stopped roofing nails
    - Roofing material (Area of roof = 3.6 sq.meters)
        - Thatch
        - 5 *chapa terni* (In Paraguay, each having dimensions of 2.5m x 0.45m)
    - 1 set of 4" hinges
    - 2 door latches
    - PVC adhesive
    - 4m of 100mm PCV piping
    - 2-100mm plastic elbows
    - 1 sq. meter plastic or metal mesh

3.4a: Framework (1-2days)

1) The first step to constructing the housing structure will be to cut, drill, and secure the footers to the *lozas*. Measure and cut to size the 5 footers that will be attached. The approximate measurements should be: one - 180cm, two -110cm, two - 60cm.

2) Line up the footers on top of the threaded bars sticking out of the *lozas*, and mark with a pencil where holes will need to be drilled (Figures 50-52). Make sure the footers are in line with the outside edge of the *lozas* (Figure 51).

Figure 50: Lining up footer with threaded bars to prepare for drilling.

Figure 51: Lining up footer with outside edge of vault to ensure a straight wall after drilling. Photo by author.

Figure 52: Lining up threaded bars in center of footer to mark for drilling. Photo by author.

3) Drill holes using 5/8" drill bit (Figure 53) and clean with knife (Figure 54).

Figure 53: Drilling footer with 5/8" bit. Photo by author.

Figure 54: Cleaning drilled holes with knife. Photo by author.

4) Measure the size of the corner posts and cut inlays into footers. Make sure to leave at least 2cm of wood on each cut to securely fasten the posts to the footers (Figure 55). Once all corner inlay cuts have been made, fasten the footers to the *lozas* using and adjustable wrench to tighten the nuts (Figure 56).

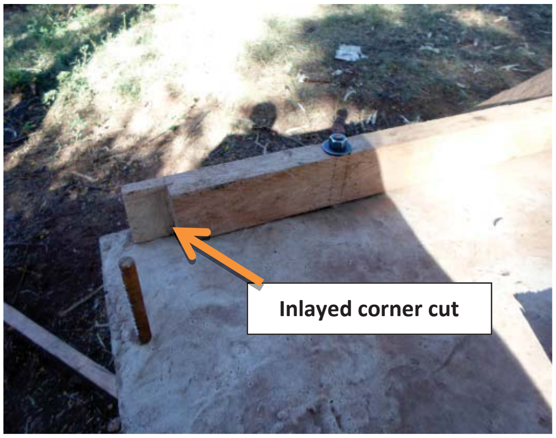


Figure 55: Inlayed corner cut. Photo by author.

Figure 56: Completed footer installation. Photo by author.

5) Cut the four corner posts to appropriate lengths. The front height should be at least 15cm taller than the back height to allow for water drainage. Typical corner post heights used with this design were 180cm for the front and 165cm used for the back. These heights will depend on the owner's preference.

6) Next the upper beams of each side wall will need to be cut and fastened. Cut two 4x6cm boards at 140cm lengths. Next measure and cut out inlays in appropriate places to attach upper beam to corner post (one should be at the backend and the other roughly 110cm from the back end) (Figure 57). Make sure to leave at least 2cm thickness of wood on the inlay cuts to fasten to the beam to the corner posts. Next, nail upper beam to corner posts and place each set of side walls into inlays cut out of the footers.

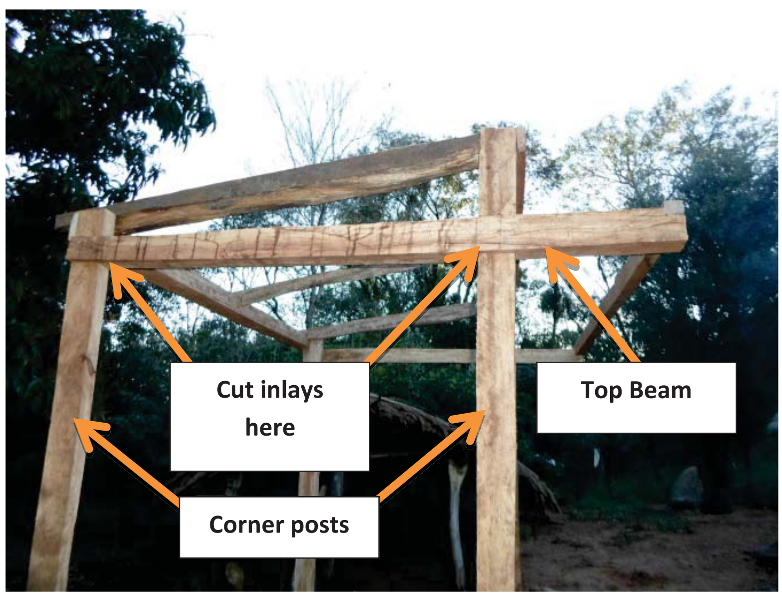


Figure 57: Side wall of latrine showing placement of corner posts and top beam. Photo by author.

7) Measure top beam lengths of housing structure. There will be three top beams in total, one on the back wall of the structure (Figure 58), one on the front wall (Figure 58), and one connecting the sidewall beams in front of the housing structure (Figure 59). Next, cut and attach all three top beams. Once all top beams are attached, square the entire structure using the hand level and scrap pieces of wood.

Figure 58: Front and back top beams placed on latrine structure. Photo by author.

Note: Use bottom lengths between corner posts to cut top beams. This will insure that the outside walls are squared to each other.

Figure 59: Top beam placement. Photo by author.

8) Measure, cut, and attach door post to front side of housing structure (Figure 60).

Figure 60: Door post placement. Photo by author.

9) Measure, cut, and attach three sets of rafters to top beams using 4x6cm boards (Figure 61). Next measure, cut, and attach the 5 top lathes to rafters. The lathes will be used to attach the roofing material (Figure 62).

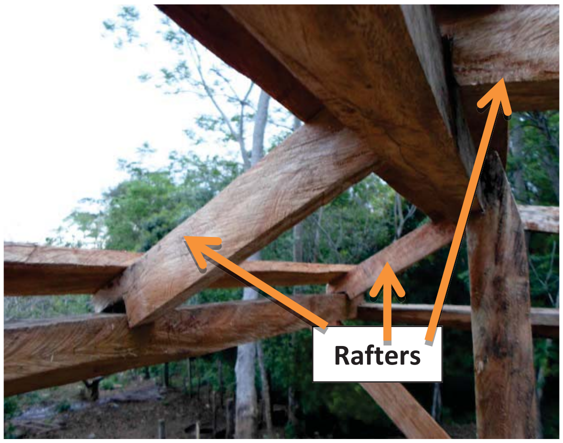


Figure 61: Rafters. Photo by author.

Figure 62: Lathes. Photo by author.

10) Cut and attach wooden planks to form walls of the housing structure (Figure 63). The door can also be fabricated and hung at this point.

Figure 63: Attaching planks to complete walls of latrine housing structure. Photo by author.

11) Measure, cut, and attach roofing material to the lathes on top of the rafters (Figure 64) using roofing nails with rubber stoppers attached. In this design the larger roof area has dimensions of 120cm X 220cm, and the smaller front roof area has dimensions of 60cm X 220cm. **If available thatch is also a viable roofing material (Figures 65 and 66).*

Figure 64: Completed latrine with chapa roofing material. Photo by author.

Figure 65: Author's completed latrine with thatch roof.
Photo by author.

Figure 66: Completing roof with thatch. Photo by author.

3.5: Ventilation Tubes Installation (1-2hrs)

1) Measure lengths needed for ventilation tubes to reach 10cm above roof in the back of the housing structure from where the holes were left in each vault. For this design the length should roughly be 180cm. Cut two 100mm PVC tubes to this length.

Figure 67: Length of tubing needed measured from opening to 10cm above roof. Photo by author.

2) Cut two 15cm lengths of 100mm PVC tubing.

3) Attach one 15cm length and one 180cm length of tubing to each 100mm PVC elbow using PVC adhesive.

4) Cover the top of each ventilation tube with plastic or metal mesh to help keep insects out of latrine (Figure 68). Also attach a small "roof" (Figure 69) to the tube so excess water does not enter the vaults from the rain. Scrap metal or plastic can be used to make the "roofs."

Figure 68: Attaching plastic screening to top of ventilation tube to prevent insects from entering. Photo by author.

Figure 69: Completed ventilation tube with attached 'roof.' Photo by author.

5) Attach ventilation tubes to back of housing structure by inserting shorter tube into vault and using mortar to secure in place (Figure 70). Tubes should also be secured half way up the tube by attaching wire to the back wall.

Figure 70: Attaching ventilation tubes to housing structure. Photo by author.

3.6: Stairs Construction (1-3 days)

The stairs of the latrine can be made from many materials, including wood, rock, or bricks. When designing and building steps keep in mind the ease of use of the stairs for very young and elderly people, the safety of the surface when it is wet, and the resulting look. Below are three different stair designs.

3.6a: Wooden Stairs (2-3days)

- Equipment needed: hammer, wood handsaw, carpenter's square, hand level, tape measure, pencil, shovel, machete
- Materials needed: 2-4x6cm board @ 2m, 8-4x6cm board @ 1.5m, 4-7x7cm post @ 2m, Six 1x10" @ 60cm (top of steps), ¼ kilo three inches nails

Figure 71: Side view of wooden stairs. Photo by author.

Wooden stairs are not recommended, as they are slow to make, rot over time, and are more expensive than the other options. However, if wood is the only material available or desired by the owner of the latrine, the design below can be successfully implemented and enjoyed by the owners (Figures 71-73).

Figure 72: Front view of wooden stairs. Photo by author.

Figure 73: Completed wooden stairs. Photo by author.

<u>3.6b: Rock Stairs (1-2days)</u>

- Equipment needed: Masonry trowel, hand level, 2 masonry buckets, hoe, shovel, hammer, 2m metal ruler, pencil
- Materials needed: Clean sand, rocks, cement, hydrated lime, water

When local rocks are a cheap and abundant construction material, stairs may be made from them (Figures 74 and 75). The only downside of using rocks is the time and physical strength needed to construct them. The work is much slower and strenuous than when using bricks. Also, it takes some level of masonry experience to construct stairs from rocks. **Note: The same mortar mix design of six parts sand – one part cement – one part hydrated lime can be used.*

Figure 74: Completed rock steps. Photo by author.

Figure 75: Side view of completed rock steps. Photo by author.

3.6c: Brick Stairs (1day)

- Equipment needed: Masonry trowel, hand level, 2 masonry buckets, hoe, shovel, hammer, 2m metal ruler, pencil
- Materials needed: Clean sand, bricks, cement, hydrated lime, water

Building stairs from bricks is the easiest and fastest option of the three presented (Figures 76-78). The only downside to using bricks is the added cost of the bricks. However, the added cost of bricks is very minimal compared to the cost to construct the entire latrine, making them well worth the added cost, because of the time and energy saved by using them. **Note: The same mortar mix design of 6parts sand-1part cement-1part hydrated lime can be used.*

Figure 76: Base layer of brick steps. Photo by author.

Figure 77: Finished three level brick steps. Photo by author.

Figure 78: Finished four level brick steps. Photo by author.

3.7: Urine Diverting Seat Fabrication (0.5-1day)

The double vault composting latrine design shown requires the use of a urine diversion system. If the contents inside the vaults become too wet it will become anaerobic and begin to produce offensive smells, and attract flies and other insects. Because of this a specialized seat is needed to divert the urine from the feces. The urine is diverted and piped into a shallow gravel filled soak pit next to the each vault using 20mm PVC tubing. The seat designs shown here (Figure 79) are only a few of many possibilities, and changes and improvements are highly recommended to fit the cultural norms and desires of the people who will be using the latrines.

Figure 79: Six different urine diverting seats. Photos by author.

- Equipment needed: wood handsaw, hand drill (if available) hammer, carpenter's square, pencil, pliers

- Materials needed: Scrap wooden planks, scrap wooden posts, scrap plastic bucket, plastic funnel, 1/8 kilo 2" nails, three inches metal hinge, 20cm plastic hose

**Note: The seat design shown was designed around a loza hole size of 10cm x 23cm. The design dimensions will change with loza hole size. These directions are to only show an example of how a seat is constructed once dimensions are known.*

1) Cut wooden planks to desired dimensions (Figure 80). The seat in this design has a final seat height of 30cm and a width of 25cm. Remember to leave an extra 5cm lip on the board which will be placed on the backside of the seat, to create a tab that goes into the *loza* hole to "lock" the seat in position.

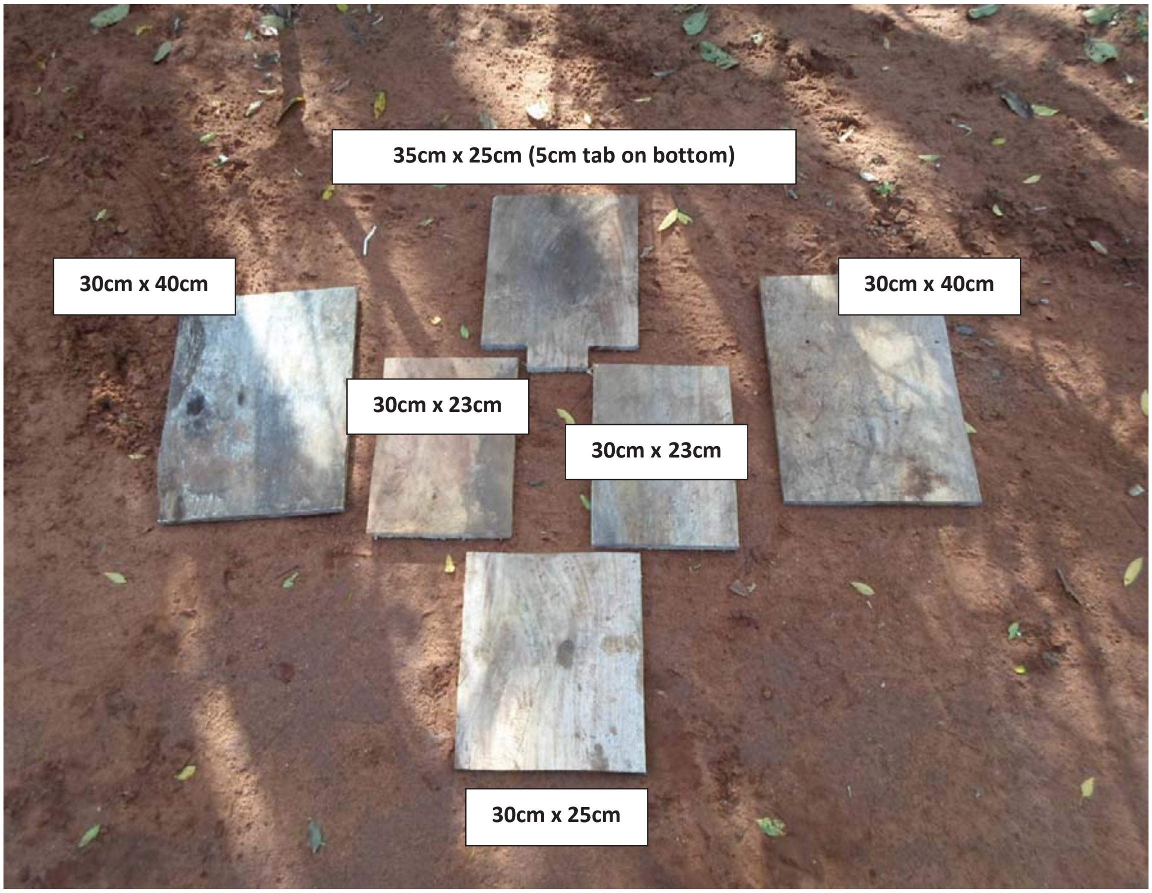


Figure 80: Board sizes and quantities needed for seat construction. Photo by author.

2) Cut plastic covers from scrap buckets or soda bottles and attach to backside board and two inside boards using nails (Figure 81). The plastic on the backside board only needs to be 10cm in width.

Figure 81: Plastic covered boards. Photo by author.

3) Cut four 30cm long posts using 4x6cm boards (Figure 82).

Figure 82: Four 30cm long posts. Photo by author.

4) Nail two posts to each inside board, on the opposite side of the plastic covering (Figures 83 and 84).

Figure 83: Back view of plastic covered board with post. Photo by author.

Figure 84: Plastic covered board with post. Photo by author.

5) Nail 30cm x 40cm boards to backside of posts (Figure 85).

Figure 85: Completed side boards. Photo by author.

6) Attach back and front boards (Figures 86 and 87).

Figure 86: Back board attached. Photo by author.

Figure 87: Front board attached. Photo by author.

7) Cut and attach cover and top pieces (Figure 88). Use the three inch hinge to attach the cover.

Figure 88: Completed seat. Photo by author.

8) Attach 20cm of plastic hose to the funnel using heat from a fire, wire, and pliers (Figure 89). **Note: The picture shown was from a failed prototype, but is shows how the hose needs to be attached to the funnel.*

Figure 89: Placement of attached hose on funnel. Photo by author.

9) Nail funnel to inside of seat. Place the seat over hole by sliding 5cm tab into the *loza* hole. Slide the plastic hose into the piece of 20mm PVC tubing sticking out of the *loza*. Place a 5cm x 5cm piece of plastic burlap or mesh in the funnel to stop debris from entering the tubing and clogging the system (Figure 90).

Figure 90: Completed seat with plastic burlap 'strainer' placed in funnel. Photo by author.

3.8: Close Vaults and Install Urine Divertion Tubing (2 hours)

- Equipment needed: Shovel, hoe, masonry trowel, handsaw, 2 masonry buckets
- Materials needed: Red clay (*vyv pyta*), sand, cement, water, rocks or bricks, gravel, 2 meters 20mm PVC piping, two 20mm PVC elbows, sticks/branches, bulky brown organic material (hay, leaves, sawdust)

3.8a: Urine Soak Pit

1) Dig shallow pits (35-45cm deep) on each side of the vaults, where the 20mm PVC tubing exits each vault (Figure 91). **Note: The picture shown is of alternate design with vault doors on sides and the soak pit in back. However, the soak pit can be seen with PVC pipe entering it.*

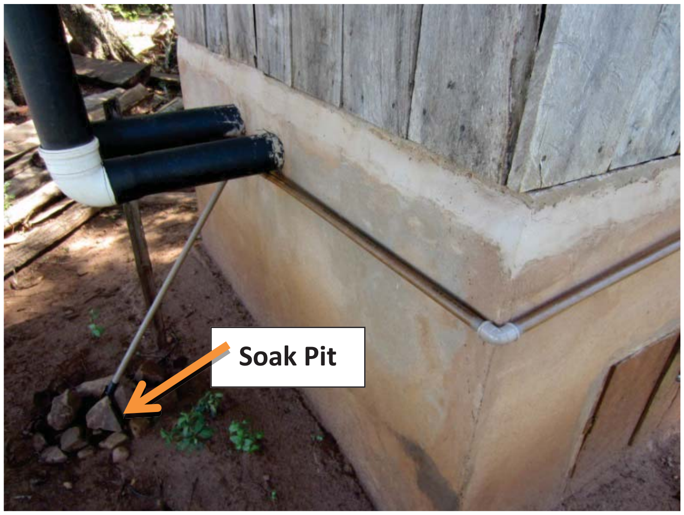


Figure 91: Location of soak pit. Photo by author.

2) Cut two 20mm PCV tubes to roughly one-meter and put a 20mm PVC elbow on end of each pipe without using adhesive. Connect tubing to exiting tube from vault and make sure there is at least 20cm of space below the tube in the soak pit (Figure 92). **Note: The picture shown is of alternate design with vault doors on sides rather than back of latrine. Do not use adhesive, as it may be necessary to detach and clean pipe when clogged.*

Figure 92: Placement of 20mm PVC urine diversion pipe. Photo by author.

3) Test that water freely passes through entire system by pouring a couple of liters of water into the connected funnel in seat. If there are clogs fix them now.

4) Fill soak pits with gravel to slightly under ground level. Top gravel with topsoil and mound up slightly around pipe to encourage sheading of rainwater.

<u>3.8b: Preparing and Closing Vaults</u>

1) Collect small branches and sticks, a quantity sufficient to cover the floor of the vault. Spread out branches and sticks evenly on vault floor.

2) Place dry bulky organic material on top of sticks (Figures 93 and 94). Create a "bed" with roughly 5-10cm of thickness. Make sure to cover all areas of vault floor with an even amount of dry bulky organic material. This "bed" allows air to get under excrement and helps to obtain the correct carbon to nitrogen ratio for proper aerobic decomposition.

Figure 93: Dried bean husks used as bulking material in latrine. Photo by author.

Figure 94: Dried corn husks used as bulking material in latrine. Photo by author.

3) Close vault opening using bricks, rocks (Figure 95), or wooden door (Figure 96). Rocks and bricks are obviously faster and easier to install, however a wooden door built from durable rot-resistant wood will last several cycles of use while a brick or rock covering will needed to be knocked out and re-built each time the compost is taken out of the vault. If bricks or rocks are used, a mortar mix of four masonry buckets of sand and one half masonry buckets of cement is recommended. A layer of stucco (revoke) is recommended to top the closure with a mix design of one masonry bucket of sand, ¼ masonry bucket of cement and ¼ masonry bucket of hydrated lime.

Figure 95: Vault closed with rocks and clay mortar. Photo by author.

Figure 96: Vault closed with wooden door. Photo by author.

3.9: Recommendations for Improvement of Construction

Through the construction of twenty one composting latrines, including his own latrine, the author collected several recommendations for future composting latrine projects. The most general recommendations, which can be used anywhere in the world when building this latrine design, are listed below.

- If clay material is abundant and used in community for home construction, use this in place of mortar when laying the vault bricks. A mix of ten parts clay to one part cement was a common home construction mix used in the community and may places in Paraguay. The author feels this mix design would give sufficient strength while cutting down on the cement and sand needed, reducing the cost of the project. It is recommended to still use the six parts sand - one part cement - one part hydrated lime mix design for the stucco of the inside and outside of the vaults, as this will protect the latrine from water damage.

- Remember to observe local building practices and mimic these as much as possible when completing a construction project.

- Put a larger hole in the *loza* to accommodate the urine diversion seat. When the author was completing his feasibility research of the project, he asked the community members if they would like to sit or squat in the latrine, as this would determine if seats were needed and how big the whole in the *loza* would need to be. Nearly every community member interviewed stated they would squat, however after one family constructed urine diverting seat they all changed their minds and wanted to sit. Design the *loza* to have a large enough hole to easily use either a seat or squat.

3.10: Recommended Use of Double Vault Composting Latrine

Below are a list of eight recommendations for correctly using and maintaining a double vault composting latrine. These steps were practiced and modified during the author's use of his own latrine, and by observing how his neighbors used the latrine.

1. Prepare the base of vault before use as described in Section 3.7b. Use dry bulking material to create a dry and elevated 'bed' for the compost to sit on and allow air to circulate.

2. Collect ample dry bulking material such as leaves, sawdust, forest litter, wood ash and dry grass clippings. The smaller the particle size the faster it will decompose, therefore sawdust mixed with wood ash mixed is recommended if available. Tough, larger material such as dried corn husks will take a very long time to decompose and will not cover the feces very well, allowing smells to escape and possibly attracting flies to the latrine. These types of material should be avoided if possible.

3. The bulking material should also be mixed with wood ash to increase the pH and aid in the pathogen destruction. In hot climates the bulking material can also be slightly moistened with water to reach a moisture level of a well wrung sponge. This will help keep the bacterial active in the compost and help reach higher temperatures. If the compost is too dry it will become less active and decrease the temperatures reached inside the compost.

4. Divert the urine from the feces using a socially acceptable manner. If the community does not want to sit, but rather squat, an alternative to a seat needs to be developed. Otherwise, build a seat similar to the tried-and-tested one presented in Section 3.6. If some urine does enter the vault it is okay but should be covered with extra bulking material to help suck up the moisture and guarantee an aerobic environment.

5. After each use of the latrine, two handfuls of bulking material should be added to the latrine to sufficiently cover the fresh feces.

6. Mix and add moisture (either water or a water/urine mixture) to the latrine at least once a month. During dry seasons this interval should be every two weeks. A two-meter long stick can be used to mix the outside compost into the center of the pile, moving the least decomposed material to the top-center of the pile where it is most active. Two-to-four liters of water can be added during this mixing, depending on how dry the compost is. A moisture level of a well wrung sponge should be sought after to keep the beneficial compost bacterial active.

7. After the first vault is 90% full, place a thick layer of bulking material on top of the compost. This bulking material does not need to be fine particle size, and therefore straw, leaves, or corn husks can be used. This layer will keep flies out

of the compost while keeping moisture in the compost. The compost may be mixed every couple of months, to ‘reactivate’ the bacteria and further break down the organic material. Water, or a water/urine mixture, should be added every two to four weeks to keep the moisture level of the compost of a well wrung sponge. The second vault should then be prepared as described in Section 3.7b, and may begin to be used.

8. Once the second vault is full, the contents of the first latrine will need to be removed. The contents should be placed in a second compost bin for further decomposition and pathogen destruction. The outside compost bin can consist of a simple bamboo or stick fence with a top to keep animals and children out. This compost can be used as a soil amendment after a second year of composting outside the latrine.

Chapter 4: Mechanics of Aerobic Composting, Pathogen Destruction and Recommendations on Use and Maintenance Practices to Maximize Pathogen Destruction

Composting and organics decomposition can be defined in many ways depending on the materials present and the microorganisms utilized in the process. Haug 1993, defines aerobic composting as "the decomposition of organic substrates in the presence of oxygen (air)." Both Haug and Dahi further define the term composting as the aerobic decomposition and stabilization of organic temperature at elevated temperatures (113^0F, 45^0C), relying on thermophilic bacteria as the major driver in the decomposition process (Haug 1993) (Dahi 1990). To avoid confusion in this report the term *composting* will refer to the decomposition of organic material in the presence of oxygen, regardless of the temperatures reached.

The decomposition of human waste relies on many living organism to return a safe and beneficial product back to the land. There are major differences between the microorganisms that accomplish this, with some that use oxygen (aerobic microorganisms), and those that do not use oxygen (anaerobic microorganisms). The double vault composting latrine presented in this report, and most open air composting methods, depends mostly on aerobic microorganisms. By utilizing aerobic decomposition, noxious fumes and leachate are kept from forming due to excess moisture, creating a clean and near odorless compost pile/latrine.

The aerobic microorganisms in the compost pile combine oxygen with carbon to produce carbon dioxide and release chemical energy (Dahi 1990). Some of the energy is used for reproduction and metabolic processes, while some is released as excess heat, classifying the reaction as exothermic. The general reaction in aerobic decomposition can be written as:

$$\text{Organics } (C_aH_bO_cN_dS_e) + O_2 = CO_2 + H_2O + NH_3 + SO_4^{2-} \text{ (Dahi 1990)} \qquad \text{Eq. (1)}$$

Equation 1: General reaction equation for aerobic decomposition. (Dahi 1990)

The excess heat released in this process is one of several aspects of a composting latrine that aids in the destruction of pathogens. This will be discussed in more depth later in this chapter.

4.1: Parameters

To create the appropriate environment for aerobic microorganisms to decompose human waste, several parameters need to be checked and sustained. These include Moisture Content, Temperature, Carbon/Nitrogen Ratio, and Oxygen Content.

4.1a: Moisture Content

The microorganisms within a compost pile need moisture to thrive and reproduce. The optimal moisture content in a compost pile is between 50-70% (Haug 1993). A rule of thumb is to keep the compost pile as wet as a well wrung sponge.

Although human excreta has a moisture content of 93% when it is fresh (Dahi 1990), it is quickly evaporated from the elevated temperatures caused by the release of heat energy from the microorganisms in the compost. Because of this it is necessary to periodically add moisture. In practice it was found necessary to add water or urine to the compost once the vaults began to fill up past 50% to keep the compost adequately moist. At this point the compost began to heat up due to thermophilic bacteria within the compost, and the added heat began to dry out the compost.

4.1a.1: Recommendation/Field Observations for Moisture Content

In practice it was hard to teach people to maintain such moisture levels as 50%-70%, as they did not want to look inside their latrine and monitor their waste. It was also thought to be better to lean on the side of too dry rather than too wet, as an overly-wet composting latrine will produce noxious fumes and attract flies while an overly-dry latrine would only take longer to decompose.

Although it is necessary to add urine or water to the compost after a sufficient amount of biomass is accumulated, it is still recommended to divert urine from the feces in developing countries, where educational levels may be low and a language/cultural barrier may result in the mismanagement of the latrine. If urine is not diverted, but mixed with the feces, a large amount of fine, absorbent cover material will be needed to soak up the urine to keep the compost adequately "dry" to foster aerobic decomposition. This is also unrealistic, as fine sawdust is hard to find in many rural areas. If there is no added urine, less absorbent and larger cover material such as leaves can be used as a very effectively. If an insufficient amount of cover material is used while combining urine and feces, the compost will begin to omit very offensive fumes and attract flies. However, urine is a very nutrient rich substance and much safer than feces. It is therefore recommended by the author to divert the urine from the feces and compost it separately in its own container if one desires to use the nutrients in their garden or on their crops.

4.1b: Temperature

There are three distinct temperature phases in the composting process (Figure 97); the mesophilic phase where there is the initial increase in temperatures up to 113^0F (45^0C), the thermophilic phase where temperatures hit their peak in the range of 125^0F (52^0C) to 158^0F (70^0C), and the cooling phase where the temperature falls back to ambient air temperatures. Although not all compost piles reach temperatures in the thermophilic range, they will follow the cycle of heating up and cooling down as the organic matter within them is diminished and replenished in the system.

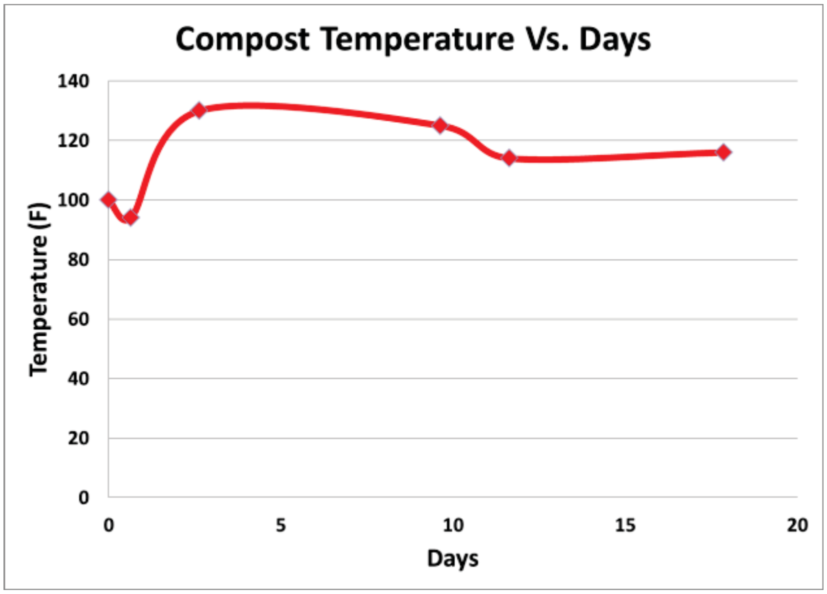


Figure 97: Graph of author's compost's temperature rising and falling in aerobic decomposition cycle

The temperature of the compost pile will determine how fast the material is decomposed and the rate of pathogens destruction. The hotter the compost, the faster the material will decompose and eliminate harmful pathogens. Temperature and pathogen destruction will be discussed in depth later in this chapter. Theremophilic bacteria, or heat loving bacteria, will take over the composting process at temperatures of 113^0F (45^0C) and above, and create a pathogen destructing environment. A well maintained double vault composting latrine will be able to reach temperatures of above 135F (see author's temperature readings in Chapter 5), and sustain this temperature for as long as there is adequate fecal matter to be broken down and moisture content. It is ideal to monitor the temperature inside the composting vaults to see when the temperature is rising and falling. When the temperature peaks and begins to fall, the compost can be mixed and moisture, either water or a water/urine mixture, added. Once the pile has been turned and used again for several days, the temperature should begin to rise as the aerobic bacteria begin to break down the newly added material and the raw material mixed into the pile.

4.1b.1: Recommendation/Field Observations for Temperature

It is unlikely that a rural community member in a developing country will have both the will and the means to measure the internal temperatures inside their composting latrine. Because of this it is recommended to suggest a turning cycle of every three-to-four weeks, along with adding water or urine to the system on this same cycle. It was found that too much mixing will dissipate the heat and slow down the composting process, while not mixing at all will cause buildup of material in the vault and cause it to fill up at a faster rate.

4.1c: Carbon/Nitrogen Ratio

In order for the compost to sustain mesophilic and thermophilic bacteria, which will bring the compost to pathogen destroying temperatures, the correct balance of nutrients need to be added to the compost. An ideal carbon to nitrogen ratio in a composting latrine is 30:1, or thirty parts carbon to each part of nitrogen (Rodale 1975). Feces has a C:N ratio of five-to-ten, and urine a ratio of 0.8; both clearly much too high in Nitrogen for optimal composting. To balance this ratio a cover material is added to the latrine's vault after each use. A cover material is any dry organic material, such as leaves, sawdust, hay, grass clippings, or forest litter. A brief list of these materials can be found in Table 2 below. A rule of thumb is to add one or two handfuls of cover material after each use; however, this amount will need to be adjusted for each latrine and user. If too much cover material is added the user will use up their supply too fast and more than likely abandon the use of it once their supply is gone, as they realize that it is more work than they expected to acquire the adequate amount of cover material to properly use their latrine. Too little cover material used will cause the latrine to omit noxious fumes and attract flies, defeating the purpose of building a composting latrine. An optimal amount can be found by starting lean and using more until all feces are covered and no smells are omitted from the latrine.

4.1c.1: Recommendation/Field Observations for Carbon/Nitrogen Ratio

In practice it was found that sawdust or fine organic material worked best. This is because composting is most efficient when decomposing particle sizes are between half-inch and two inches (Coker 2014).

While working in developing countries this ratio can be above the scope of building and using a composting latrine, as education levels may be low. It is doubtful that community members will understand the concept of different elements in the composting latrine (i.e. carbon and nitrogen) which need to be balanced. Because of this it is recommended to teach people to use enough cover material to keep the smells covered in the latrine, which should be adequate to balance out the ratio.

Table 2: Common materials found in rural Paraguay and their corresponding C:N ratio. Table adapted from(Gotaas 1956).

Material	C:N Ratio
Cow Manure	19
Grass Clippings	12-19
Raw Sawdust	511
Rotted Sawdust	200-500
Straw	80
Hay	58
Hen manure	6-15

4.1d: Oxygen Content

Another added benefit of using a cover material, besides smell reduction and balancing the carbon-to-nitrogen ratio, is the amount of oxygen that is trapped and made available to the aerobic bacteria within the system. Sawdust and pieces of hay or leaves create small air pockets in the compost which supply oxygen to the bacteria. The bacteria within the compost need an oxygen level of at least 5%, with some bacterial having the ability to live in levels as low as 2% (Becker 2006). Compost piles typically start with an oxygen content of 15-20% due to pore spaces within them, but drop to levels around 5% after the decomposition has begun (Richard 1995). Without these entrapped air pockets it would be possible for the compost to reach very low oxygen levels, below 2%, and become anaerobic (i.e. without air). When this happens the compost will begin to omit noxious fumes such as hydrogen sulfide and valeic acids.

Oxygen can be introduced both passively and mechanically to the compost. Passively it is introduced through convection, and mechanically by turning or mixing. As the compost heats up the warm air begins to rise and pulls cooler fresh air down along the sides of the compost to replenish the oxygen (Richard 1995). Adding cover material aids in this process by creating a porous compost, allowing more warm air to leave and more oxygen to enter. Mechanically oxygen can be added through mixing and poking holes into the pile with a stick or rod. There is a tradeoff however to mixing small batches of compost in a latrine, as the heat will dissipate quickly and take several days if not weeks to recover if insufficient raw material is not added immediately to the compost.

Research has also shown that "turning [compost] piles has a temporal but little sustained influence on oxygen levels," and that "even with no turning, all piles eventually resolve their oxygen tension as maturity approaches, indicating that self-aeration alone can adequately furnish the composting process" (Brinton). Because of this is recommended to both mix sparingly and add water/urine when mixing the compost to create a favorable environment for the bacteria to continue to decomposes the material. If it is possible to measure the temperature of the compost, it should only be mixed once the temperature has peaked and is back close to ambient outside temperatures. This will ensure that heat produced by the bacteria is not wasted in the mixing process. If temperature readings are not available, the compost can be mixed on a three-to-four week cycle. By adding urine a "boost" will be given to the system, as it is very high in nitrogen, helping to reach high temperatures again (Gonzalez 2014).

4.2: Phases

The latrine presented in this report uses a continuous composting system, opposed to a batch system. Because of this there may be several of these phases, if not all, going on in the latrine at any given time.

4.2a: Mesophilic

The mesophilic phase is the first of the four. The bacteria in the compost during this phase begin to heat up the pile by letting off excess heat as they feed on and decompose the organic material in the pile, steadily raising the temperature up to 111^{0}F (44^{0}C). The bacteria in this phase are found in the intestinal track of humans, including E. coli (Jenkins 2005). If there is enough organic material present this phase can rapidly heat up the pile pushing it to the next phase in a very short amount of time.

4.2b: Thermophilic

Once the mesophilic bacteria have heated the pile into the transition phase of 111^{0}F-125.6^{0}F (44^{0}C-52^{0}C) the thermophilic bacteria take over the decomposition of the organic material. Thermophilic (i.e. heat loving) describes this phase and bacteria very well as temperatures can reach up to 158^{0}F (70^{0}C) (Lynch 1979). In practice it has been found that these temperatures are unlikely to be sustained or reached inside a double vault composting latrine. The data shown in Chapter 5 shows that a transitional phase of 111^{0}F-125.6^{0}F is much more likely to be both the max temperature reached and sustained in the latrine.

4.2c: Cooling phase

After the thermophilic bacteria have consumed the limited amount of organic material in the compost, the cooling phase begins. A slow cooling of the compost happens in the phase with more mesophilic bacteria moving back to the pile to continue the decomposition process. The coarser material in the compost is also broken down in this phase by fungi and larger organisms such as earthworms and other larvae. The tough organic materials such as lignin are also broken down during the cooling phase (Jenkins 2005).

4.2d: Curing phase

Once the compost has cooled to the ambient air temperature it has entered the final phase of composting, that of curing. The curing phase is when the "more resistant reactions occur" (Haug 1993). This phase and these reactions can be very slow but are very important to the composting process, especially if the resulting compost will be used as a soil amendment or fertilizer. There are many pathogens that may be in the compost of human waste and the longer the curing time the more likely they will be destroyed. Many pathogens have evolved to live inside the human body, therefore the longer they are in an environment different than one inside the human body, the more likely they are to be destroyed (Jenkins 2005).

Immature compost may also produce substances such as phytotoxins and organic acids which are harmful to plants. Some areas of the compost may also not be completely decomposed and still be using the oxygen and nitrogen present in the compost to complete the decomposition process. If this immature compost was put into the soil it would then rob the soil of such nutrients and lead to a degradation of the soil instead of adding nutrients and fertility (Jenkins 2005). Therefore it is a good practice to let the compost cure for at least a year once it has been taken out of the composting latrine. The curing process can take place in another compost pile where the compost is simply left to sit for an additional year.

4.3: Pathogen Destruction

According to the World Health Organization (WHO) pathogens are destroyed in composting latrines using several mechanisms. These mechanisms include: Storage Time, Temperature, pH/Alkalinity, and Moisture Content. Each of these will be discussed in detail in this section, along with showing how the double vault composting latrine described in this report hopes to achieve them.

The effectiveness of these methods of pathogen destruction can be analyzed by looking at the necessary treatment needed to destroy certain indicator pathogens. In the composting of human waste the *Ascaris lumbricoides* (roundworm) eggs are such an indicator (Cheng 2012), as they have very durable shells and are resistant to chemical degradation and desiccation (Haug 1993).

4.3a: Storage Time

The length of adequate storage time for sufficient pathogen reduction depends on the ambient temperature of the compost. The lower the temperature, the longer the compost will need to stay in storage for safe pathogen destruction. Table 3 below shows the World Health Organization's recommend storage times for different ranges of ambient temperatures.

4.3a.1: Recommendations for Storage Time

The double vault composting latrine system described in the report was designed to allow for at least one year of storage time inside the vault before removal. To design the volume of the vaults, similar double vault composting designs were reviewed (Hurtado 2005) (Pacey 1978) to find a size that would allow for at least one year of storage of the compost. Cost was also a variable in determining how big the latrine could be. A volume of $0.58 m^3$ was designed and achieved the goal of storage time of at least one year with typical use of the latrine by the community members. With this designed volume, and an ambient temperature in Paraguay of 22.7 ^{0}C (climatemps.com 2013), an adequate storage time for acceptable pathogen destruction regarding the WHO's recommendations was achieved.

Table 3: WHO's recommended storage time of compost corresponding to ambient temperatures. Adapted from (WHO 2006).

Ambient Temperature	Recommended Storage Time
Storage ; Ambient temperature 2-20 ^{0}C	1.5 – 2 years
Storage Ambient temperature >20-35 ^{0}C	> 1 year

4.3b: Temperature

As shown in Table 3 above, temperature plays a significant role in the destruction of pathogens in the composting process. The lower the temperature the longer it will take to kill pathogens. The EPA Class A (intended for distribution and marketing to public) has requirements of 53 ^{0}C/5days or 55 ^{0}C for 2.6days, or 70 ^{0}C for 30 minutes and a minimum temperature requirement of 50 ^{0}C for adequate pathogen destruction (Haug 1993). In developing countries it has been shown that sustaining these temperatures may be unrealistic, and should not be depended on for acceptable pathogen destruction (Hurtado 2005). However, the data presented in Chapter 5 taken from the author's personal composting latrines shows that it is possible to reach and sustain such temperatures using a double vault design and practicing the correct maintenance schedule.

Because temperature alone should not be depended on for pathogen destruction, a combination of storage time and temperature should be considered. Feachem et al. stated that "[the] effectiveness of excreta treatment methods depends very much on their time-temperature characteristics. The effective processes are those that either make the excreta warm (55^{0}C/131^{0}C), hold it for a long time (one year), or feature some effective combination of time and temperature" (Feachem 1980). Below in Figure 98 is a graph of the temperatures and corresponding duration times needed to successfully destroy harmful pathogens.

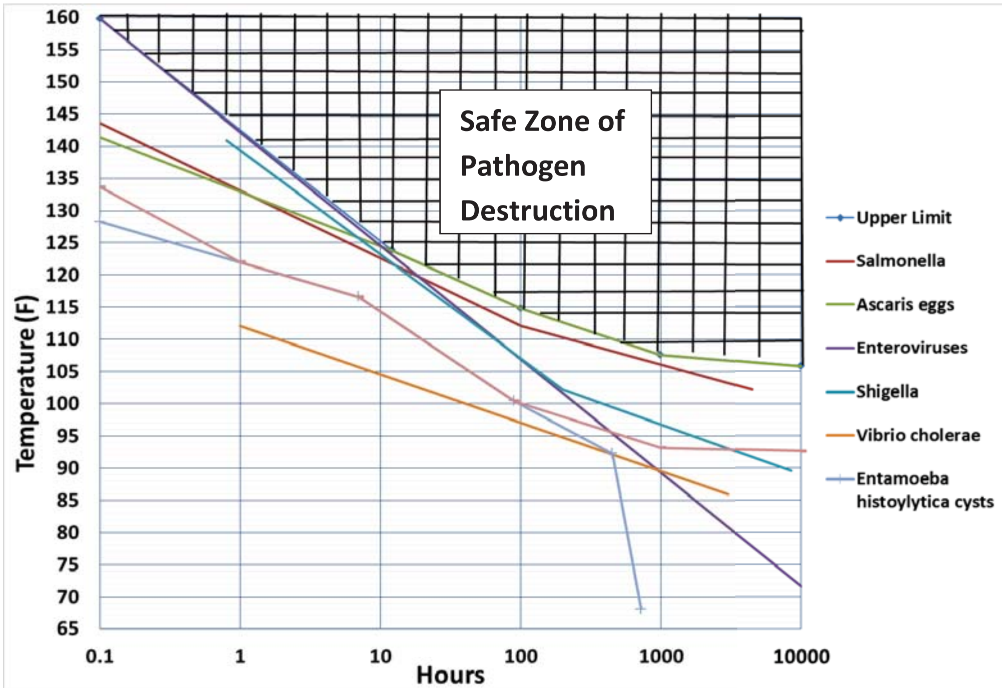


Figure 98: Graph showing temperature and time combinations need to hit points in Safe Zone of Pathogen Destruction. Data from (Feachem 1980).

Although it is unlikely in this design of composting latrine, it is possible for the aerobic decomposition process to reach very high temperatures and sterilizes itself by killing beneficial bacteria due to the high temperatures. Temperatures above 160^0F can significantly reduce beneficial bacteria levels, and therefore temperatures slightly lower are idea top limits to strive for (Richard 1995).

4.3c: pH/Alkalinity

A significant drop in pathogen concentrations in the composting of human waste can be achieved by increasing the alkalinity of the compost. Several readily available, and many times free, additives can be used in developing countries to achieve this. These common materials are listed below in Table 4.

Table 4: Several materials and their corresponding pH values. Adapted from (Kaiser 2006).

Basic Material	pH
Wood ash	9.4-11.3
Rice husks	10.6
Lime (agricultural limestone)	10.3

Compost reaching a pH of at least nine and stored for six months has been shown to greatly reduce and eliminate many pathogens, including the indicator pathogen *Ascaris* (roundworm) *(Kaiser 2006)*. Table 5 shows these reductions.

Table 5: Several pathogens and their corresponding reduction efficiency due to a pH of 9 or higher in compost. Adapted from (Stenstrom 2002).

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

The World Health Organization (WHO) recommends raising the pH to above nine by the addition of 200-500ml of lime or wood ash after each defecation. Enough material should be used to completely cover the fresh feces. Table 6 clearly presents the WHO's recommendations.

Table 6: WHO's recommendations on alkalinity treatment of compost for pathogen destruction. Adapted from (WHO 2006).

Pathogen Destruction Method	Time needed
Raise pH through addition of lime, rice husks or wood ash	pH > 9 during > 6 months

During the project presented in this report, the author educated the community members on the necessity of using wood ash in their composting latrines to help reduce pathogen concentrations. Many community members seemed to already have this knowledge, and previously demonstrated the use of ash to reduce odors and flies in their current pit latrines. The community members used a combination of dry bulking material, such as sawdust or leaves, and wood ash in their composting latrines. It was believed in the community that using only wood ash would create bad odors in the latrines. This belief was beneficial as the addition of too much wood ash would not only kill the infectious pathogens, but also the beneficial bacteria as well. Many of the bacteria responsible for the decomposition and heat increase in the composting process are adapted to low pH values found in the human digestion system (around a pH of two) (Hurtado 2005). When the pH gets too high these bacteria die off and the compost becomes significantly less biologically active. A mixture of wood ash and sawdust or leaves was found to be the best combination and to foster the highest temperatures in the author's personal composting latrine during his research.

4.3c.1: Field Practices/Recommendation on use of pH level for Pathogen Destruction

Wood ash was used during the use of the latrines presented in this thesis to raise the pH of the compost. Wood as was mixed with the cover material before it was used in the latrine. Wood ash was chosen as the basic material to be used as it was widely available due to the fact that the majority of rural Paraguayan use wood as their primary cooking fuel.

4.3d: Moisture Content

The moisture content of compost plays a significant role in pathogen destruction. A moisture content of less than 25% is recommended in urine diverting composting latrines to allow for adequate pathogen destruction (Esrey 1998). An even lower moisture content of >5% is recommended for the destruction of *Ascaris* eggs (Feachem 1983). However, these recommendations are detrimental to the parameters necessary for proper decomposition of organic matter, where an optimal moisture content of 50-70% is recommended (Haug 1993). The validity of lowering the moisture content for pathogen destruction is also hurt by the studies that have shown that reactivation of many viruses including *Salmonella* may occur once the dried compost is rehydrated (Austin 2001).

4.3d.1: Recommendation/Field Observations for Pathogen Destruction through Proper Moisture Content

In practice the author found it more beneficial to keep the compost pile damp to allow for proper composting. By doing this two standards were achieved for proper pathogen destruction, high temperatures and storage time. With a higher moisture content the compost became more active and was able to reach temperatures exceeding 138^{0}F (58^{0}C). During the use of his composting latrine, the author found that when the temperature dropped in the compost, adding water or urine to increase the moisture content drastically increased the activity of the compost and resulted in a rebound of temperatures (Figure 99). Having a higher moisture content also increased the storage time of the compost. When the moisture content was too low, and temperatures dropped, the decomposition rate was significantly reduced. This reduced rate resulted in a much higher rate of volume increase of the compost, leading to a shorter time of vault capacity and shorter retention time of the compost. When the author's compost had adequate moisture, the volume of the compost seemed to shrink faster than new contents were added, due to the increased biological activity in the latrine. Because of this the author highly recommends sustaining a 50-70% moisture content in the latrine during the decomposition of the organic material. Once the compost pile has entered a curing stage due to lack of new nutrients in the system, a lower moisture content can be achieved to help ensure pathogen destruction. Lowering the moisture content should be done during the storage of the compost in the latrine during the use of the second vault.

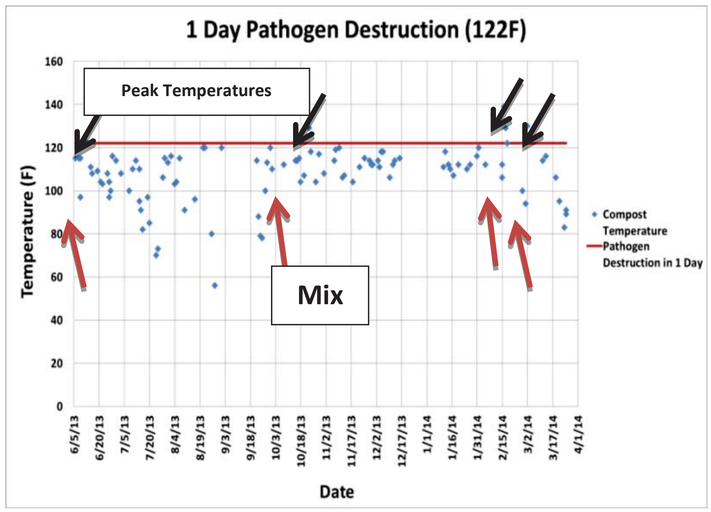


Figure 99: Graph showing the high temperatures reached in author's compost after moisture was added and the compost was mixed.

Chapter 5: Methods Used for Date Collection

5.1 Introduction:

Temperature measurements and visual observations of fourteen community member's latrines were taken over a period of three months, along with those of the author's personal latrine for a period of ten months. The outside temperatures were also taken and recorded during this time.

The author carefully managed the carbon-to-nitrogen ratio by using more or less bulking material, stirred the latrine contents upon temperature drops, and maintained a healthy moisture level in his latrine, hoping to reach the best results possible for this design of composting latrines.

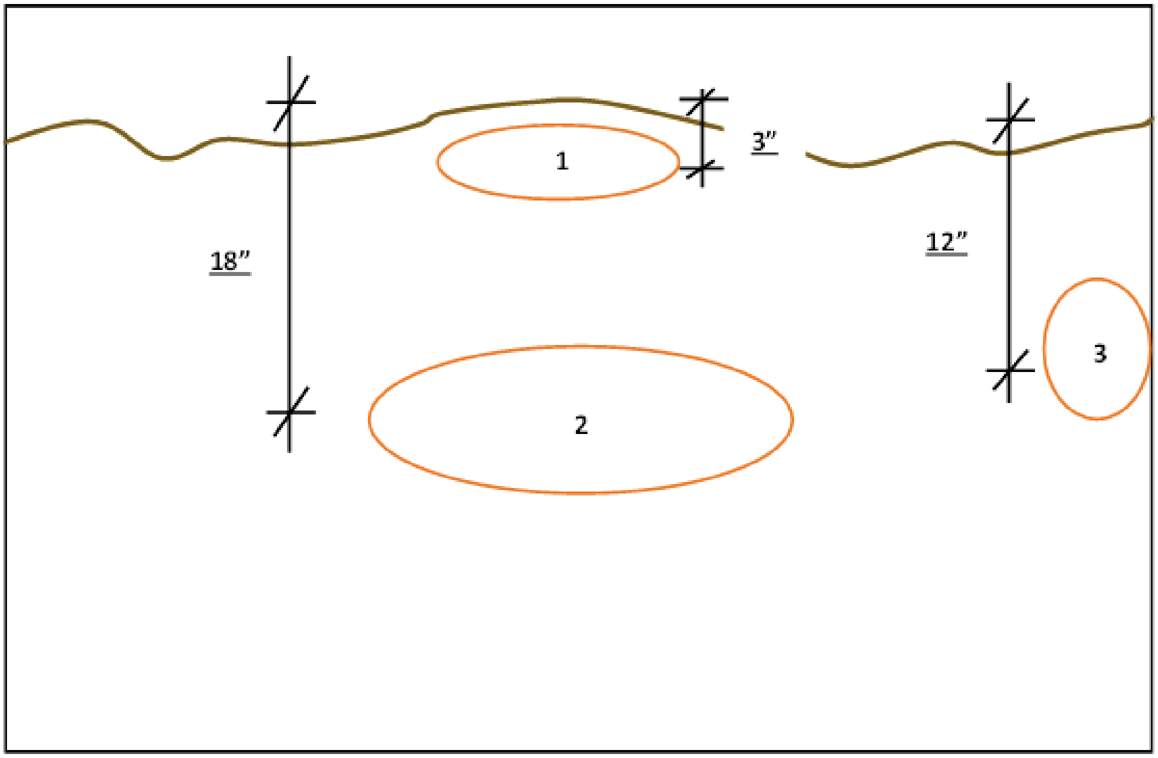
Through visual observations and conversations with community members it was found that the majority of the community members did not use sufficient bulking material, and no households mixed their latrine contents.

5.2: Methods Used

5.2a: Personal Latrine

To measure outside and compost temperatures a *REOTEMP 20" Compost Thermometer* was used (Figure 100). Outside temperatures were taken by leaving the thermometer outside of the latrine for at least two minutes and recording the temperature reading. Inside the latrine, measurements were taken in three locations, as shown in Figure 101, to observe temperature variations, from the most active region to areas with lower activity. Temperatures were taken in the top three inches where fresh feces was present (most active zone), eighteen inches down under the most active zone, and approximately twelve inches down from the surface on the side of the vault. These zones are shown in Figure 101 below. Visual observations were also made to note the smells, flies and insects present, along with overall appearance of the decomposing feces and bulking material.

Figure 100: Picture of thermometer used during temperature reading of compost in author's latrine. Photo by author.



Zones

1: Top 3" - Most Active

2: 18" Down – Second Most Active

3: 12" Down on Side of Vault – Least Active

Figure 101: Zones of temperature readings in latrine vault. Figure by author.

5.2b: Community Latrines

The same method used on the author's personal latrine was also used to obtain temperature measurements and visual observations for the community member's latrines. However, only the temperature in the most active region (top three inches) where the fresh feces was present was taken. This was done because the majority of the latrines had not been used for a sufficient amount of time to allow for more than one region of temperature readings. Each latrine owner was also asked about smells coming from the latrine, their intensity and frequency, along with the type and quantity of flies and insects observed in their latrines.

5.2c: Daily High Temperature Readings (Sun and Shade)

The daily highs, in direct sunlight and in the shade, were taken by the author's neighbors between the dates of 1/14/14 - 4/10/14. These readings were taken from two household alcohol thermometers, one in direct sun and one in the shade (Figure 102). The date, time, and temperatures were recorded daily (Figure 103). A full list of these temperatures can be found in Appendix B.

Figure 102: Author's neighbor reading temperature in shade. Photo by author.

Figure 103: Author's neighbors recording outside temperatures. Photo by author.

5.3: Weather, Visual, and General Observations

The weather was also recorded during temperature measurements, along with visual and general observations of the latrine. These general observations included smells, insects present, and overall "look" of the compost. The full list of temperature and visual observations can be found in Appendix C.

5.4: Assumptions and Limitations

Several assumptions were used when analyzing the available data. They are the following:

1) The outside and compost temperatures vary linearly between each data point.
2) When the time of day of temperature readings was not recorded it is assumed that they occurred at the same time of day as the temperature reading taken before them. For example, if a compost temperature reading was taken at 5pm on Monday and no time recorded on Tuesday for the reading, it is assumed it happened at 5pm, twenty four hours after Monday's reading.

3) When the outside temperature was not recorded at the time of the compost temperature readings, the high temperature in the sun for that day was used in its place. The daily highs were recorded by the author's neighbor using a household alcohol thermometer.

The data available poses many limitations. Listed below are the limitations that were taken into account when analyzing the data:

1) Temperature readings were not taken every day, making it difficult to find correlations of time delayed responses between outside temperatures and the compost temperatures.
2) Temperature readings for the community member's latrines were only taken on a two- to four-week basis. Because of this limited data, no strong results can be made about the correlations the temperatures had to different variables. Only a temperature range of the functioning latrines could be found with this data.
3) Two periods of no data collection occurred during the research. These occurred between 9/1/13-9/22/13 and 12/16/13-1/11/14 when the author was on vacation and away from the latrines.

Chapter 6: Results - Outside Temperature and Its Effect on Compost Temperature of Author's Latrine

As shown below in Figure 104, there are many rises and falls in the compost temperature readings, shown in the top red data set. A possible correlation between the variations of outside temperatures and those of the compost was analyzed in this chapter.

6.1: Top Three Inches of Compost

The top three inches of the compost was the most active region of the compost due to the fresh feces added daily to this region. The highest temperature readings were recorded there.

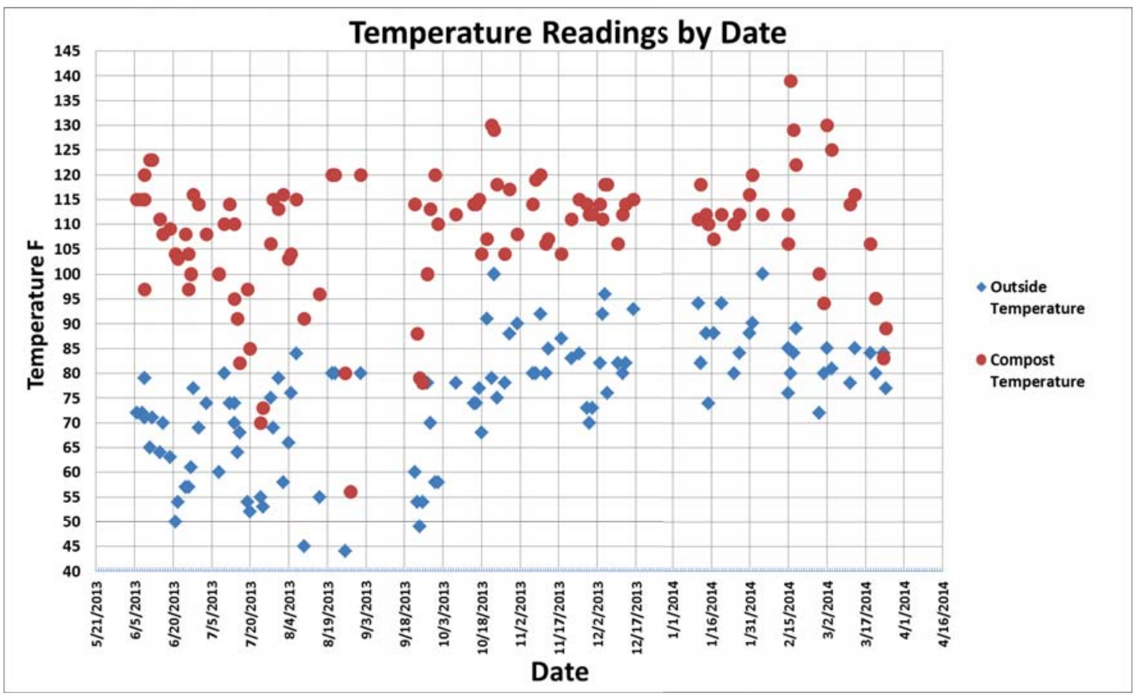


Figure 104: Graph showing compost and outside temperature readings taken by author during 10 month study of his latrine.

6.1a: Analysis of Direct Correlation between Change in Outside Temperature and Compost Temperature

On the graph shown above in Figure 104, there appears to be a direct correlation between the change in the outside temperature readings and those of the compost. The validity of this assumption was investigated by graphing the change in outside temperatures compared to the change in compost temperatures, and running a linear regression test (Figure 105). This test resulted in a R^2-value of only 0.16, showing no linear correlation between outside temperature changes and those of the compost. Since the scatter was so high in the data, only a linear regression was run to check for a correlation between these two variables.

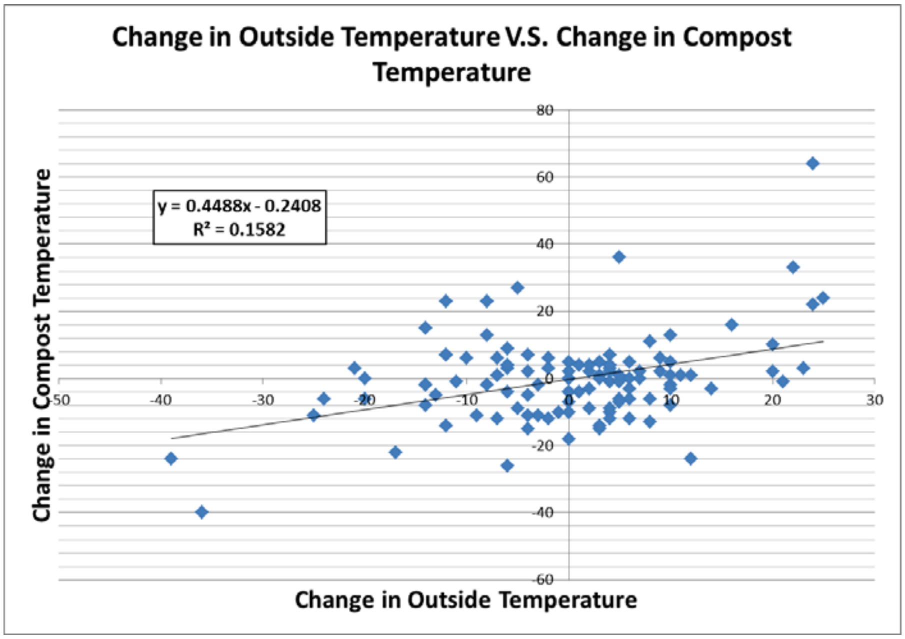


Figure 105: Graph of linear regression of change in outside temperatures Vs. change in compost temperatures.

6.1b: Analysis of Lag Time:

The possibility of a delayed response (i.e. lag time) between the changes in the outside temperatures and those of the compost was considered. It seemed plausible that the thermal mass of the compost would not simultaneously change temperature with the outside temperature, but rather “react” to these changes and show a correlation days later.

To check this possibility, inflection points were found for both the outside and compost temperature readings. The inflection points were found using two guidelines: 1) Changing point of temperature trends (i.e. if the temperature was increasing for several points then started to decrease, the last increase would be the inflection point), 2) The points were not taken from times when the compost was mixed. Once the inflection points of the outside temperature were found, they were matched up with the inflection points of the compost and the lag time found between the points.

The limitations to this method are the following:

- Temperatures were not taken each day at the same time.
- The act of matching up inflection points is subjective and may lead to false correlations.

The points chosen are shown below in Figure 106.

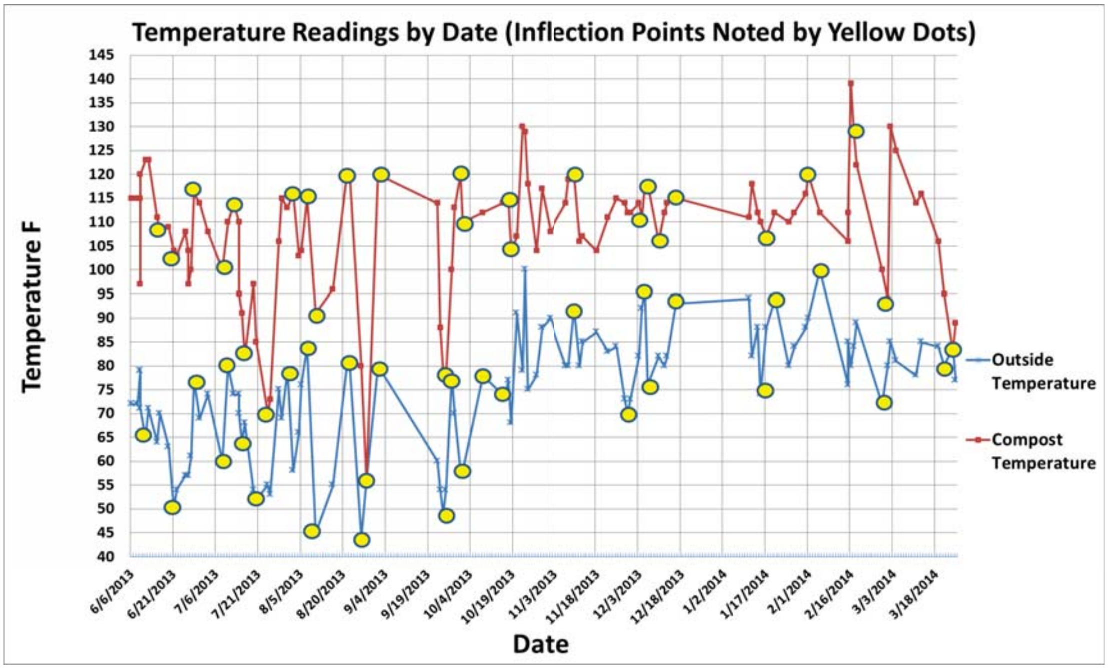


Figure 106: Graph showing inflection points chosen to analyze lag time response.

The different lag times were calculated between the inflection points and are presented in the Table 7 below.

Table 7: Lag times found from inflection points.

Lag Time (Days)	Number of inflection points
0	10
1	3
2	5
3	3
4	3
5	2
9	1
12	2

As seen in Table 7, a zero-day lag time was the most common, showing there was probably no delayed effect from the outside temperature changes. However, the method used to define these data points was subjective, looking at each data set and making an educated guess at which inflection points correlated. Because of this the second most common lag time of two days was analyzed to check for a correlation.

The change in the outside temperature data points were then compared to the change in the compost temperature data points two days later. There was not sufficient data to offset each data point by two days because temperature readings were not taken each day for the duration of the research. This resulted in only thirty-two out of the one hundred and eight data points matching up with a two day lag time, resulting in roughly two thirds less data points to analyze.

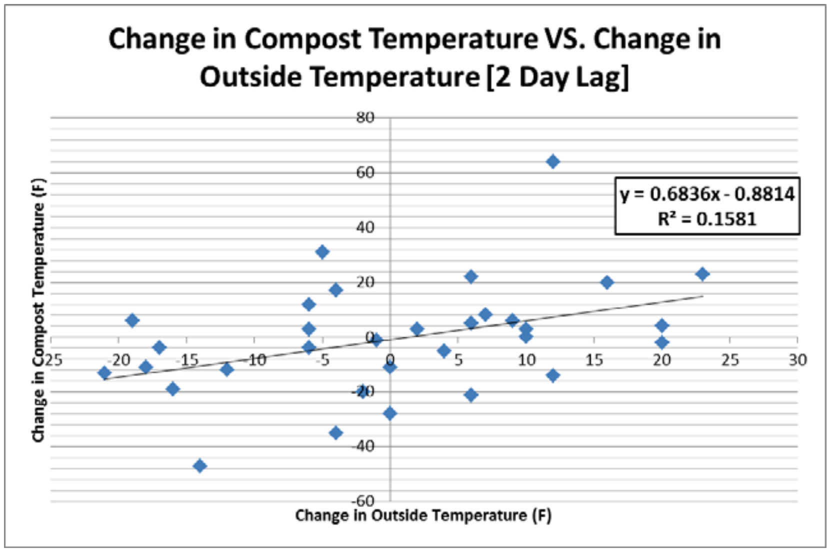


Figure 107: Graph of change in compost temperature VS. change in outside temperature with 2 day lag.

The result from this calculation showed a R^2-value of 0.16 (Figure 107) for a two day lag time, which is nearly identical to the lag time of zero days. This again shows no linear correlation between the daily fluctuations of the outside temperatures and those of the compost.

6.1c: Analysis of Major Inflection Points

A final correlation between the change of outside temperatures and those of the compost were checked using major inflection points of the data. These dates were chosen as points of major trend inflections on the graph of outside temperatures to represent seasonal trend changes in the temperatures. They were chosen by finding maximum or minimum points in regions of seasonal trends. Data points immediately after mixing occurred were not used.

A correlation between seasonal temperature changes and those of the compost were noted by Rodale in *The Complete Book of Composting*, where he stated that "as the average daily temperature decrease in autumn and winter, the decomposition in the heaps slows down gradually and almost stops altogether during the coldest parts of the winter" (Rodale 1975). This analysis looked to find a seasonal effect on the compost.

The method of choosing major inflection points is somewhat subjective and one should consider this when reviewing the presented data. The points and trends used to find them are shown in the graph in Figure 108 below.

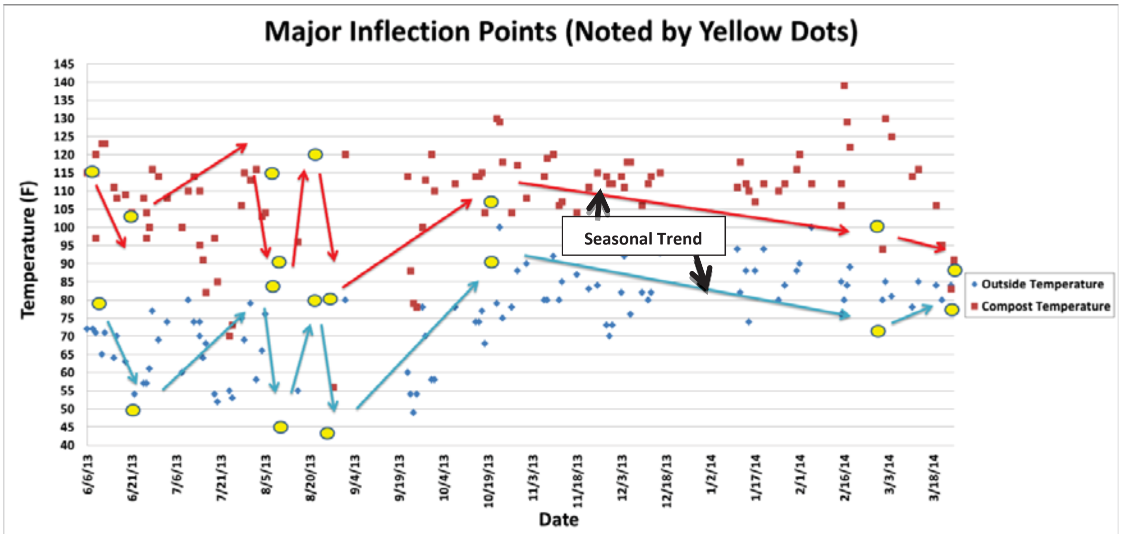


Figure 108: Graph showing the major inflection points chosen (yellow dots) and seasonal temperature trends (red and blue arrows).

Using these points a R^2-value of 0.89 was found (Figure 109), showing a reasonable linear correlation between major trends of outside temperature changes and those of the compost. This conclusion agrees with Rodale's observations, along with the author's personal observations of slower biological activity in his latrine during colder months.

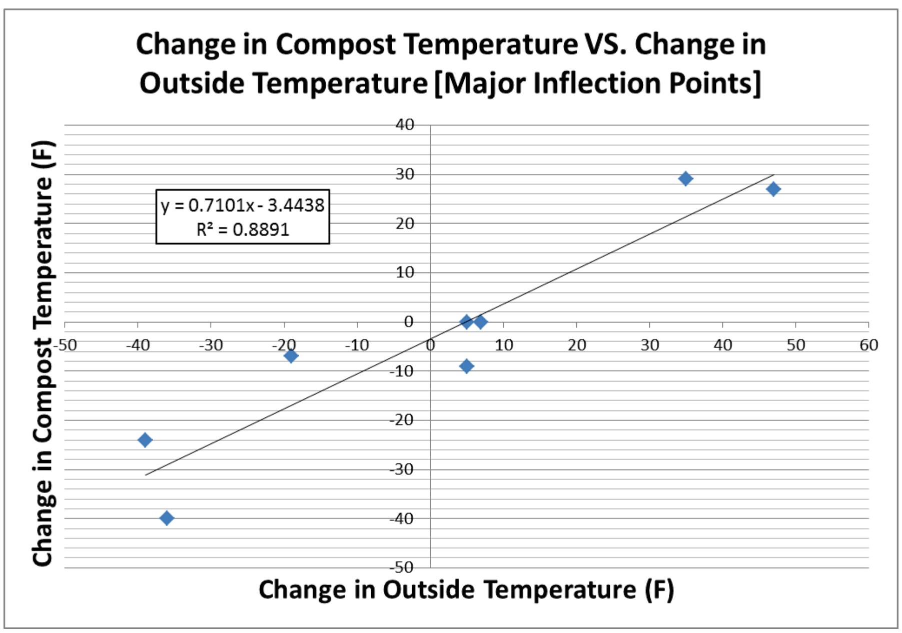


Figure 109: Graph of linear regression of change in compost temperature VS. change in outside temperature using major inflection points.

6.2: Eighteen Inches Down and Twelve Inches Down On Side of Compost

The available data for Zones 2 and 3 of the compost were only recorded from 11/28/13 – 3/19/14, offering thirty three data points for analysis. These zones are shown in Figure 110 and are hoped to represent a moderate active zone (eighteen inches down) and the least active zone (twelve inches down on side) in the composting vault.

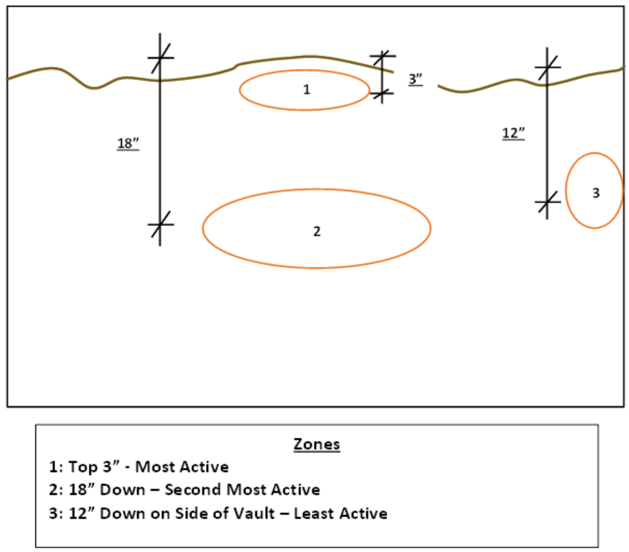


Figure 110: Zones of temperature readings in latrine vault.

The graph in Figure 111 below shows the complete data set for these two zones. Much like the temperature readings in the top three inches of the compost, there are many drops and rises in temperature. These were analyzed in the same way as the top three inches of the compost to look for correlations.

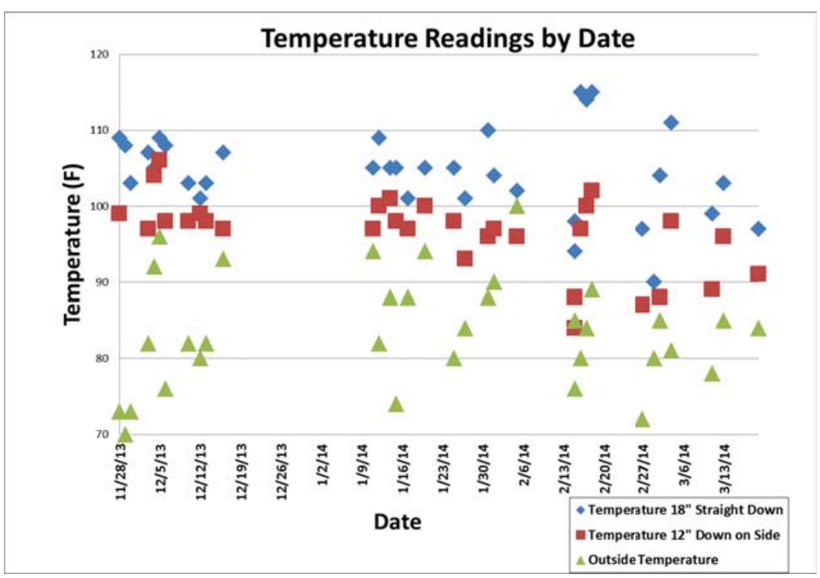


Figure 111: Graph of complete data set for Zones 1 and 2 temperature readings with outside temperature readings as well.

6.2a: Analysis of Direct Correlation between the Change in Outside Temperature and Compost Temperature

The change in outside temperatures and those of the compost for both zones were plotted resulting in R^2-values of 0.06 and 0.29, showing no linear correlation between these two variables. See the graphs below in Figures 112-113.

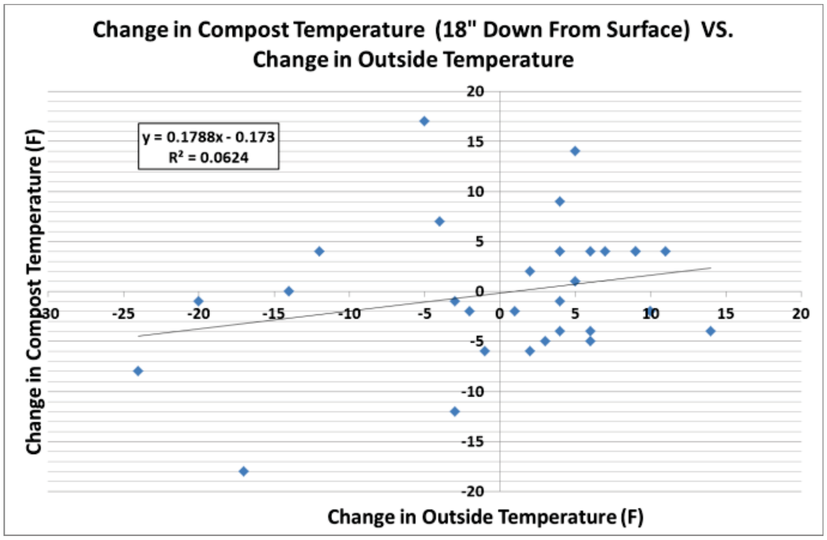


Figure 112: Graph of linear regression of change in compost temperature eighteen inches down from surface VS. change in outside temperature.

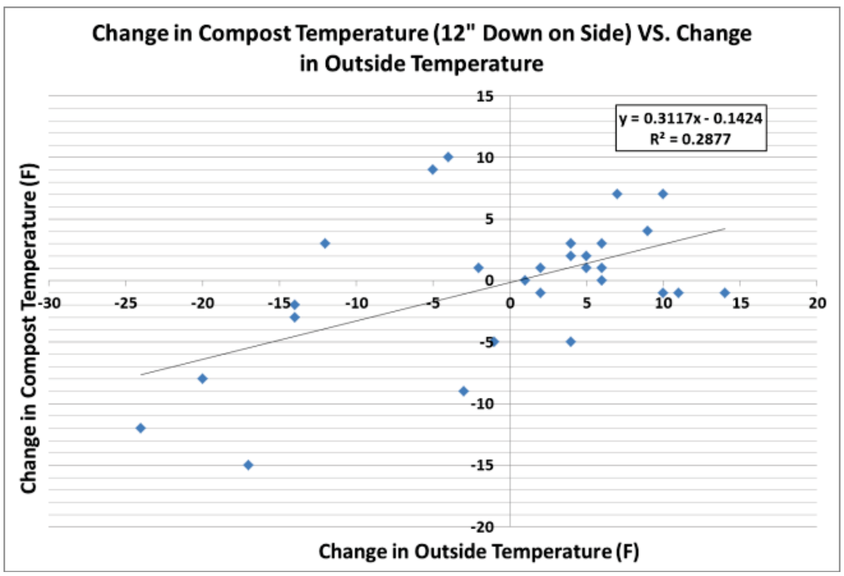


Figure 113: Graph of linear regression of change in compost temperature twelve inches down on side VS. change in outside temperature.

6.2b: Analysis of Lag Time

A lag time of two days was also used to analyze a delayed correlation between the change in outside temperatures and those of the compost in Zones 2 and 3. The resulting linear regressions are shown in the graphs in Figures 114-115 below.

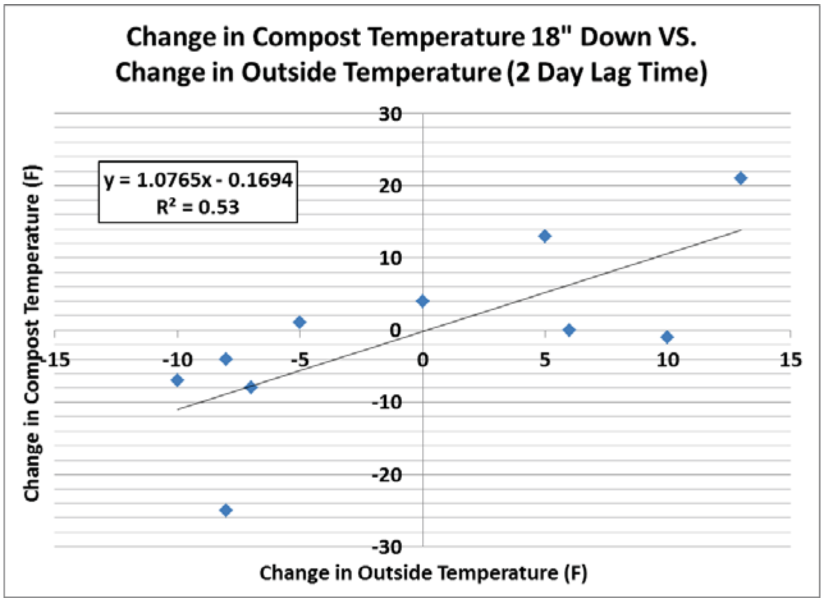


Figure 114: Graph of linear regression of change in compost temperature eighteen inches down from surface VS. change in outside temperature with 2 day lag time.

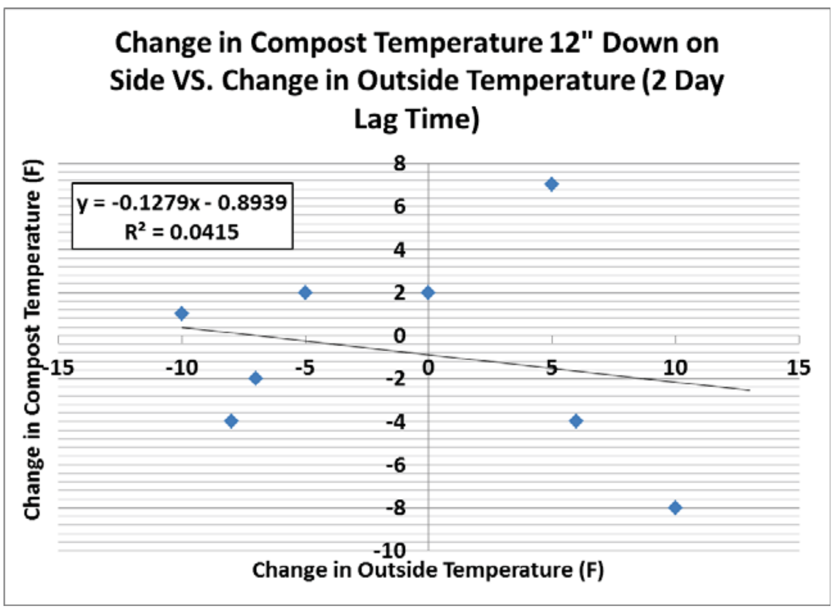


Figure 115: Graph of linear regression of change in compost temperature twelve inches down on side VS. change in outside temperature with 2 day lag time.

The R^2-values again were very low, 0.53 and 0.042, showing no linear correlation between these two variables with a lag time of two days.

6.2c: Analysis of Major Inflection Points

The major inflection points chosen for the outside temperatures during 11/28/13 – 3/19/14 are shown on the graph in Figure 116 below. These points were chosen to represent major changes in the overall trends of the outside temperature.

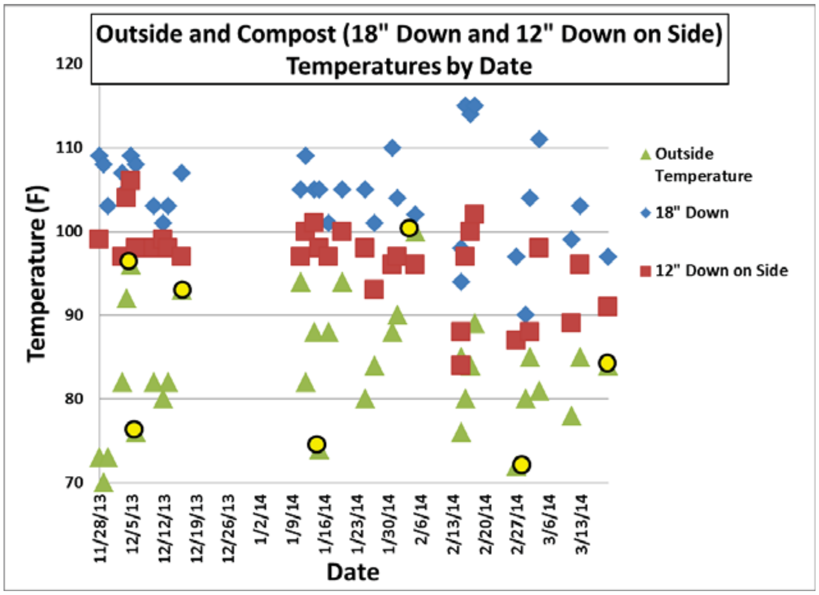


Figure 116: Graph of major inflection points (yellow dots) of temperature readings of Zones 2 and 3 of compost.

The corresponding temperatures for Zones 2 and 3 were then used to determine if there was any correlation between these two variables. The points chosen are shown below in Table 8, along with the corresponding graphs in Figures 117-118 showing the linear regressions.

Table 8: Temperatures corresponding to major inflection points in zones 2 and 3 of compost.

Major Inflection Points						
Date	Temperature (F) 18" Down	Change in Temp. 18" Down	Temperature (F) 12" Down on Side	Change in Temp. 12" down on side	Outside Temperature (F)	Change in Outside Temp.
12/5/13	109		106		96	
12/6/13	108	-1	98	-8	76	-20
12/16/13	107	-1	97	-1	93	17
1/15/14	105	-3	98	0	74	-2
2/5/14	102	-3	96	-2	100	26
2/27/14	97	-5	87	-9	72	-28
3/19/14	97	0	91	4	84	12

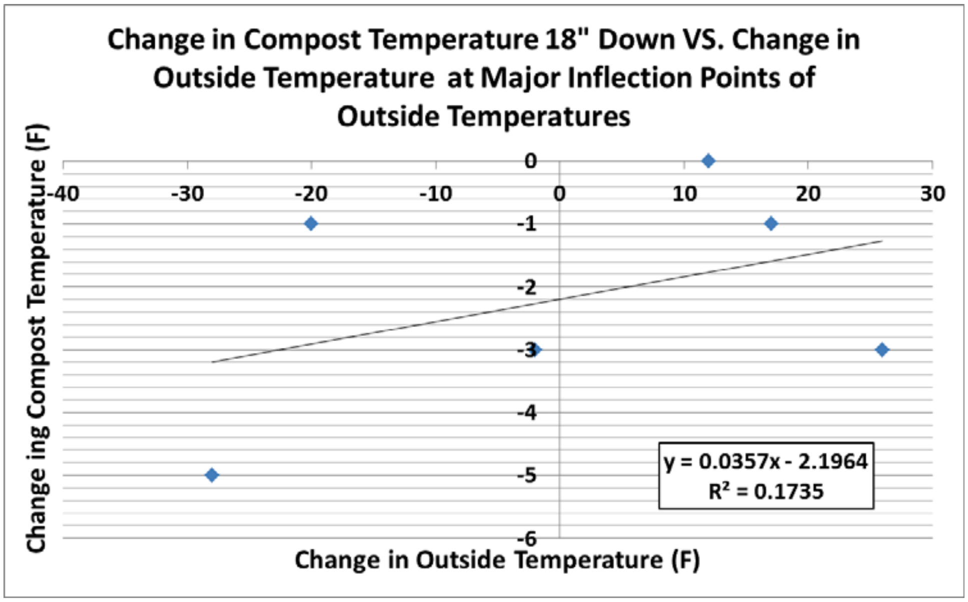


Figure 117: Graph of linear regression of change in compost temperature eighteen inches down VS. change in outside temperature of major inflection points.

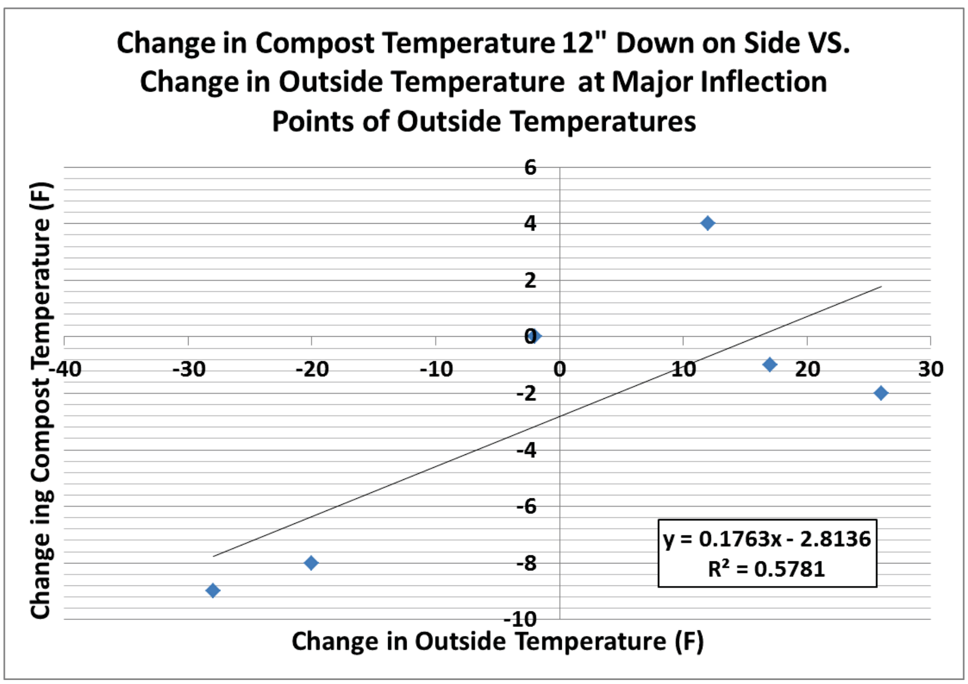


Figure 118: Graph of linear regression of change in compost temperature twelve inches down on side VS. change in outside temperature of major inflection points.

As seen from the graphs in Figures 117-118 above, R^2-values of only 0.17 and 0.58 were found in these linear regressions, showing no linear correlation between the major trend changes in the outside temperature and those of the compost.

6.3: Mean Seasonal Temperatures; Outside and in the Top Three Inches of the Compost

The graph shown below in Figure 119 shows the mean outside and compost temperatures recorded over ten months in Paraguay. It appears there is a seasonal correlation between the outside temperature and the compost temperature. Both data sets drop during the winter months and rise during the warmer summer months. The percent change in the temperatures for both data sets are shown in Tables 9-10 below.

The outside temperature data points for Fall 2013 and Fall 2014 are very different because each was taken at the opposite end of the season. In 2013 the temperatures were taken closer to winter weather and in 2014 closer to summer, resulting in a much higher mean outside temperature in 2014 than in 2013.

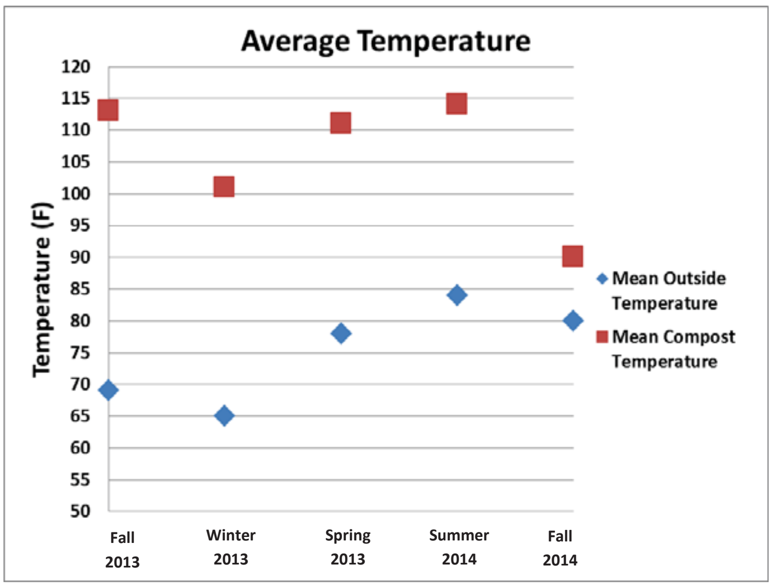


Figure 119: Mean outside and compost temperatures for each season.

The mean compost temperatures for Fall 2013 and 2014 are also very different. It appears the compost was much more active during Fall 2013 than in Fall 2014, with a mean temperature twenty-three degrees higher. This might be explained by noting that in the Fall 2013 season there was more fresh organic material available to the compost, which could result in higher temperatures. By Fall 2014 the compost in the vault was maturing and much less active, resulting in lower temperatures. However, there is no complete set of data for an entire Fall season, therefore no assumptions or conclusions should confidently be made with the present data.

Table 9: Mean temperatures and standard deviations of outside temperatures during seasons of 2013-2014.

Outside Temperatures					
Dates	**Season**	**Mean**	**StDev**	**Change in temp**	**% change**
6/6-6/21/13	Fall 2013	69	8		
6/22-9/1/13	Winter 2013	65	11	-4	-6%
9/22-12/16/13	Spring 2013	78	12	13	20%
1/11-3/19/14	Summer 2014	84	7	6	8%
3/21-3/25/14	Fall 2014	80	3	-4	-5%

Table 10: Mean temperatures and standard deviations of compost temperatures (top 3") during seasons of 2013-2014.

Compost Temperatures (Top 3")					
Dates	**Season**	**Mean**	**StDev**	**Change in temp**	**% change**
6/6-6/21/13	Fall 2013	113	8		
6/22-9/1/13	Winter 2013	101	16	-12	-11%
9/22-12/16/13	Spring 2013	111	11	10	10%
1/11-3/19/14	Summer 2014	114	10	3	3%
3/21-3/25/14	Fall 2014	90	5	-24	-21%

Chapter 7: Results-Effects of Rain on Compost Temperature-Author's Latrine

While using and monitoring the temperature changes of the compost, the author felt that rain may have an effect on the compost temperature. To analyze this assumption all rain events were plotted on the temperature graph of the compost to see if a correlation could be found (Figure 120).

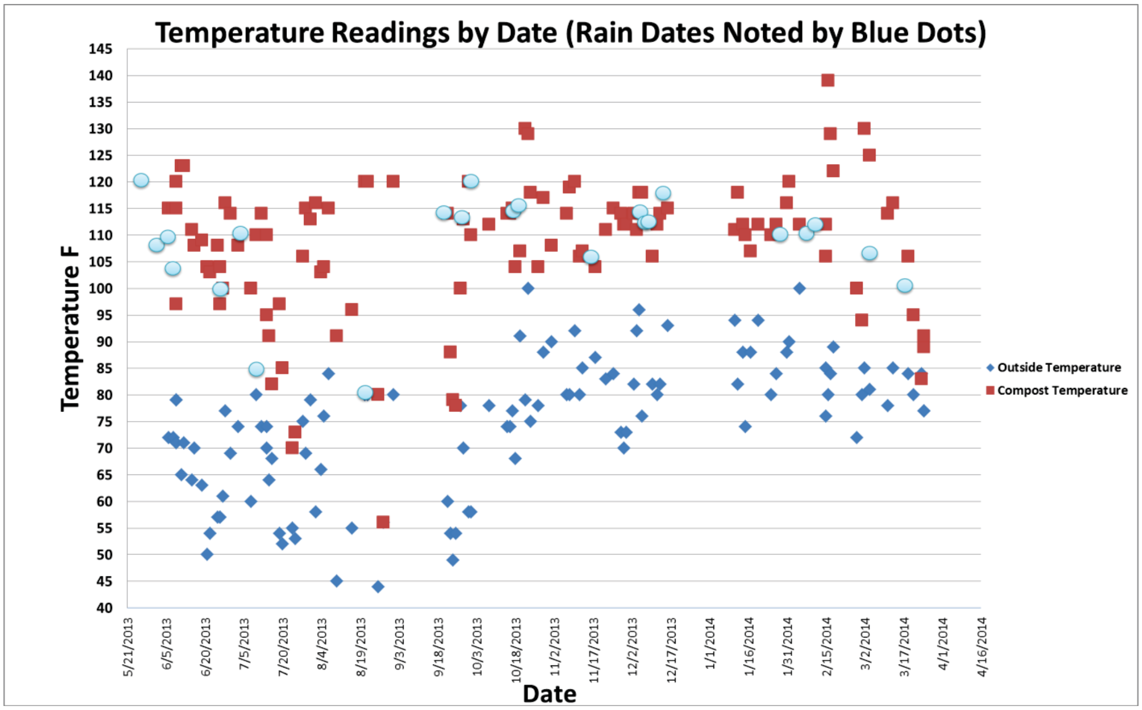


Figure 120: Graph of rain dates noted by blue dots.

7.1: Top Three Inches of Compost

The temperature changes after each rain event were noted, with either an increase of temperature or decrease of temperature, to see if a correlation could be found. The number of increases and decreases (Table 11) were nearly equal, nine and eleven respectively, showing no trend of the effects of rain on the compost temperature.

Table 11: Total number of temperature increases and decreases in top 3" of compost after rain events.

Increase in Temperature After Rain Event	Decrease in Temperature After Rain Event
9	11

7.2: Eighteen Inches Down in Compost

As seen in the graph below in Figure 121, there are double the regions (six) of temperature drops after a rain event than temperature increases (three) (Table 12). With such little data however it cannot be determined if there is a significant correlation between these two variables.

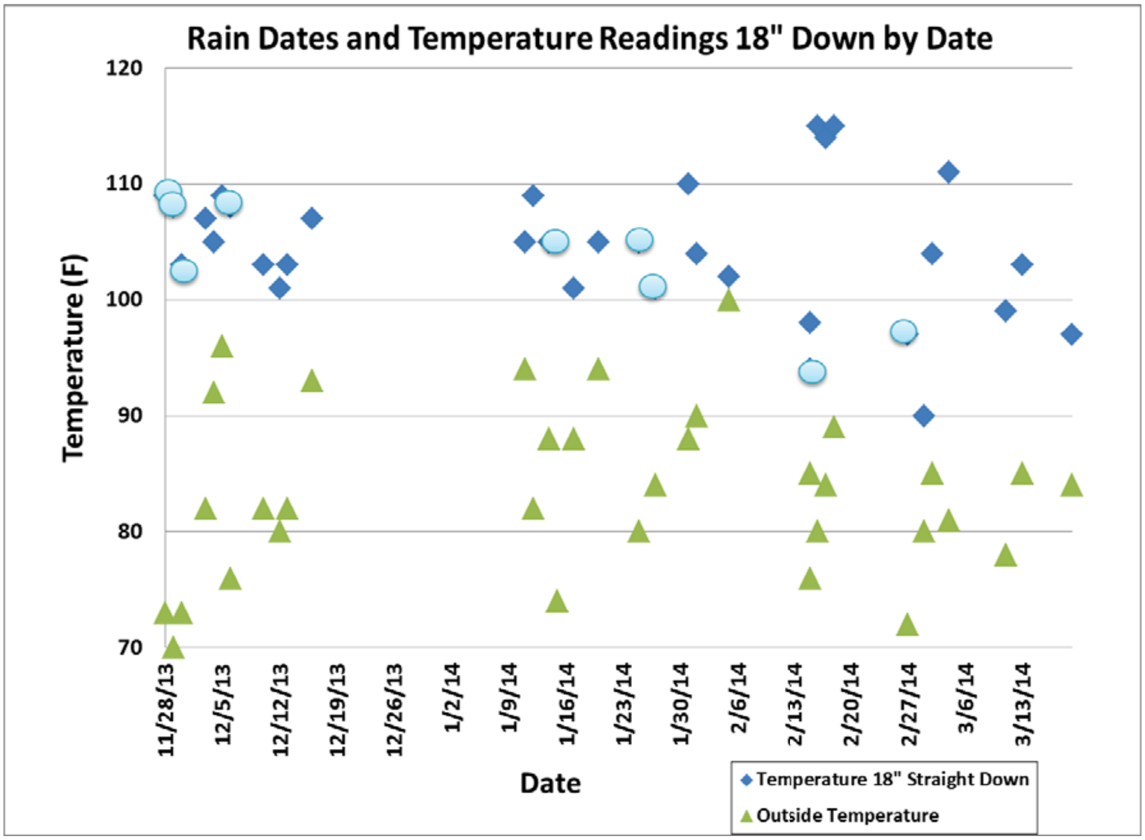


Figure 121: Graph of rain dates and compost temperatures eighteen inches down.

Table 12: Total number of temperature increases and decreases eighteen inches down in compost after rain

Increase in Temperature After Rain Event	Decrease in Temperature After Rain Event
6	3

7.3: Twelve Inches Down on Side of Compost

There was only four rain events that could be analyzed in this region of the compost resulting in equal temperature increases and decreases after rain events (two and two). This is very limited data and no correlations can be made. Refer to Figure 122 and Table 13 below.

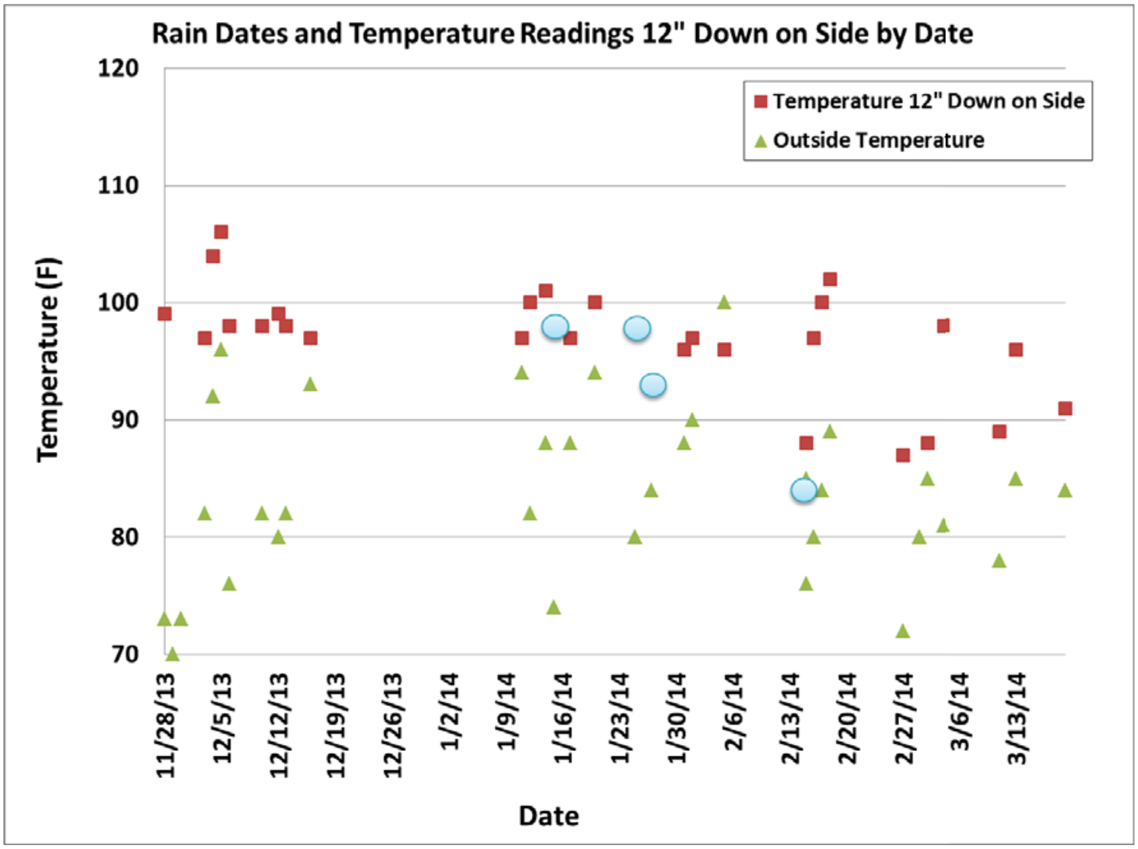


Figure 122: Graph of rain dates and compost temperatures twelve inches down on side of vault.

Table 13: Total number of temperature increases and decreases twelve inches down on side of vault in compost after rain events.

Increase in Temperature After Rain Event	Decrease in Temperature After Rain Event
2	2

Chapter 8: The Effects of Mixing and Adding Moisture on the Compost Temperature-Author's Latrine

According to Rodale in *The Complete Book of Composting*, it is essential to mix compost to speed up the process of decomposition (Rodale 1975). The author routinely mixed the compost in his latrine during its use in Paraguay. The temperatures before and after each mixing event were recorded to attempt to show the effects it had on the temperatures of the compost.

Through conversation with an in-country agricultural expert, it was presented to the author that mixing should occur when the temperature of the compost began to drop to near ambient temperatures, to "reactivate" the compost and raise temperatures again (Gonzalez 2014). The graphs presented below in Figures 124-134 show the temperature readings in the top three inches of compost before and after each mixing event. The origin (time=0) was the time of mixing in each of these graphs. All eleven different mixing events are shown together in Figure 123.

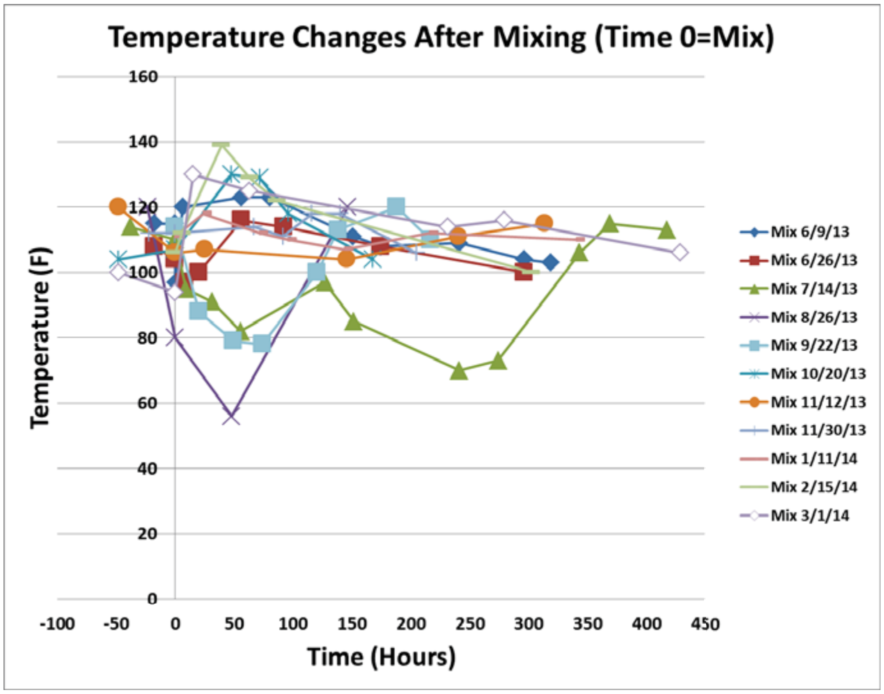


*Figure 123: Graph of temperature changes in top 3" of compost after 11 mixing events. *Note: the connecting lines are only used to help clarify the graph, not to represent continuous data**

It should be noted that each time the compost was mixed moisture was also added. Either water alone or a mixture of water and urine was added.

8.1: Method of Mixing and Adding Moisture to the Compost

The author used a very simple method of mixing and moisture addition involving a long robust stick and watering can. The author used the long stick to stir the compost in the vault, while periodically adding water, or a water and urine mixture, to the compost with his watering can to evenly moisten the compost. The goal of the mixing was to bring the compost material from the outside to the inside of the pile, and vice versa, to obtain a homogeneous mixture of cover material, fecal matter, and fully decomposed material.

This method is both simple and cheap, making it possible in any region in the world where composting latrines are used. If water is not available, pure urine can be used to moisten the compost.

8.2: Effect of Outside Temperature Changes on Compost Temperatures in Top Three Inches During Mixing Events

The eleven graphs below in Figures 124-134 show the compost and outside temperatures during each mixing event. A linear regression was run for each of the graphs to determine if there was a linear correlation between the outside temperature changes and those of the compost. No strong linear correlations were found, with the highest R^2-value reaching 0.57, showing that the immediate temperature changes of the compost were independent of those of the outside temperatures.

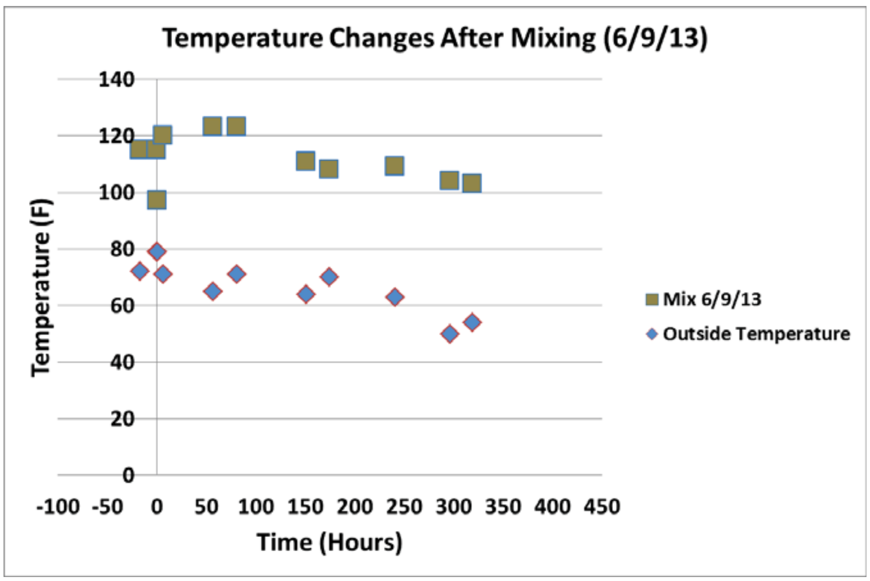


Figure 124: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 6/9/13.

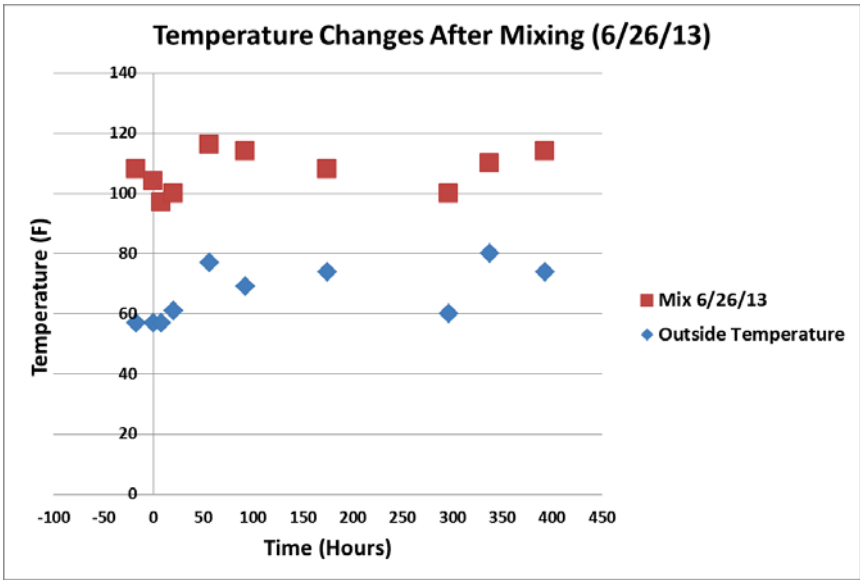


Figure 125: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 6/26/13.

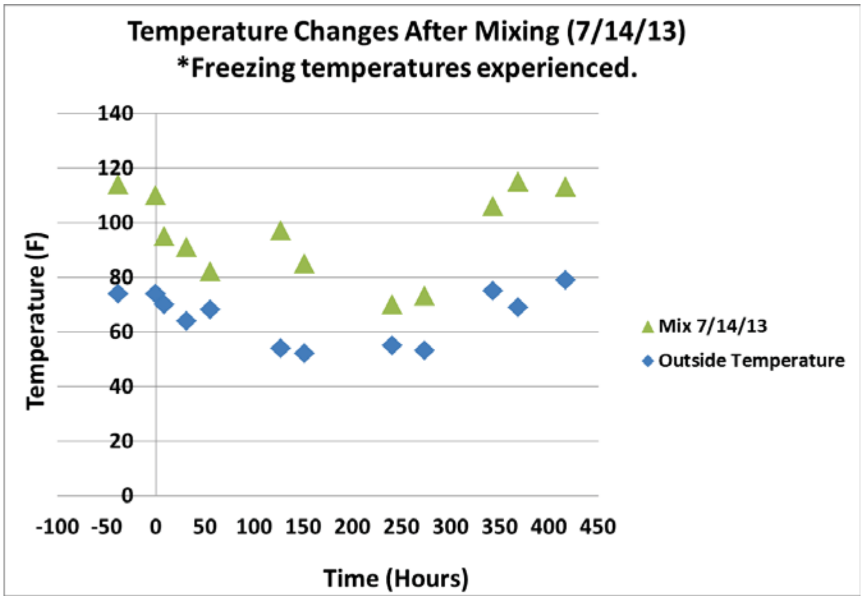


Figure 126: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 7/14/13.

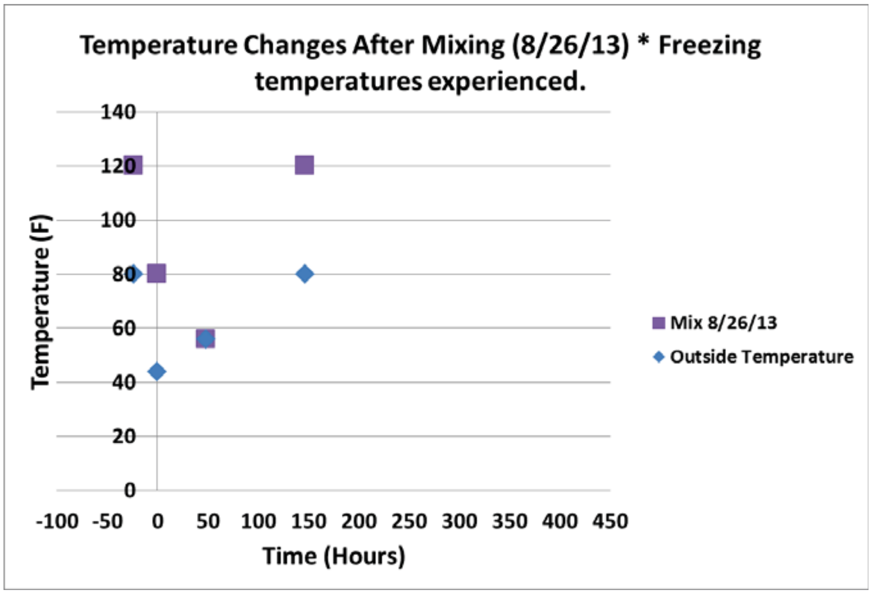


Figure 127: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 8/26/13.

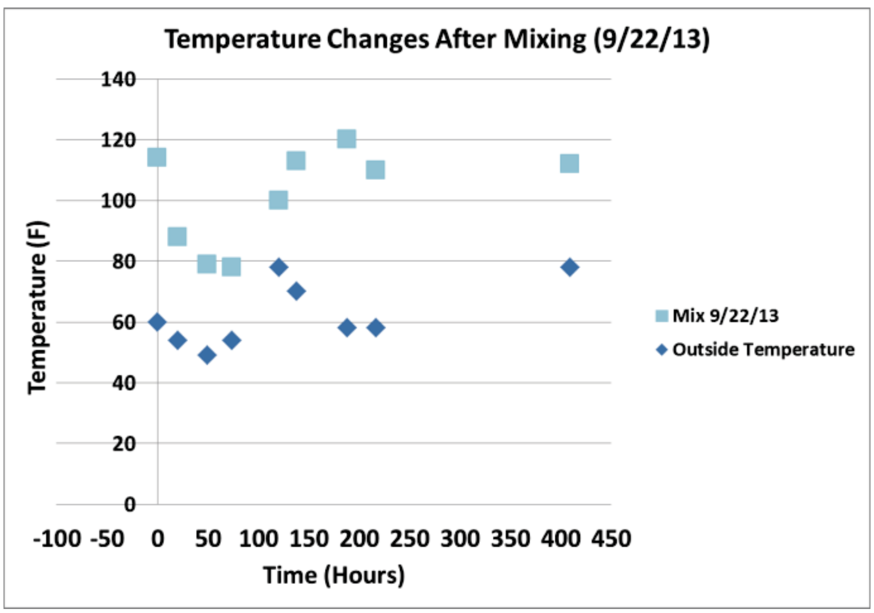


Figure 128: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 9/22/13.

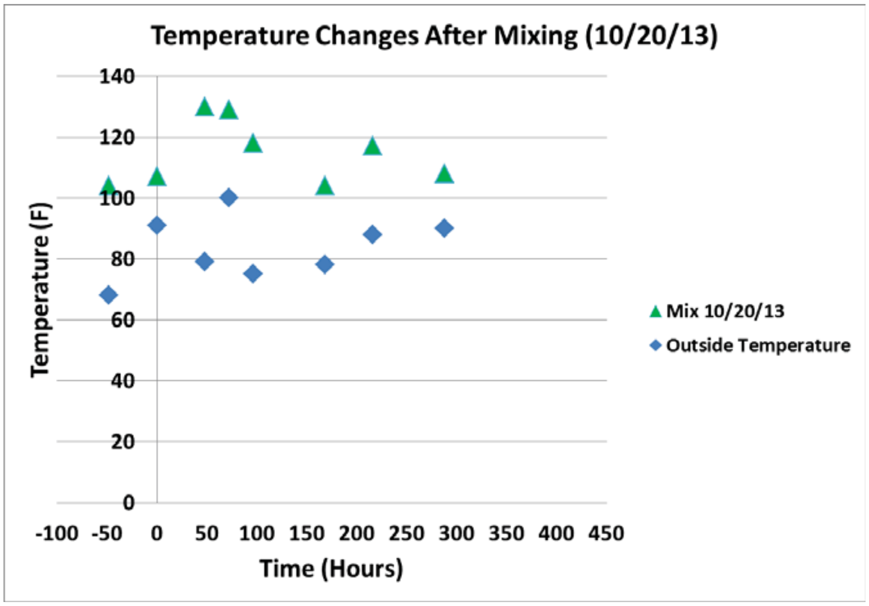


Figure 129: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 10/20/13.

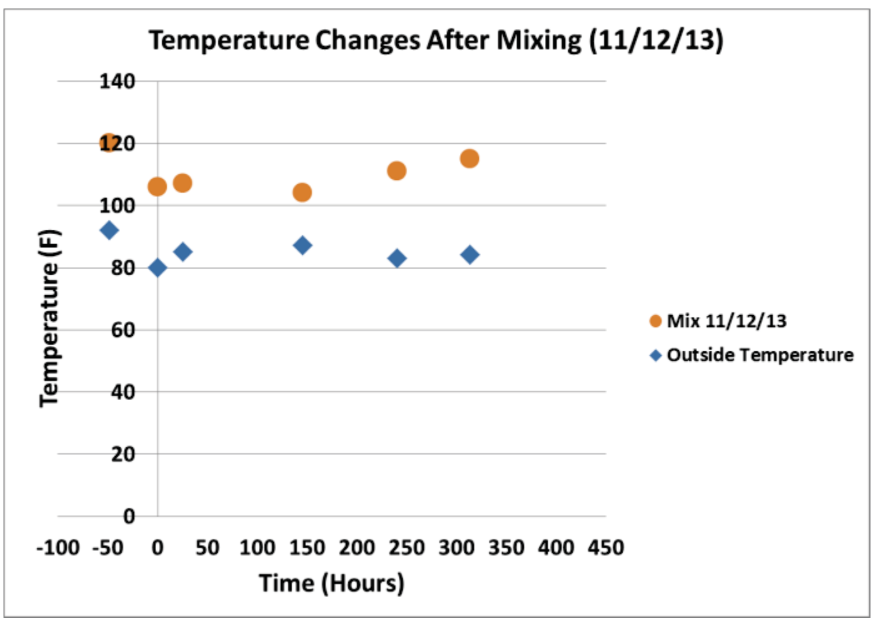


Figure 130: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 11/12/13.

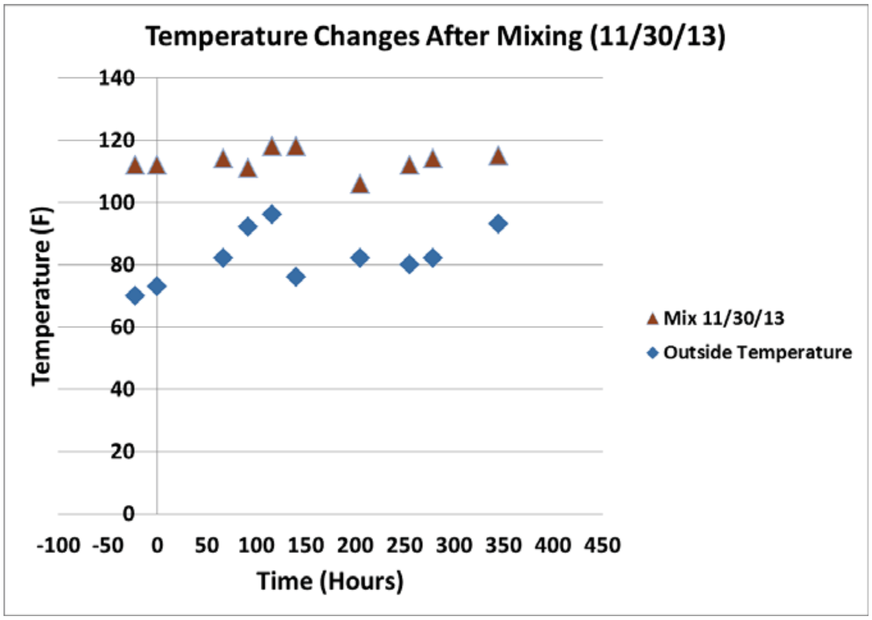


Figure 131: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 11/30/13.

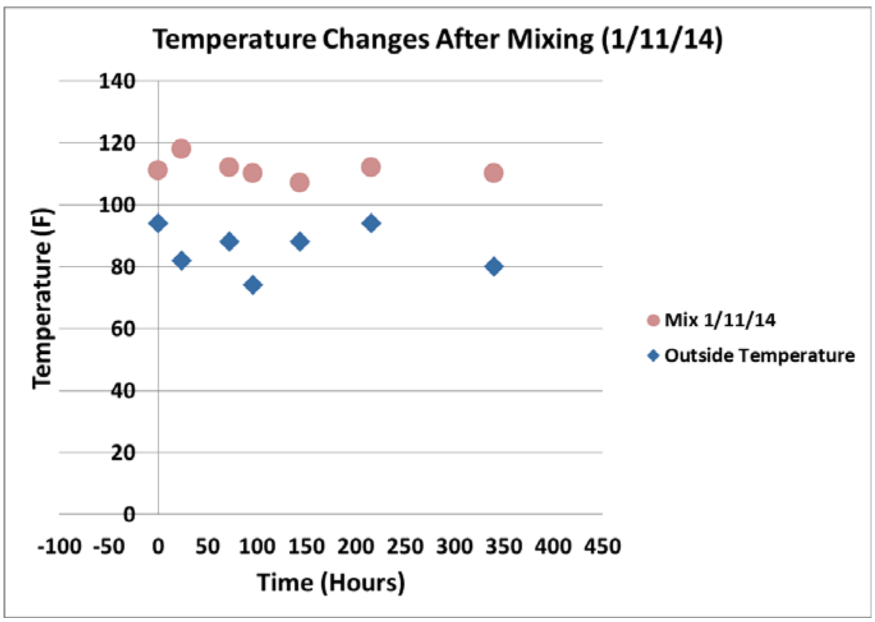


Figure 132: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 1/11/14.

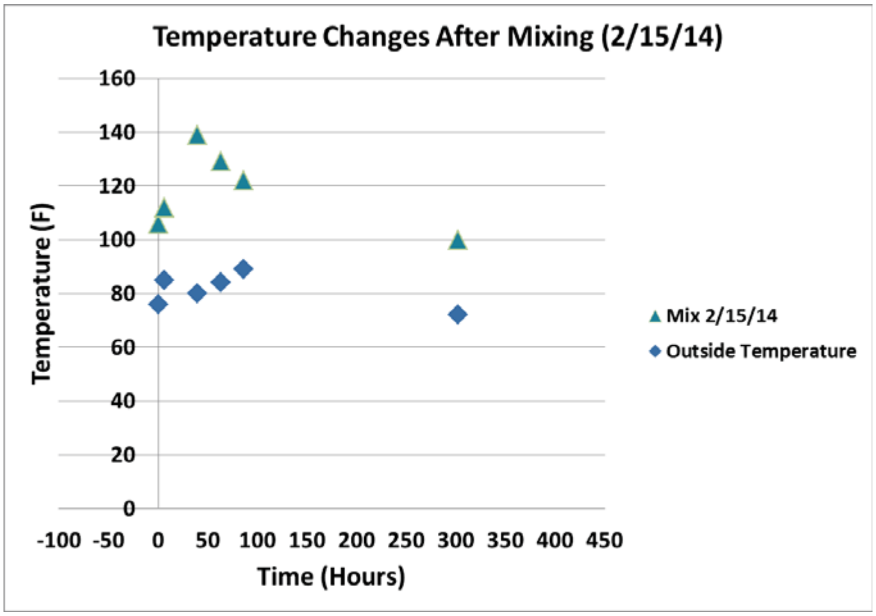


Figure 133: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 2/15/14.

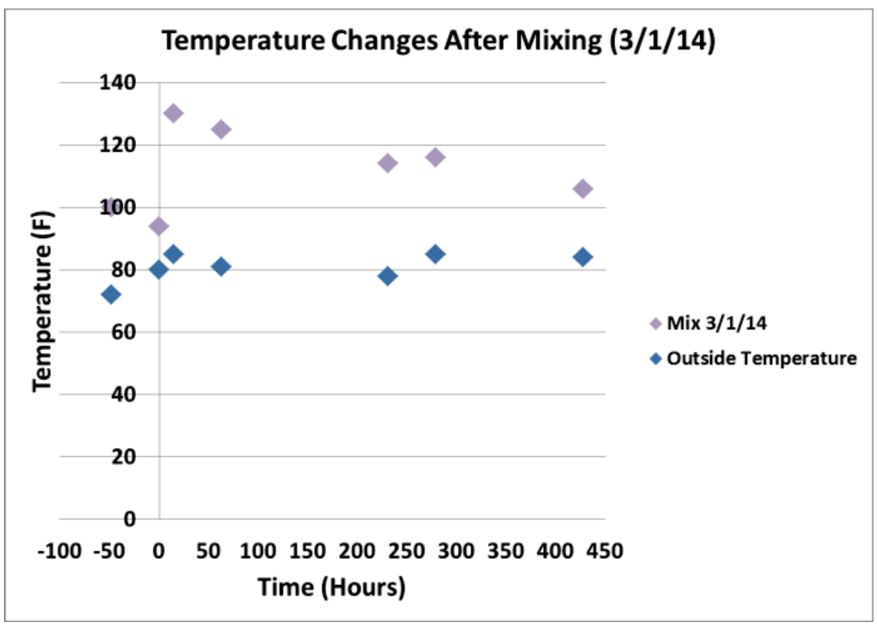


Figure 134: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 3/1/14.

8.3: Temperature Changes in Top Three Inches of Compost after Mixing

Several trends and similarities are present in the graphs in Figures 124-134 above. These trends and observations are discussed below.

8.3a: Initial Temperature Drop Followed by Rapid Temperature Increase

The first two mixing events (6/9 and 6/26 in Figures 124-125) show a sudden temperature drop followed by rapid temperature recovery and increase. Due to the fact that each of the graphs above show an overall increase in compost temperatures, it is believed that only these two graphs show a short temperature drop followed by rapid temperature increase because of the detailed readings taken. During both of these mixing events three temperature readings were taken within the first twenty four hours. During the other mixing events the temperature readings were far less frequent at the beginning, not allowing for a detailed graph of the initial reaction to the mixing event.

Through personal experience/observations, the author agrees with Jenkin's that mixing can "dilute the thermophilic layer with the spent layers and can abruptly stop all thermophilic activity" (Jenkins 2005). When the top layer was mixed, a lot of heat could be felt leaving the top of the pile. This is believed to be the reason for the sudden decrease in temperature seen in the mixing events of 6/9/13 and 6/26/13 (Figures 124-125). This may also explain why the three mixing events from 7/14/13-9/22/13 (Figures 126-128) took longer to recover temperatures than the other mixing events, since these mixing event occurred during the coldest part of the year. If the compost was mixed during cold weather and a significant amount of heat was released when the mixing occurred, it is logical that it would take longer for the temperature to increase compared to warmer times of the year, as biological activity slows as temperatures decrease (Rodale 1975).

8.3b: Temperature Increases in Top Three Inches of Compost

Eight-out-of-the-eleven mixing events showed an increase of compost temperatures within the first fifty hours after mixing occurred, and all eleven showing an eventual increase of temperature compared to the compost temperature at the time of mixing (t=0). This observation strengthens the explanation of the agricultural specialist in Paraguay who stated that turning the compost will "reactivate" the compost and result in increased temperatures (Gonzalez 2014).

8.3c: Extended Temperature Decreases in Top three inches of Compost

Three of the eleven mixing events showed a continual drop of temperatures after mixing, with an eventual temperature increase occurring at least one hundred hours after the mixing occurred. These three graphs are shown in Figures 135-137.

The first two mixing events, 7/14 and 8/26 (Figures 135-136), experienced freezing temperatures during the period of recorded temperatures, and the mix occurring on 9/22 (Figure 137) experienced temperatures in the high forties, which are seasonal lows for Paraguay. While linear correlations were not found between immediate outside temperature changes and those of the compost (Section 6.1a), in Section 6.1c a decently strong linear correlation was found between the major trends in outside temperatures and those of the compost, with a R^2-value of 0.89 found. The data presented here supports this correlation, since the three mixing event shown took the longest to recover after mixing. As stated by Rodale in *The Complete Book of Composting*, this slower recovery time and temperature increase should be expected because "as the average daily temperature decrease in autumn and winter, the decomposition in the heaps slows down gradually and almost stops altogether during the coldest parts of the winter" (Rodale 1975).

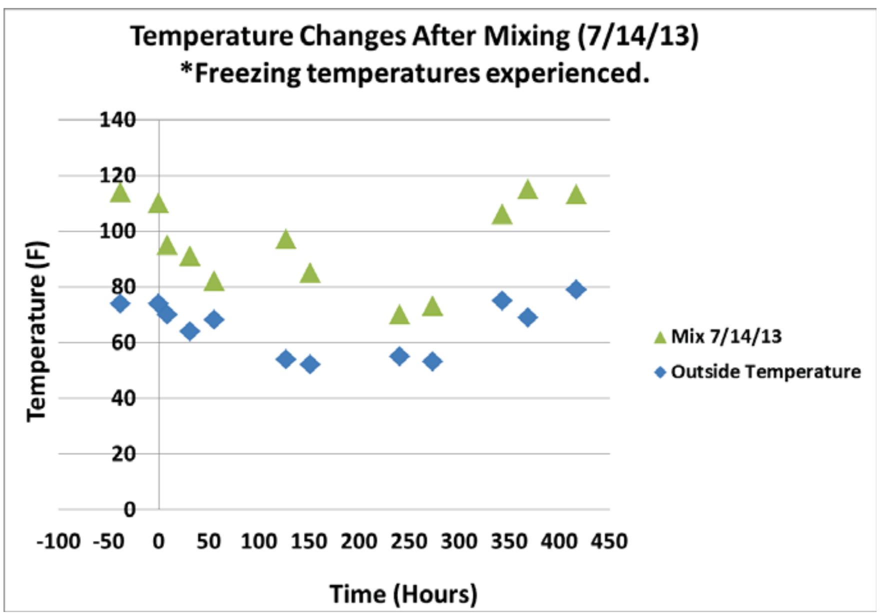


Figure 135: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 7/14/13.

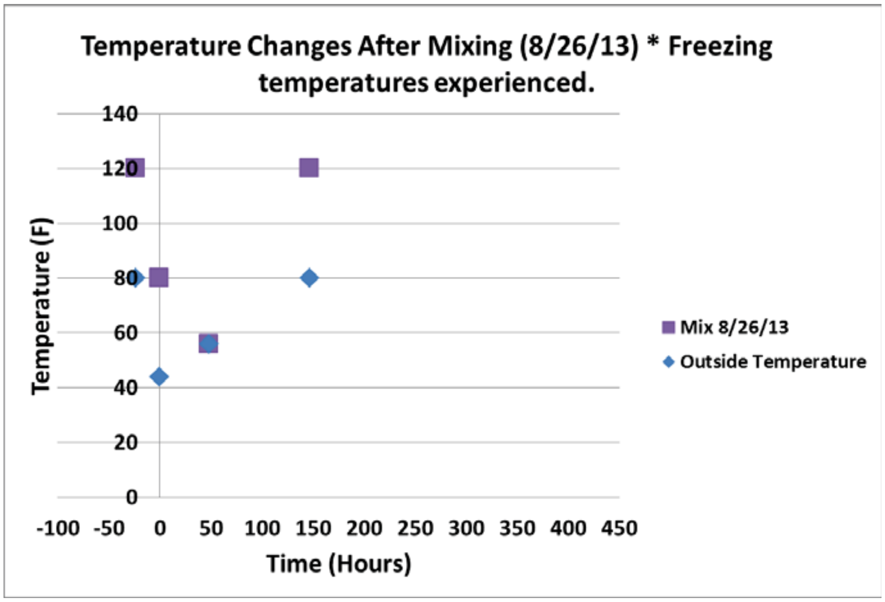


Figure 136: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 8/26/13.

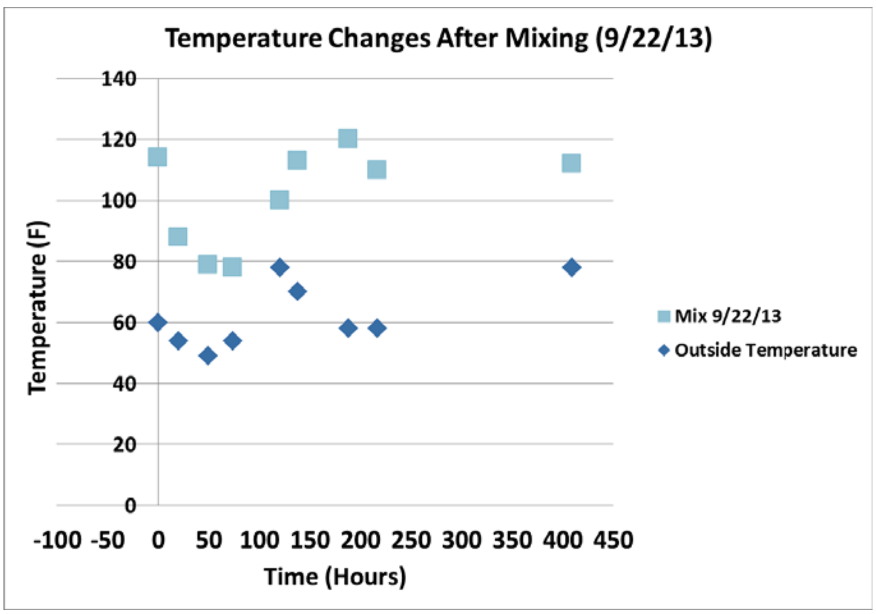


Figure 137: Graph of temperature change in top 3" of compost compared to outside temperature after mixing event on 9/22/13.

8.4: Temperature Changes in Zones 2 and 3 after Mixing

As was shown in the top three inches of the compost, an increase of temperature was also recorded in Zones 2 and 3 of the compost (eighteen inches down from surface and twelve inches down on the side of the compost). This is shown below in Figures 138-143 below.

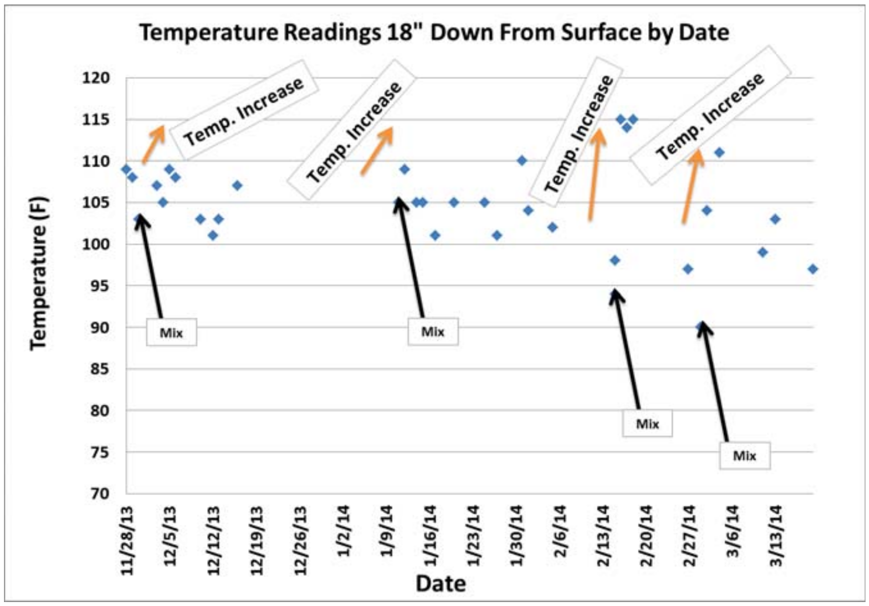


Figure 138: Graph of temperature readings eighteen inches down in compost with mixing dates indicated.

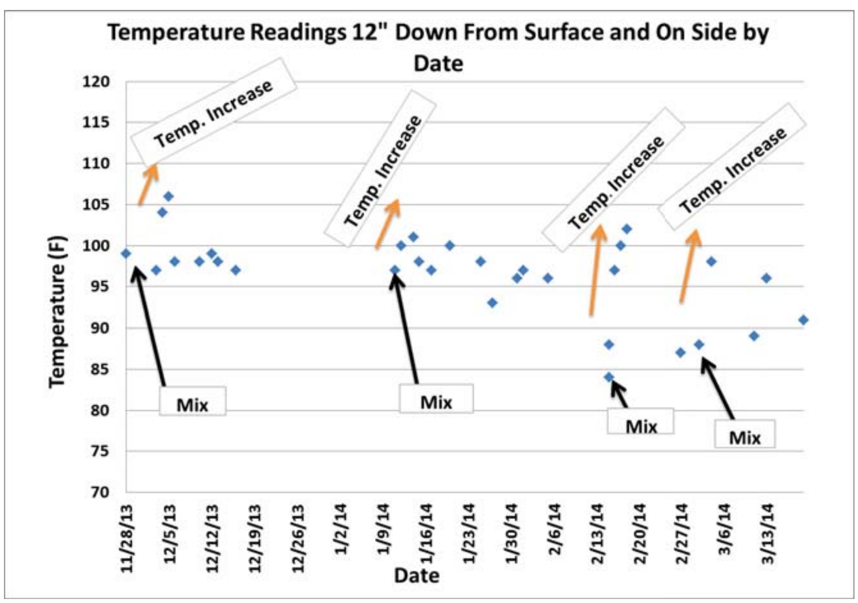


Figure 139: Graph of temperature readings twelve inches down on side of compost with mixing dates indicated.

The graphs shown above in Figures 138 and 139 show an increase in temperatures in both Zones 2 and 3 after each mixing event. These data strengthen the explanation of the agricultural specialist in Paraguay who stated that turning the compost will “reactivate” the compost and result in increased temperatures (Gonzalez 2014).

More detailed graphs are shown here in Figures 140-143 of each mixing event.

<u>11/30/13 Mix:</u>

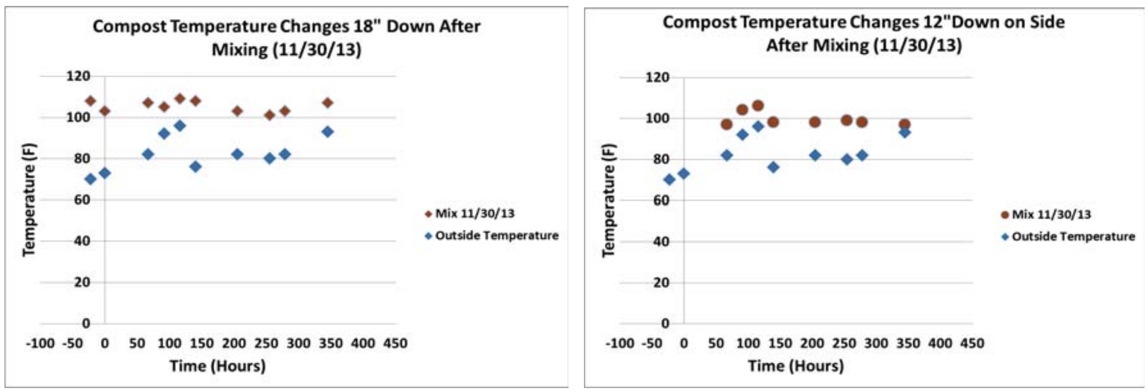


Figure 140: Graphs of temperature change in compost eighteen inches down and twelve inches down on side compared to outside temperature after mixing event on 11/30/13.

<u>1/11/14 Mix:</u>

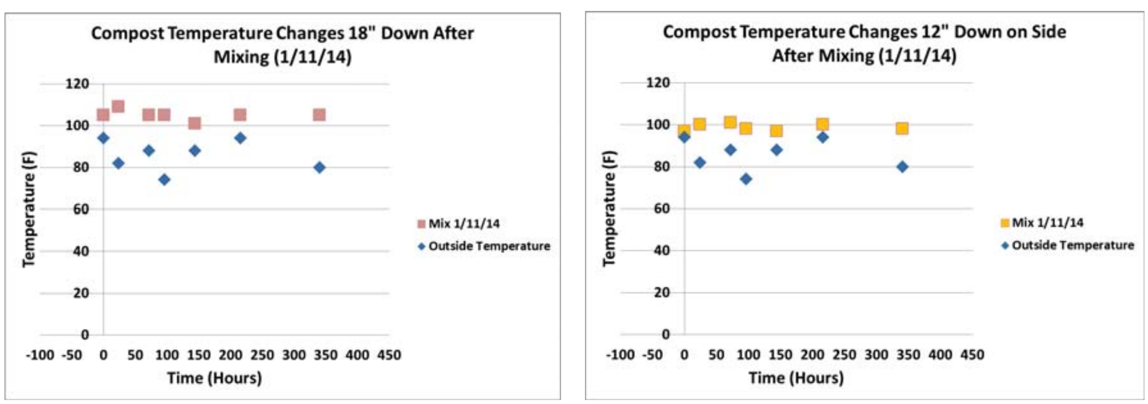


Figure 141: Graphs of temperature change in compost eighteen inches down and twelve inches down on side compared to outside temperature after mixing event on 1/11/14.

2/15/14 Mix:

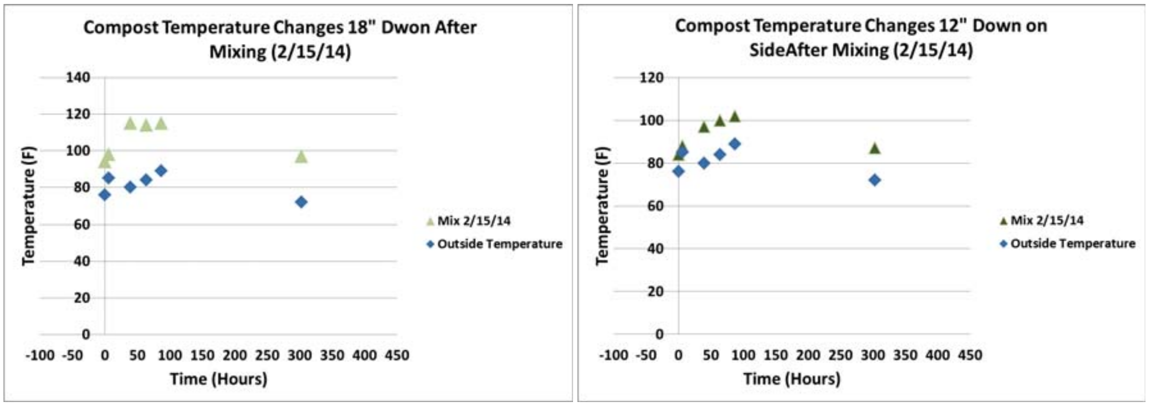


Figure 142: Graphs of temperature change in compost eighteen inches down and twelve inches down on side compared to outside temperature after mixing event on 2/15/14.

3/1/14 Mix:

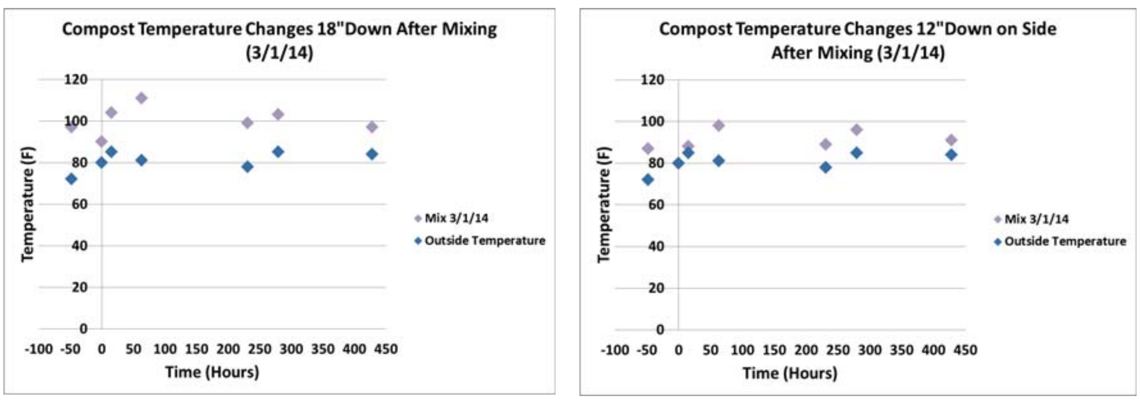


Figure 143: Graphs of temperature change in compost eighteen inches down and twelve inches down on side compared to outside temperature after mixing event on 3/1/14.

8.5: Results of Mixing

The graphs above show that mixing resulted in an increase of compost temperatures in all three zones of the compost. Although some areas and times of mixing took longer to heat up after a mixing event, every graph presents an eventual increase in the compost temperature. Following the results found in Section 6.1c, where a linear correlation was observed between major outside temperature trends and those of the compost, it appears the outside temperature trends can either speed up or slow down the temperature increase after a mixing event. Figures 135-137 show a slower rate of temperature increase after mixing most likely due to the cold outside temperatures experienced during this time. This result also agrees with Rodale in his book *The Complete Book of Composting*, where he states that "as the average daily temperature decreases…..decomposition in the heaps slows down gradually," (Rodale 1975) resulting in slower temperature recovery times after mixing occurs.

Chapter 9: Reaching Total Pathogen Destruction in Compost

To reach an environment to achieve total pathogen destruction, certain temperature thresholds need to be reached and held for specific amounts of time in the compost. The graph below in Figure 144 shows the different combinations of temperatures and times necessary to reach the "Safe Zone of Pathogen Destruction." When the compost reaches these temperatures, and holds them for sufficient amounts of time, we can be confident that sufficient pathogen destruction is occurring in the compost to produce a safe and beneficial product.

It was assumed that the temperatures stayed constant between each data point when analyzing the data. This assumption was made to allow for a duration time to be calculated for each temperature reading.

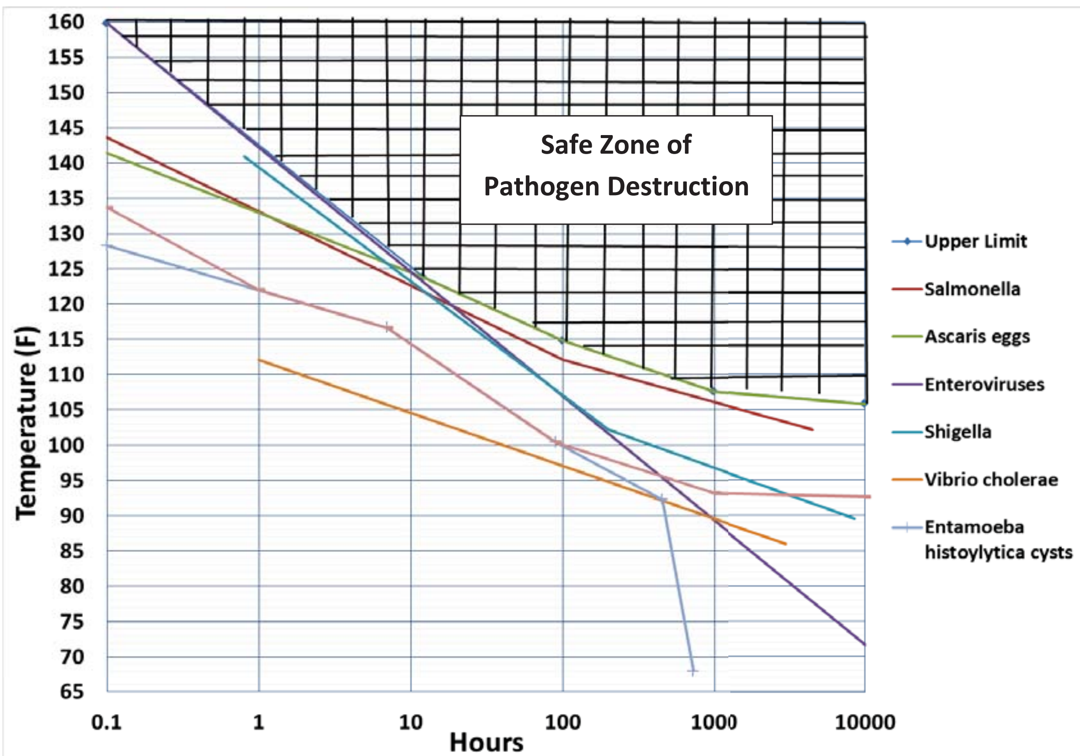


Figure 144: Graph of temperature and time combinations to reach a safe zone of pathogen destruction. Data from (Feachem 1980).

9.1: Pathogen Destruction in Top Three Inches of Compost

As shown in the graph in Figure 144, there are infinite combinations of times and temperatures to reach the Safe Zone of Pathogen Destruction. Below are five temperatures and times that are convenient to measure and comprehend to allow us to judge the effectiveness of the composting latrine in achieving pathogen destruction.

9.1a: One Hour Pathogen Destruction (143.6^{0}F)

A temperature of 143.6^{0}F needs to be reached and held for one hour to achieve sufficient pathogen destruction to produce a safe and beneficial product. As shown in the graph in Figure 145 below, this temperature was never reached during temperature recordings in the author's latrine, showing that more time is needed for pathogen destruction.

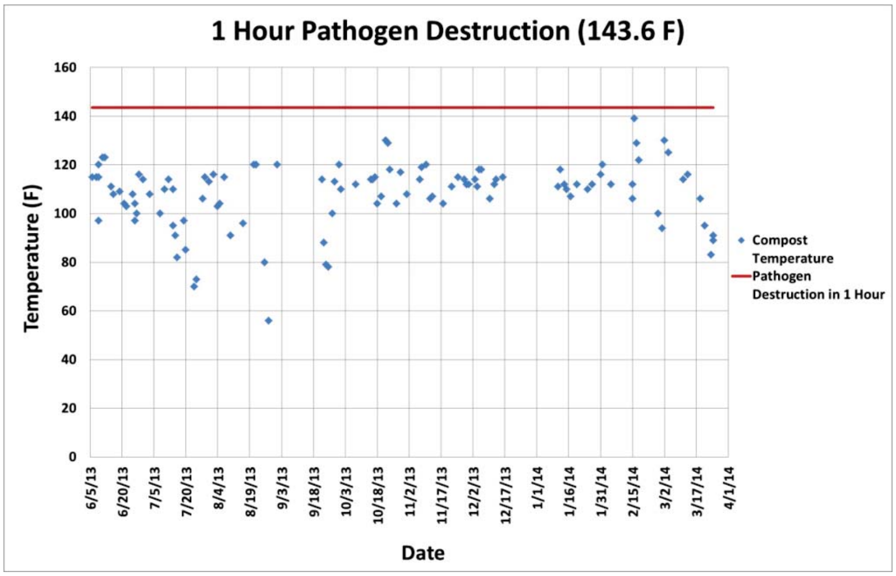


Figure 145: Graph of the 1 hour pathogen destruction temperature compared to compost temperatures in top 3" recorded.

9.1b: One Day Pathogen Destruction (122^{0}F)

A temperature of 122^{0}F needs to be reached and held for one day to achieve sufficient pathogen destruction to produce a safe and beneficial product. As shown in the graph in Figure 146 this temperature was reached and held for at least one day during four separate occasions, resulting in a safe level of pathogen destruction in the top three inches of the compost after these occasions.

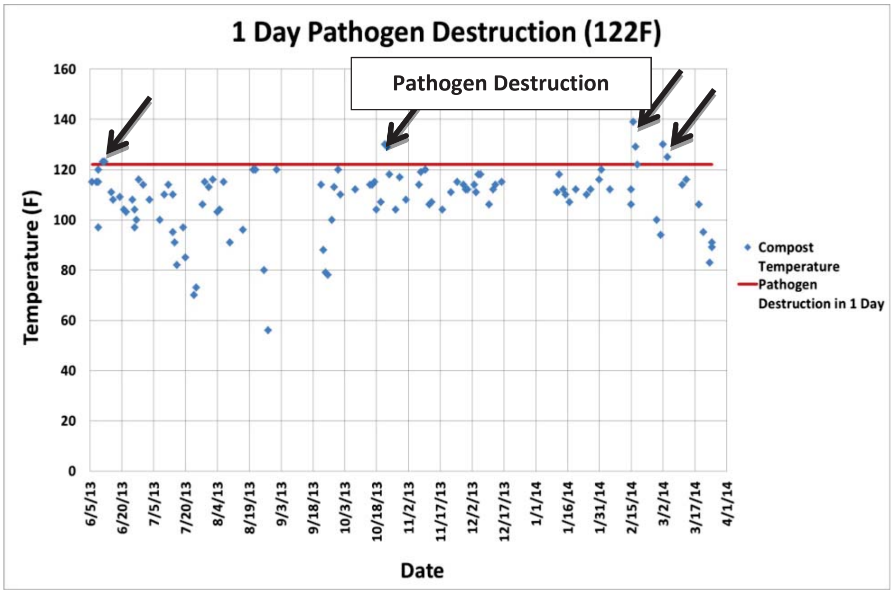


Figure 146: Graph of the 1 day pathogen destruction temperature compared to compost temperatures in top 3" recorded, showing four times when pathogen destruction was achieved.

9.1c: One Week Pathogen Destruction (114.8^{0}F)

A temperature of 114.8^{0}F needs to be reached and held for one week to achieve sufficient pathogen destruction to produce a safe and beneficial product. As shown in the graph below in Figure 147 this temperature was reached and held for at least one week during the dates of 3/2/14-3/13/14, resulting in a safe level of pathogen destruction in the top three inches of the compost. This event occurred during the same period of one-day pathogen destruction during these dates.

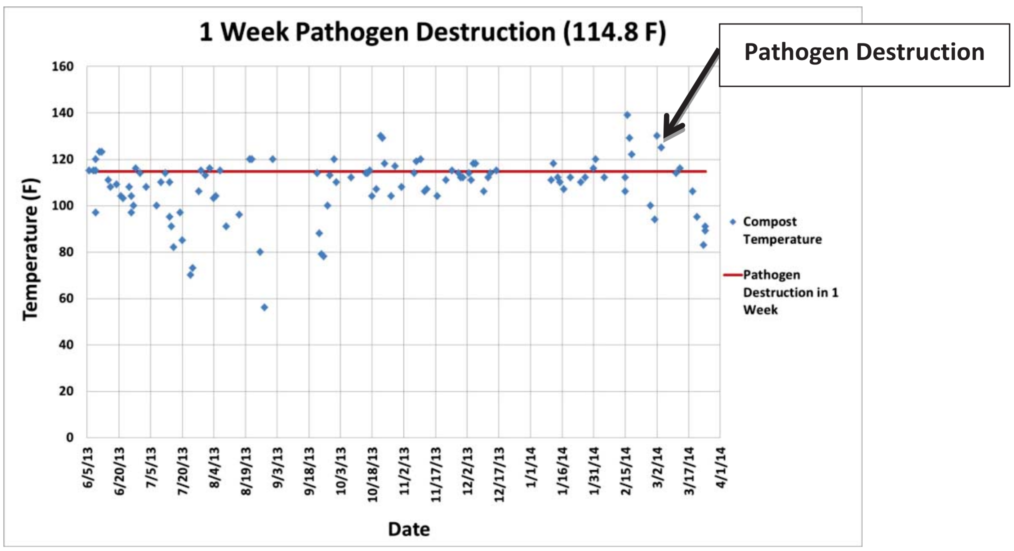


Figure 147: Graph of the 1 week pathogen destruction temperature compared to compost temperatures in top 3" recorded, showing the single time when pathogen destruction was achieved.

9.1d: One Month Pathogen Destruction (109.4^{0}F)

A temperature of 109.4^{0}F needs to be reached and held for one month to achieve sufficient pathogen destruction to produce a safe and beneficial product. As shown in Figure 148 this temperature was reached and passes many times but not held for the sufficient amount of time to ensure a safe level of pathogen destruction.

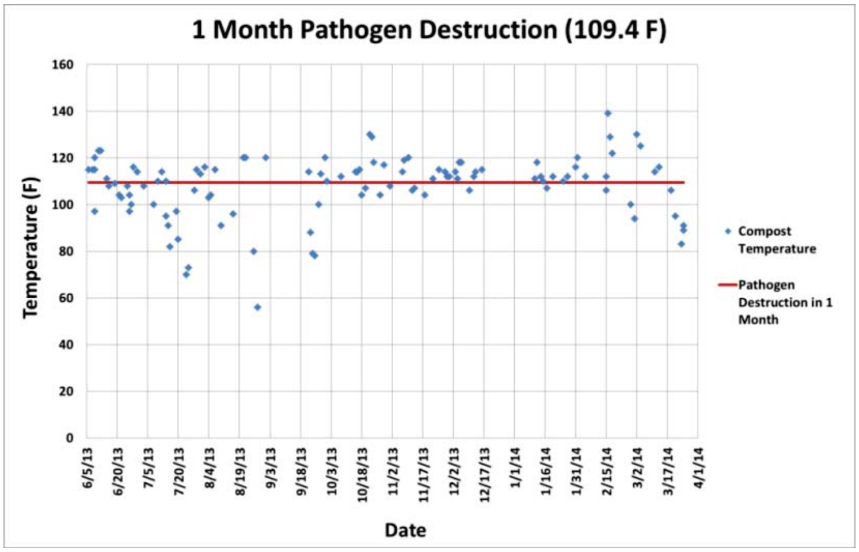


Figure 148: Graph of the 1 month pathogen destruction temperature compared to compost temperatures in top 3" recorded.

9.1e: One Year Pathogen Destruction (105.8^{0}F)

A temperature of 105.8^{0}F needs to be reached and held for one year to achieve sufficient pathogen destruction to produce a safe and beneficial product. As shown in Figure 149 this temperature was reached and passes many times but not held for the sufficient amount of time to ensure a safe level of pathogen destruction.

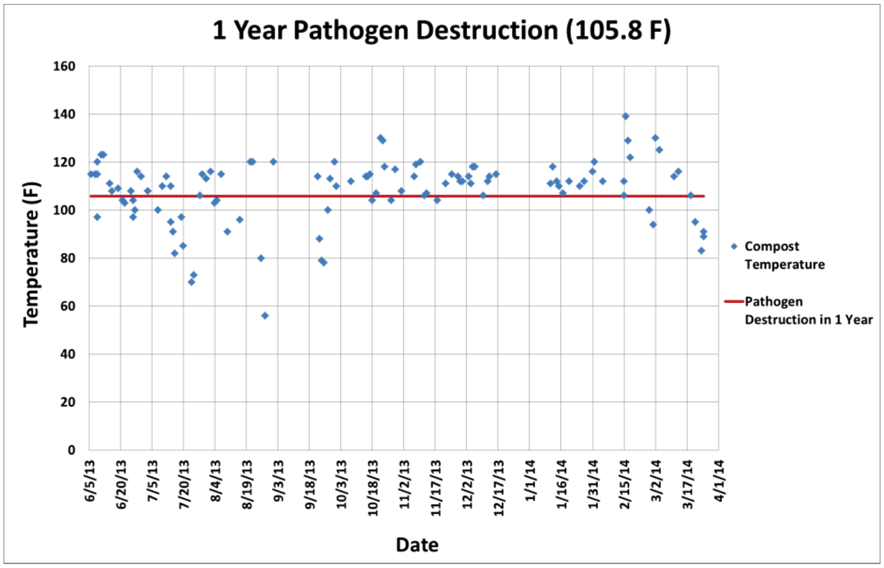


Figure 149: Graph of the 1 year pathogen destruction temperature compared to compost temperatures in top 3" recorded, showing four times when pathogen destruction was achieved.

9.1f: Observations of Pathogen Destruction in Top Three Inches of Compost

From the graphs above (Figures 145-149) it appears that the most probable temperature and time duration to hit in this design of compost latrine in the top three inches of compost is the one day duration time at 122^0F. This point in the Safe Zone of Pathogen Destruction was achieved four times during the recorded temperature readings. The one week duration time of 114.8^0F was achieved once, but with the one day temperature being hit during these dates (3/2/14-3/13/14). It appears that the compost temperature fluctuates too much during an average week to attempt to sustain a temperature of at least 114.8^0F needed for safe pathogen destruction.

9.2: Pathogen Destruction in Zone 2

As shown in the graph in Figure 144 above, there are infinite combinations of times and temperatures to reach the Safe Zone of Pathogen Destruction. Below are two temperatures and times that are convenient to measure and comprehend to judge the effectiveness of the composting latrine in achieving pathogen destruction. These temperatures were chosen because the compost eighteen inches down reached or surpasses these temperatures several times during the duration of temperature recordings.

9.2a: One Month Pathogen Destruction (109.4^0F)

A temperature of 109.4^0F needs to be reached and held for one month to achieve sufficient pathogen destruction to produce a safe and beneficial product. As shown in Figure 150, this temperature was reached and passed several times but not held for the sufficient amount of time to ensure a safe level of pathogen destruction.

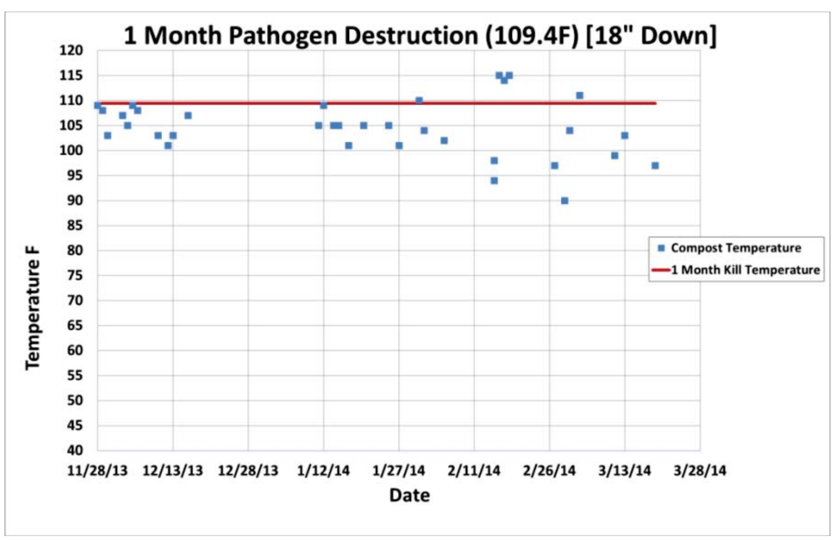


Figure 150: Graph of the 1 month pathogen destruction temperature compared to compost temperatures eighteen inches down.

9.2b: One Year Pathogen Destruction (105.8^{0}F)

A temperature of 105.8^{0}F needs to be reached and held for one year to achieve sufficient pathogen destruction to produce a safe and beneficial product. As shown in Figure 151 this temperature was reached and passed many times but not held for the sufficient time to ensure a safe level of pathogen destruction.

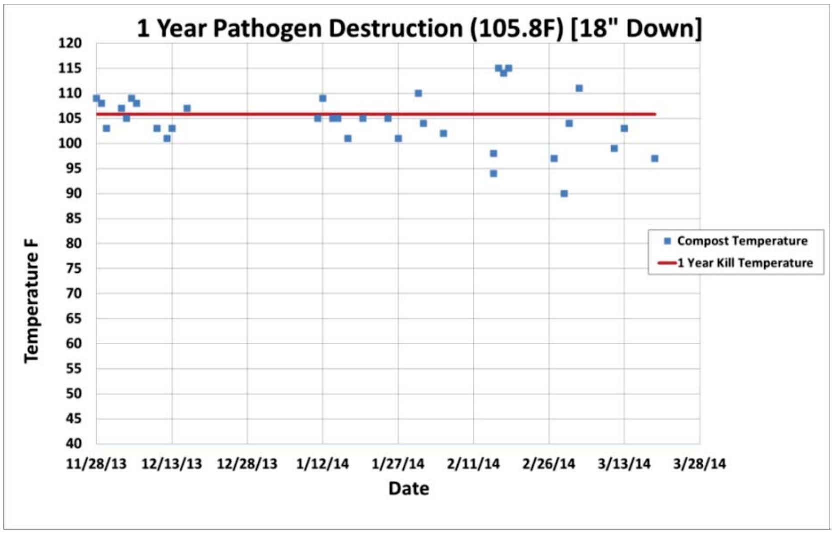


Figure 151: Graph of the 1 year pathogen destruction temperature compared to compost temperatures eighteen inches down.

9.3: Pathogen Destruction in Zone 3

As shown in the graph in Figure 144 above, there are infinite combinations of times and temperatures to reach the Safe Zone of Pathogen Destruction. Below is one temperature and time that is convenient to measure and comprehend to judge the effectiveness of the composting latrine in achieving pathogen destruction.

9.3a: One Year Pathogen Destruction (105.8^{0}F)

A temperature of 105.8^{0}F needs to be reached and held for one year to achieve sufficient pathogen destruction to produce a safe and beneficial product. As shown in Figure 152 this temperature was reached but not held for the sufficient time to ensure a safe level of pathogen destruction.

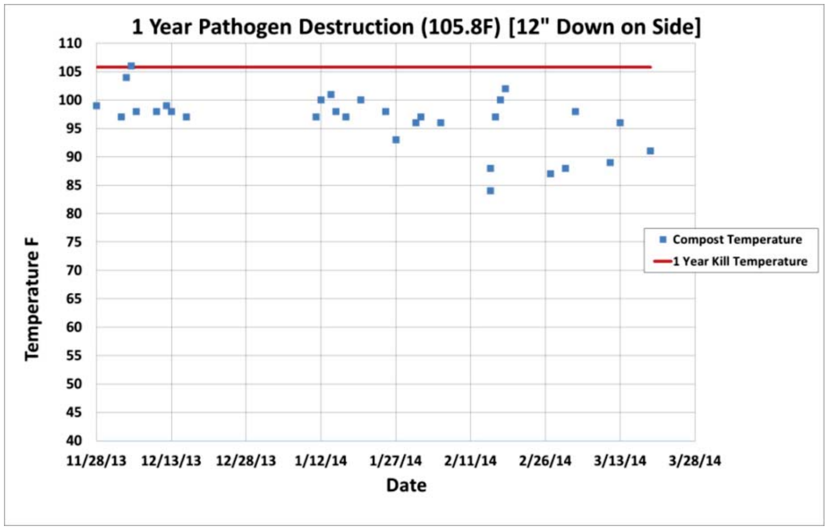


Figure 152: Graph of the 1 year pathogen destruction temperature compared to compost temperatures twelve inchesdown on side of vault.

9.4: Mixing's Effect on Pathogen Destruction

The five events where the compost reached the safe zone of pathogen destruction occurred directly after the mixing of the compost, as shown in Figure 153. As presented in Chapter 8, it was shown that the temperature of the compost increased after each mixing event. Therefore, it may be necessary to mix the compost to reach the safe zone of pathogen destruction in this particular design of composting latrine.

As was stated in Chapter 8, each time the compost was mixed moisture was added as well (either water or a mixture of water and urine).

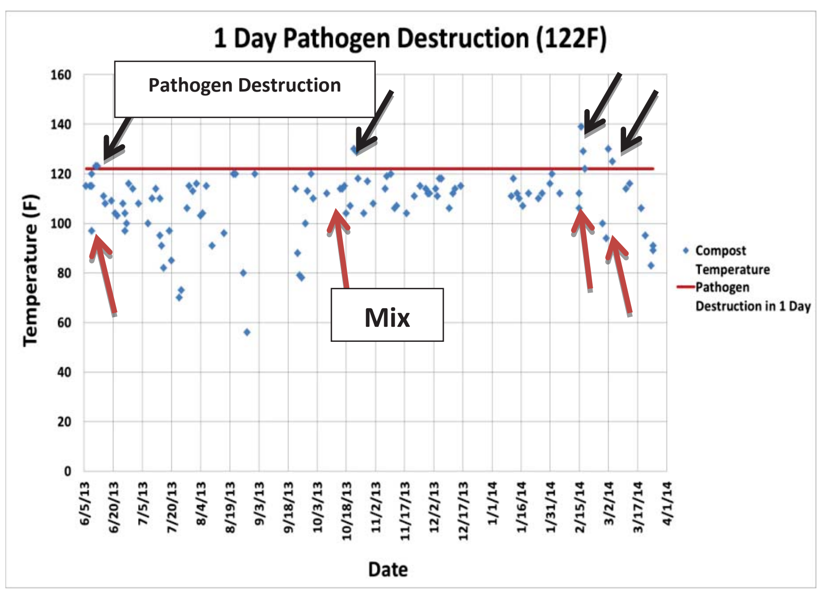


Figure 153: Graph of the 1 day pathogen destruction temperature with mix dates noted.

9.5: Pathogen Destruction through Storage Time

As shown in the graphs above, a sufficient time and temperature for safe pathogen destruction was only reached five times in the top three inches of the compost during the ten months of data recordings. From this observation we cannot confidently say that this design of composting latrine will successfully destroy pathogens by reaching and holding temperatures to reach points in the Safe Zone of Pathogen Destruction. Although reaching points of safe pathogen destruction five times will undoubtedly help in the destruction of pathogens leading to a safe and useful product, another variable will need to be depended on to reach this. This variable is time.

As presented in Chapter 4, the World Health Organization has guidelines for human waste compost storage times for safe pathogen destruction. These guidelines are the following:

Table 14: WHO's recommend storage time of human waste compost depending on ambient temperatures (WHO 2006).

Ambient Temperature	Recommended Storage Time
2-20^{0}C	1.5 – 2 years
20-35^{0}C	> 1 year

The average ambient temperature of Paraguay is 22.7^{0}C (climatemps.com 2013), and the average temperature of the compost was 42.2^{0}C in the top three inches, 40^{0}C eighteen inches down, and 36^{0}C twelve inches down on the side. From these temperatures and WHO guidelines, it is recommended that the compost in this latrine design be contained for at least one year.

9.6: Conclusion

Although temperatures were reached and held several times to enter the Safe Zone of Pathogen Destruction, it is necessary to follow the WHO's guideline of containment for at least one year when using this design of composting latrine in a climate similar to Paraguay's. With this containment time we can be confident that a sufficient amount of pathogen destruction has occurred to produce a safe and beneficial product.

Chapter 10: Results of Community Member's Latrines

Temperature readings were taken in fourteen community composting latrines after their completions. Temperature readings were taken from January 11th, 2014 – March 27th, 2014. The complete data set can be found in Appendix D. This is a limited amount of time for thorough data collection and no definitive conclusions should be made from this information. Rather, the data presented in this chapter should be used for general information about temperatures that may be reached inside this design of composting latrine in a climate similar to Paraguay's.

10.1: Difference in Mean Outside and Compost Temperatures

As shown in Figure 154, nine-out-of-the-fourteen latrines analyzed showed a mean compost temperature greater than the outside mean temperature, with an overall mean difference of 4^0F. This is not a significant difference in outside and compost temperatures for this design of composting latrine, as the mean difference in the author's latrine was 33^0F.

Table 15: Number of latrines with average temperature above and below average outside temperature.

Average Compost Temperature Above Average Outside Temperature	Average Compost Temperature Below Average Outside Temperature
9	5

Average Diff=	4

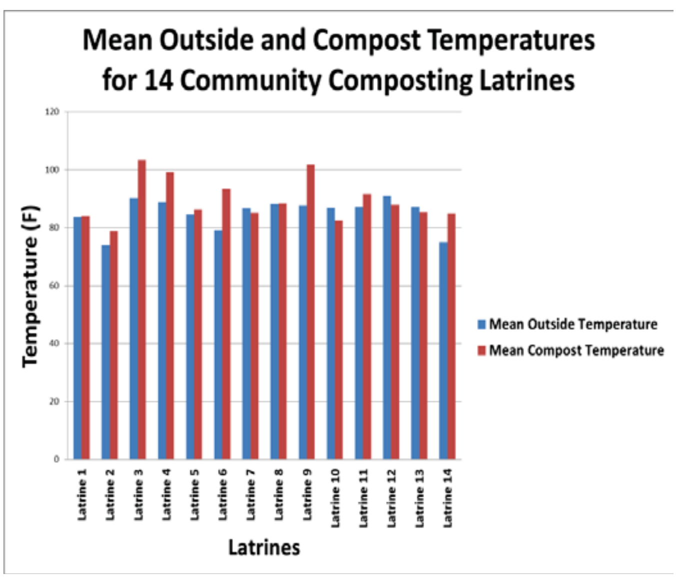


Figure 154: Bar graph comparing mean outside temperatures with mean compost temperatures of 14 community composting latrines.

10.2: Best Performing Community Latrines

Although there was only a 4^0F mean difference of all fourteen latrines analyzed, there were four latrines that performed much better than the average. The temperature readings for these latrines are shown in Table 16 below.

Table 16: Temperature readings of the four best performing community latrines.

Best Performing Latrines					
Owner		**Outside Temperature (F)**	**Compost Temperature (F)**	**Difference**	**Months of use**
Adriano	1/12/2014	90	107	17	5.5
	1/27/2014	99	101	2	6
	2/28/2014	88	108	20	7
	3/27/2014	84	98	14	8
	Mean Temperature (F)	90	104	13	
Tale	1/13/2014	90	98	8	4.5
	1/29/2014	104	103	-1	5
	3/2/2014	84	101	17	6
	3/27/2014	78	95	17	7
	Mean Temperature (F)	89	99	10	
Manecio	1/14/2014	92	97	5	1.5
	3/3/2014	74	94	20	3
	3/21/2014	72	89	17	3.5
	Mean Temperature (F)	79	93	14	
Tila	1/18/2014	105	110	5	2
	1/27/2014	98	108	10	2.5
	3/4/2014	78	101	23	3.5
	3/22/2014	70	88	18	4
	Mean Temperature (F)	88	102	14	
			Mean Difference (F)=	**13**	

Two of these latrines (Adriano's and Tila's latrines) were also close to or above the one month pathogen destruction temperature of 109.4^0F, showing the possibility of this design achieving safe pathogen destruction. More frequent data would need to be recorded from these latrines to determine if they could realistically produce environments for pathogen destruction of adequate temperatures and time durations.

10.3: Conclusion

Although pathogen destruction temperature were reached several times in multiple latrines, it is still necessary to follow the WHO's guideline of containment for at least one year when using this design of composting latrine (WHO 2006). With this containment time we can be confident that a sufficient amount of pathogen destruction has occurred to produce a safe and useful product.

Chapter 11: Insects Observed in Compost

Throughout the collection of temperature readings and visual observations, several insects were observed. These included fly larvae, large beetles, and millipedes. These insects were rarely found outside of the latrine's vault, and appeared to be helping the decomposition process.

Figure 155: Picture of Black Soldier fly found in author's composting latrine. It was found dead. Photo by author.

Black Soldier flies and larvae were also observed in many latrines. Few adult flies were observed in the latrines, and when found were usually dead or dying (Figure 155). The presence of soldier fly larvae (Figure 156) was thought to be benefit since they would significantly reduce the volume of compost in the latrine vault and allow for the compost to be stored for much longer before filling up the vault. The Black Soldier fly is also unlike the common house fly, or 'green fly' found in Paraguay, as it rarely enters dwellings and seems to stay away from humans ((Newton 1995) cited by (Hurtado 2005)). The temperatures inside the latrines also supported only the larval stage of the fly. This was because the increased temperature made it hostile for the larvae since they "need a cooler, dryer place in order to pupate" ((Frankel 2005_ENREF_11) cited by (Hurtado 2005)). The larvae would rarely get to the mature adult phase of their life but would consume a substantial amount of feces during their larval stage.

Figure 156: Picture of soldier fly larvae found in community member's composting latrine. Photo by author.

While the presence of fly larvae may be unsightly for many people, the flies may actually significantly aid in the decomposition process. The majority of latrine users do not look down into the vault, creating situations where they, more than likely, do not know the larvae are there. If there is a hatching of a significant amount of adult flies, however, putting wood ash on the compost seemed to kill a majority of the flies.

Chapter 12: Summary and Conclusions

As the world's water resources continue to be used at an increasing rate, composting latrines have been shown to be an acceptable sanitation alternative to flushed toilets, which waste and soil water resources. Through aerobic decomposition, temperatures and conditions can be reached to sufficiently destroy harmful pathogens and create a safe and beneficial soil amendment. The double vault composting latrine is one design of latrines that can create such environments and be implemented to safely manage human waste.

It was found that clay can be a substituted for a cement mortar mix to save money when constructing this design of composting latrines. If clay material is abundant and used in community for home construction, use this in place of mortar when laying the vault bricks. A mix of ten-parts-clay-to-one-part-cement was a common home construction mix used in the community and may places in Paraguay. The author feels this mix design would give sufficient strength while cutting down on the cement and sand needed, reducing the cost of the project.

Several maintenance practices can increase the temperature and activity in a double vault composting latrine. These practices include: regular mixing of compost every two-to-four weeks, addition of moisture (water or water/urine mixture) when the compost is mixed, and the use of fine bulking material such as sawdust. The mixing and addition of moisture significantly affects the compost by increasing the internal temperature. During the eleven mixing and moisture addition events recorded, a temperature increase was demonstrated in each event.

Outside variables also have an effect on the composting process. A correlation between outside seasonal temperatures and those of the compost were found, with a R^2-value of 0.89 calculated. This showed a reasonably high correlation between these variables. A direct linear correlation, however, was not found between short-term outside temperature changes and those of the compost. It appears that the temperature of the compost follows larger, long-term trends and experiences independent temperature fluctuation on a daily basis.

Adequate temperature and time requirements for total pathogen destruction were shown to be obtainable in a double vault composting latrine. A temperature of at least 122^0F was reached and held for at least one day on four separate occasions. A temperature of at least 114.8^0F was also reached and held for at least one week on another occasion. During these occasions of sustained elevated temperatures, total pathogen destruction was achieved in the regions of the compost, showing documented accounts of a double vault composting latrine achieving sufficient pathogen destruction to produce a safe and useful product.

More research and observations need to be done to better understand the mechanics of the double vault composting latrine. However, this report has shown that it is a safe and effective form of alternative human waste management when used and maintained correctly.

Chapter 13: Future Research Needed

Further research should be done on the double vault composting latrine to help understand how this technology works, and how to best optimize its use. The following are suggestions on where research should be done.

13.1: Temperature Readings of More Zones in Latrine

The majority of the temperature readings in this report were taken in only the top three inches of the compost, the most active zone. This could be improved upon by taking more temperature readings in Zones 2 and 3, areas of moderate and low activity (see Figure 112). The fresh organic material is only in the top three inches for a brief amount of time before it is covered by new organic matter or mixed in. There needs to be more knowledge of the different temperature zones in the entire compost pile to know what temperatures the pathogens are being exposed to during their time in the vault.

13.2: Additional Temperature Readings

To truly understand the decomposition process occurring inside the vaults of the composting latrine, temperature readings will need to be taken for a longer period of time. The temperatures presented in this report covered only ten months in a three year process of total decomposition. It would be useful to see what temperatures are sustained in the compost once the vault is filled and left to mature. If the temperature drops very low during this time the storage time may need to be extended to confidently produce a safe and beneficial product, or vice versa.

13.3: Consistent Temperature Readings

If the time of day stayed consistent when the temperature readings were taken, the data could more easily be analyzed for lag responses from outside temperature changes. The data presented in this report were not taken every day or at the same time of day. It would be very beneficial, and allow for simplified analysis, if the data were taken at a specific time of day every day.

13.4: Increase Number of Latrines Studied

There was only one latrine in this report with detailed temperature readings. It would be very useful to have at least three latrines observed simultaneously to show what can be expected on a more general scale from this technology. It would also be beneficial to have a “control” latrine, where no mixing was done or moisture was added, to better show the affects that both these variables have on the decomposition and temperatures reached in the latrines.

Chapter 14: Discussion

Several questions and subjects of interest were presented to the author of this thesis during a presentation of the findings and analysis presented in this paper. Below are list of discussion questions that were put forward during this session and answers/recommendation given by the author.

1) How much air flow is delivered by the ventilation tubing:

The amount of air that is drawn up the ventilation tubing could significantly help in the aeration of the compost and aid in the aerobic decomposition process. The air flow was not measured during the author's time in Paraguay due to lack of proper instruments. The suggestion of using smoke or very fine dust particles to observe air flow in the vault were presented to the author during this discussion, and it is highly advised to do this if someone is planning on using and improving a double vault composting latrine. It is felt by the author that many improvements could be made on this latrine design to increase air flow, which would help enable a more active aerobic decomposition process within the vaults.

It was believed that the black ventilation pipes would heat up in the sun and begin to draw air through the entire system. More studies on the validity of this are highly suggested by the author of this thesis.

2) Source of design:

The design of the double vault composting latrine presented in this thesis was developed by modifying existing composting latrine designs researched by the author. The basic design was observed in other parts or Paraguay, showing the author the acceptance of this design within the culture of Paraguay. The author also took design considerations by researching project completed in Panama by former PCMI students Josephine Kaiser (Kaiser, 2006) and Daniel Hurtado (Hurtado, 2005), both of which are cited in the reference list of this thesis.

Two books were also used to develop a design for the author's community. These books were the following:

- *The Humanure Handbook*
  By: Joseph Jenkins, 2005
- *Environmental Engineering in Developing Countries*
  By: E. Dahi, 1990

3) Nutrient Balance:

The use of the resulting compost could potentially close the nitrogen cycle within the family using the latrine. The food grown from their garden would be eaten, digested, defecated, composted, and returned to the garden as compost to enable the further growth of crops through the use of the nutrients within the compost. However, it is believed by the author that this is a very unlikely scenario, as many people were very concerned that the use of the compost may contaminate their food, and were not planning on using the resulting compost on their gardens. The amount of compost produced by the latrine was also at such a small level that it would do little to aid in the fertilization of their cash crops in the community. Therefore it would be doubtful that the use of these latrines would lead to a reduction of petroleum based fertilizers in the community.

Reference List

Austin, A. (2001). Health aspects of ecological sanitation. 1st International conference on Ecological Sanitation. Nanning, China: 104-111.

Becker, J. (2006). Compost Biology. Better Composting School, Hanover, MD, University of Maryland.

Cheng, T. C. (2012). General parasitology, Elsevier.

climatemps.com (2013). "Climate, Averagre Weather of Paraguay." from http://www.paraguay.climatemps.com/.

Coker, C. (2014). "Aerobic Composting And Anaerobic Digestion." BioCycle **55**(3): 32-35.

Dahi, E. (1990). Environmental Engineering in Developing Countries. Copenhagen, Denmark, Polyteknisk Forlag.

EPA (2004). from http://cfpub.epa.gov/npdes/cso/cpolicy_report2004.cfm.

Esrey, S. e. a. (1998). Ecological Sanitation. Stockholm, Sweden, Swedish International Development Cooperation Agency.

Feachem, e. a. (1980). Appropriate Technology for Water Supply and Sanitation. Washington D.C. 20433, The World Bank, Director of Information and Public Affairs.

Feachem, R. e. a. (1983). Sanitation and Disease-Health aspects of excreta and wastewater management. Chichester, John Wiley and Sons.

Frankel, S. Z. (2005). from www.wormdigest.org/crittergallery.html.

Gonzalez, F. (2014). Personal conversation with Fernando Gonzalez the Agriculture Project Specialist for Peace Corps Paraguay.

Haug, R. T. (1993). The Practical Handbook of Compost Engineering. Boca Raton, Florida, Lewis Publishers.

Hurtado, D. (2005). "Composting latrines in rural Panama: Design, construction and evaluation of pathogen removal.".

Jenkins, J. C. (2005). The Humanure Handbook. Grove City, PA, Joseph Jenkins, Inc.

Kaiser, J. (2006). "An Analysis of the Use of Desiccant As a Method of Pathogen Removal In Compost Latrines in Rural Panama."

Lynch, J. M. a. P., N.L. (1979). Microbial Ecology: A Conceptual Approach. London, Blackwell Scientific Publications.

Montgomery, M. A. and M. Elimelech (2007). "WATER And SANITATION in Developing Countries: Including Health in the Equation." Environmental Science & Technology **41**(1): 16-24.

Naím, M. (2008). "Can the World Afford A Middle Class?" Foreign Policy(165): 96-96,95.

Newton, G. L. S., D.C; Thompson, S.A.; Savage, S.I. (1995). Soldier Fly Benefits: House Fly Control, Manure Volume Reduction, and Manure Nutrient

Recycling., UGA Animal & Dairy Annual Report.

Pacey, A. a. L. (1978). Sanitation in Developing Countries. New York, John Wiley & Sons Ltd.

Postel, S. L. (2000). "Entering an era of water scarcity: The challenges ahead." Ecological Applications **10**(4): 941-948.

Richard, T. (1995, October 2000). "Temperature." Cornell Cooperative Extension Operator's Fact Sheet #5 of 10. Retrieved November 14, 2014, from http://compost.css.cornell.edu/Factsheets/FS5.html.

Rodale, J. I. (1975). The Complete Book Of Composting, Rodale Books, Inc., Emmaus, Penna.

Seckler, D., R. Barker, et al. (1999). "Water Scarcity in the Twenty-first Century." International Journal of Water Resources Development **15**(1-2): 29-42.

Stenstrom, T. A. (2002). Reduction Efficiency of Index Pathogens in Dry Sanitation Compared with Traditional and Alternative Wastewater Treatment Systems, Swedish Institute for Infectious Disease Control.

WHO (2006). "WHO guidelines for the safe use of wastewater, excreta and greywater." **v. 4. Excreta and greywater use in agriculture.**

Appendix A: Materials List

Table 17: Materials List

Materials	Unit	Quantity /house
Hueco Bricks	brick	111
Common Bricks	brick	72
#2 Nails	kilo	0.5
#3 Nails	kilo	0.5
Roofing Nails	bag (20 nails)	1.2
Hydrated Lime	bag	2
Cement	bag	3
Rebar 8mm	12m length	0.5
Rebar 6mm	12m length	2.5
10cm Plastic Tube	6m length	0.67
10cm Plastic Elbow Joint	part	2
20mm Cano	6m length	0.22
20mm coldo	part	2
Large Funnel	part	1
Hose	m	3
Hinges 4"	pair	1
Hinges 3"	pair	2
Door Latch 5"	part	2
Wire for tying rebar	kilo	0.25
1/2" Nut	part	22
1/2" Washer	part	22
1/2" Threaded Bar	m	1.5
Screen	m2	0.5
Corregated roofing material	parts	4
Crushed rock	buckets	12

Appendix B: Temperature Readings in Sun and Shade from 1/14/14-4/10/14

Table 18: Temperature Readings in Sun and Shade 1/14/14-4/10/14 (Pages 110-111)

Date	Temperature in Direct Sun (F)	Temperature in Shade (F)	Time	Weather
1/14/2014	91.4	88	12:00	
1/15/2014	91.4	86	14:00	
1/16/2014	104	93	15:00	
1/17/2014	107.6	95	15:00	
1/18/2014	105.8	97	15:00	
1/19/2014	100.4	93	16:00	
1/20/2014	104	97	15:30	
1/21/2014	104	99	15:30	
1/22/2014	105.8	100	15:30	
1/23/2014	100.4	97	14:00	
1/24/2014	105.8	100	15:00	
1/25/2014	89.6	86	14:00	
1/26/2014	84.2	82	18:30	
1/27/2014	98.6	91	15:00	
1/28/2014	98.6	86	14:00	Rain showers
1/29/2014	104	95	14:20	
1/30/2014	100.4	93	14:00	
1/31/2014	102.2	95	15:00	
2/1/2014	104	95	15:30	
2/3/2014	107.6	97	15:00	
2/4/2014	104	99	15:30	
2/5/2014	107.6	100	15:00	
2/6/2014	96.8	93	14:00	Rain showers
2/7/2014	111.2	100	15:30	
2/8/2014	107.6	102	15:00	
2/9/2014	96.8	95	12:00	Rain showers
2/10/2014	98.6	95	15:00	
2/11/2014	107.6	100	16:00	
2/12/2014	100.4	97	14:45	
2/13/2014	96.8	90	15:00	
2/14/2014	86	84	14:45	
2/15/2014	90	84	14:30	
2/15/2014	89.6	84	16:30	
2/16/2014	105.8	90	15:00	
2/17/2014	104	93	16:45	
2/18/2014	104	95	16:00	
2/19/2014	91.4	77	15:00	

2/20/2014	104	91	15:45	
2/21/2014	95	90	14:45	Rain showers
2/22/2014	100.4	95	12:45	Rain
2/23/2014	102.2	97	12:30	
2/24/2014	98.6	93	12:30	
2/25/2014	96.8	91	15:15	
2/26/2014	82.4	82	12:30	
2/27/2014			15:15	
2/28/2014	84.2	82	15:15	
3/1/2014	98.6	88	12:45	
3/2/2014	95	88	12:15	
3/4/2014			13:30	
3/5/2014	91.4	84	16:30	
3/6/2014	91.4	91	16:30	
3/7/2014	93.2	88	14:30	
3/8/2014	98.6	91	15:15	
3/9/2014	102.2	95	13:15	
3/11/2014			15:45	
3/12/2014	102.2	100	15:30	
3/13/2014	104	100	14:15	Rain
3/14/2014	98.6	93	16:00	Rain
3/15/2014	84.2	81	11:45	Rain in morning
3/16/2014	93.2	91	12:45	Rain
3/17/2014	96.8	93	16:00	
3/18/2014	73.4	72	15:00	
3/19/2014	80.6	81	15:00	
3/20/2014	80.6	79	14:30	
3/21/2014	86	81	15:15	
3/22/2014	86	84	14:00	
3/24/2014			15:30	
3/25/2014	95	88	14:45	
3/26/2014	93.2	86	15:15	
4/3/2014	98.6	90	14:30	
4/4/2014	91.4	88	15:45	Rain
4/5/2014	93.2	86	15:30	
4/6/2014	96.8	93		
4/7/2014	98.6	97		
4/8/2014	102.2	99		
4/9/2014	82.4	72		
4/10/2014	89.6	88		
Average=	**97**	**91**		

Appendix C: Complete Data of Personal Latrine

Table 19: Complete Data of Personal Latrine (Pages 112-117)

Date	Outside Temp (F)	Compost Temp (F)	Time	Weather	Notes
6/6/2013	72	115	4:45pm	Sunny day	
6/8/2013	72	115	5:30pm		
6/9/2013	79	115	10:45am	Partly cloudy	Mixed compost and added water/urine
6/9/2013	79	97	11:00am	Partly cloudy	
6/9/2013	71	120	5:15pm	Sprinkling	6 hours after mix and watering
6/11/2013	65	123	7:15pm	Sunny day	Ambient temp in surrounding compost was 108 F
6/12/2013	71	123	7:30pm	Sunny day	
6/15/2013	64	111	5:45pm	Cloudy	Switched to large pieces of wetted hay, no ash
6/16/2013	70	108	5:30pm	Showers	Large hay with no ash
6/19/2013	63	109	11:45am	Lots of rain last night	Switched back to hay dust. 4 mushrooms seen on edges coming from bottom of compost with temp of 88 F in that area.
6/21/2013	50	104	7pm	Rainy cold	
6/22/2013	54	103	5:30pm	Cloudy to sunny	Back to sawdust
6/25/2013	57	108	5:50pm	Damp Cloudy	
6/26/2013	57	104	11:30am	Damp Cloudy	Stirred and put in old sink water
6/26/2013	57	97	7:45pm	Damp Cloudy	8hrs after stir and water added
6/27/2013	61	100	7:45am	Damp Partly sunny	
6/28/2013	77	116	7:30pm	Sunny	
6/30/2013	69	114	8:00am	Sunny	
7/3/2013	74	108	6:00pm	Sunny and windy	
7/8/2013	60	100	7:45pm	Rainy	Lots and toilet paper present, dry

7/10/2013	80	110	1:00pm	Sunny/windy	
7/12/2013	74	114	8:10pm	Sunny (90F + today)	
7/14/2013	74	110	10:00am	Partly cloudy/rained last night	Stirred and added water
7/14/2013	70	95	7:00pm	Partly sunny	9 hrs after stir
7/15/2013	64	91	5:30pm	Sunny, cold south wind	
7/16/2013	68	82	5:30pm	Sunny, cold south wind	
7/19/2013	54	97	5:00pm	Sunny, cold south wind	Switched to damp ash yesterday
7/20/2013	52	85	5:30pm	Rainy, cold	Switched back to sawdust b/c of smell and temp drop
7/24/2013	55	70	11:00am	Froze last two nights	
7/25/2013	53	73	8:00pm	Cold	Froze last night and high today of 65F
7/28/2013	75	106	5:00pm	High of 30C today	
7/29/2013	69	115	6:45pm	High of 30C today	
7/31/2013	79	113	7:00pm	Hot and sunny	Saw high of 32C at 3pm
8/2/2013	58	116	8:00pm	Cool and cloudy	High of 34C yesterday
8/4/2013	66	103	5:00pm	Cool nights	Added 1 liter if water
8/5/2013	76	104	5:45pm	Hot	94F in sun today, 84F in shade
8/7/2013	84	115	4:30pm	Sunny dry wind	
8/10/2013	45	91	6:50pm	Cold south wind	Cold and rainy yesterday
8/16/2013	55	96	7:30pm	Cold	Froze last two nights
8/21/2013	80	120	8:00pm	Hot	90sF past two days
8/22/2013	80	120	5:45pm	Hot	37C high today

8/26/2013	44	80	5:00pm	Cold/rainy	Cold steady rain for past 3 days, Mixed
8/28/2013	56	56	5:00pm	Cold	Froze last 4 nights
9/1/2013	80	120	8:30pm	Hot	100F last 3 days (vacation for 3 weeks now)
9/22/2013	60	114	4:45pm	Cool/rainy	Mix
9/23/2013	54	88	1:00pm	Cold/rainy	
9/24/2013	49	79	6:30pm	Cool, sunny, windy	
9/25/2013	54	78	7:00pm	Cool, sunny	
9/27/2013	78	100	5:15pm	Cloudy and warmer	
9/28/2013	70	113	11:00am	Rainy, windy	Rained a lot last night and this morning
9/30/2013	58	120	1:00pm	Cloudy, rained a bit	
10/1/2013	58	110	5:30pm	Partly cloudy	
10/8/2013	78	112	6:00pm	Sunny/Hot	Too wet. Many soldier fly maggots
10/15/2013	74	114	7:15pm	Moist, rain showers	Added 16oz of ash because lot of fly larvae
10/16/2013	74	114	7:15pm	Humid and hot w/ rain showers	Added 3 shovels of ash b/c of maggots
10/17/2013	77	115		Hot and humid, sunny	Lots of maggots still after ash added, no smell, no flies (Side temp of 112)
10/18/2013	68	104		Hot and humid, sunny	Less maggots, Looks like ran out of food, saw 3 soldier flies in latrine dead or dying
10/20/2013	91	107		Hot (37C)	Still maggots, Mixed latrine, while mixing saw only humus looking material, no feces left just sawdust/chips and dark organic material
10/22/2013	79	130			Lots of soldier fly larvae
10/23/2013	100	129			Lots of soldier fly larvae
10/24/2013	75	118			

10/27/2013	78	104			Less maggots, put in lot of ash
10/29/2013	88	117			Lots of maggots,(110F deep at side)
11/1/2013	90	108		Hot, windy, sunny past two days	Still maggots, dry so added water
11/7/2013	80	114		sunny	still maggots
11/8/2013	80	119		sunny, windy	lots of maggots, (107F twelve inches down)
11/10/2013	92	120		100F+ today, windy	
11/12/2013	80	106	6:00pm	Hot, rained yesterday	Less maggots, MIX
11/13/2013	85	107	7:30pm	Hot and sunny	
11/18/2013	87	104	7:45pm	Hot and sunny	lots of maggots, seems like they are eating all poop
11/22/2013	83	111	6:30pm	Sunny	
11/25/2013	84	115	7:30pm	Sunny	
11/28/2013	73	114	5:45pm	Rain, drizzle	twelve inches down 109F, side 99F
11/29/2013	70	112	7:30pm	Rained all day	twelve inches down 108F
11/30/2013	73	112	5:45pm	Rainy	twelve inches down 103F, MIX
12/3/2013	82	114	1:45pm	Humid	twelve inches down 107F, side 97F
12/4/2013	92	111	2:15pm	Sunny and hot	twelve inches down 105F, side 104F
12/5/2013	96	118	2:50pm	Sunny, hot, humid	twelve inches down 109F,side 106F
12/6/2013	76	118		Rainy and cloudy	14" down 108, side 98F
12/10/2013	82	106	5:30pm	Sunny, cold south wind	14" down 103, side 98
12/12/2013	80	112	7:30pm	sunny and hot and humid	14"down 101, side 99, (looks like running out of food)

12/13/2013	82	114	7:00pm	Hot and humid	14" 103, side 98, lots of maggots
12/16/2013	93	115	1:30pm	Hot, sunny, humid,	14" 107, side 97, lots of maggots
1/11/2014	94	111		Hot and dry, no rain for 4 weeks,	14" 105, Side 97, new larger maggots, *MIX AND WATER ADDED*
1/12/2014	82	118		Partly cloudy, hot, dry	14" 109, side 100
1/14/2014	88	112		hot,dry, no rain yet	14" 105, side 101
1/15/2014	74	110		rain showers, hot and partly cloudy	14" 105, side 98
1/17/2014	88	107		Hot (108 @ 4pm)	14" 101, side 97, less maggots
1/20/2014	94	112		Hot (40C)	14" 105, side 100, lots of maggots
1/25/2014	80	110	6:00pm	Cloudy, rained last night, humid	14" 105, side 98, less maggots
1/27/2014	84	112		rain showers	14" 101, side 93, lot of maggots
1/31/2014	88	116	5:30pm	Hot, 39C @ 2pm	14" 110, side 96,no smell of flies, less maggots,
2/1/2014	90	120	7pm		14" 104, side 97Medium amounts of maggots
2/5/2014	100	112		Hot (42C today)	14" 102, side 96, less maggots
2/15/2014	76	106	10:30am	Cool south wind, cloudy, rained last two days a little bit	14" 94, side 84, Lots of Toilet paper, Less maggots, *MIX AND WATER ADDED*, when mixing good compost smell, larger bugs inside eating
2/15/2014	85	112	4:30pm		14" 98, side 88, **6 hours after water added and mix**
2/16/2014	80	139	8pm		14" 115, side 97, Big beetles present **36 hours after mix

					and water added**
2/17/2014	84	129	8pm		14" 114, side 100, Big beetles present, Not a lot of maggots, well moist
2/18/2014	89	122	7pm		14" 115, side 102, big beetles, less maggots, smells from 10ft away
2/27/2014	72	100	7pm	Rained yesterday	14" 97, side 87, mounding feces and cover material up on top, damp cover material being used, less maggots, seems to be running out of fuel…mix needed.
3/1/2014	80	94	7pm		14" 90, Very damp with little activity, smells like wet feces, ***mixed**
3/2/2014	85	130	10:15am		14"104, side 88, No smell
3/4/2014	81	125			14" 111, side 98, No smell/flies, still damp but not too wet any more, switched to dry sawdust only 3 days ago.
3/11/2014	78	114			14" 99, side 89, Lots of maggots, lots of big beetles, still using dry sawdust.
3/13/2014	85	116		Hot dry winds	14" 103, side 96, Lots of maggots, lots of big beetles, still using dry sawdust.
3/19/2014	84	106	3:30pm		14" 97, side 91, No smell/flies, less maggots, good looking/smelling abono underneath, ***Mixed and topped with kapi'i. END OF FIRST CAJA***
3/21/2014	80	95			Abono looked dry
3/24/2014	84	83	4pm		Water added, no smell/flies
3/25/2014	77	89	6:30pm		No smell or flies ***FIRST CAJA***
3/25/2014	77	91	6:30pm		Little smell but not bad ***2ND CAJA***
Average=	75	108			

Appendix D: Temperature Readings and Visual Observations of Community Member's Latrines

Table 20: Temperature Readings and Visual Observations of Community Member's Latrines (Pages 118-124)

Date	Time	Outside Temp. (F)	Compost Temp. (F)	Months used	Number of users	Notes
Arminda Godoy						
1/11/2014	4:30pm	79	86	2.5	4	Very little compost, Lots of maggots, No flies, Wet, No smell, *Seems too little cover material is being used, Using sawdust and ash for cover material
1/27/2014	9:30am	99	90	3		Lots of maggots, no flies or smell, too little compost to leave thermometer alone, it has been hot!!!, rained yesterday
2/28/2014	2:50pm	78	83	4		Wet, no smell or flies ***Told here to use more dried sawdust***
3/24/2014	5:30pm	79	77	5		No smell or flies, too wet, told to use more sawdust, *been cold last two nights!*
	Mean Temp	84	84			
Ida						
1/12/2014	4pm	90	N/A	1.5	4	Very little compost (too little to measure temp), No smell of flies, Using sawdust for cover material, *seems too little cover*
2/28/2014	3:50pm	79	83	3		No smell or flies, using good amount of sawdust, good dampness
3/22/2014	10:45am	69	75	4		Too wet, no smell or flies, told to add more ash to dry it out.

	Mean Temp	74	79			
Adriano						
1/12/2014	5pm	90	107	5.5	3	Lots of hatched soldier flies but none in their house or even around latrine, Partly cloudy day, Use sawdust and ash as cover material, No smell, not enough compost to measure in different areas
1/27/2014	3pm	99	101	6		A few soldier flies, no smell, 6" of compost
2/28/2014	4pm	88	108	7		Looks just like my compost, no smell or flies, using sawdust and ash *mixed compost*
3/27/2014	2pm	84	98	8	2	No flies or smell, using sawdust and ash.
	Mean Temp	90	104			
Tale						
1/13/2014	5pm	90	98	4.5	3	Little smell, lots of maggots, wet, most flies I've seen in chamber yet but none in their house or around latrine, soldier flies, hot and sunny, light breeze
1/29/2014	1:15pm	104	103	5		Little smell, maggots, a few soldier flies present, latrine in direct sunlight
3/2/2014	6:30pm	84	101	6		Less Flies (none), no smell, hot vapor coming off of compost, using sawdust
3/27/2014	9:45am	78	95	7		No smell or flies,

						using sawdust
	Mean Temp	89	99			
Lucio						
1/14/2014	2:15pm	91	97	5	4	Wet, no smell or flies, lots of beetles, no bugs leaving latrine, use sawdust and ash, *seems too little cover used*, hot and sunny, happy with latrine
2/28/2014	11:20am	88	78	6.5		Wet, no smell or flies, wetted ash and sawdust being used, few maggots.
3/21/2014	11:45am	75	84	7		No smell or flies, told to put more cover material in, a little too damp
	Mean Temp	85	86			
Manecio						
1/14/2014	3:30pm	92	97	1.5	3	no smell or flies, had lots of flies a few weeks ago for a few days but have all died (put lots of ash in during this time), no maggots, little compost, use sawdust and ash, hot and sunny
3/3/2014	4:20pm	74	94	3		No smell or flies, good dampness, sawdust and ash used
3/21/2014	12:30pm	72	89	3.5		Few soldier flies, no smell, lots of toilet paper, good dampness level.
	Mean Temp	79	93			

Narcisa						
1/16/2014	2:50pm	104	95	2.5	1	no smell of flies, uses sawdust, very little compost, very hot and sunny
1/27/2014	12:15pm	98	84	3		No smell of flies,uses sawdust, 2" of compost (kapi'I still seen under feces)
3/4/2014	9:50am	73	82	4		No smell, no flies, using sawdust, lots of Toilet Paper
3/22/2014	3:45pm	72	80	4.5		No smell or flies, using sawdust, very little use (only her)
	Mean Temp	87	85			
Jorgelina						
1/18/2014	2pm	105	99	5.5	2	No smell of flies, uses shredded cana dulce for cover, 4" of compost, flies only in top of vent tube, soldier fly maggots, black mold on walls (maybe from cana dulce)
1/27/2014	11am	98	96	6		few flies, no smell, very little compost (three inches), use very little cover material
3/4/2014	1:30pm	78	81	7		Using sawdust, no flies, little smell, black crust on compost
3/22/2014	2:40pm	72	78	7.5		No smell/flies, not a lot of maggots, black!
	Mean Temp	88	89			
Tila						
1/18/2014	4pm	105	110	2	4	Smells bad, not wet, use sawdust and leaves, not many soldier flies, looks like my compost (not wet

						and holds its shape as small mound)
1/27/2014	10:30am	98	108	2.5		Still smells but less than before, green flies present (don't use cover), use forest litter and ash
3/4/2014	1:30pm	78	101	3.5		Less smell, using grass clippings, lots of green house flies, big beetles present like in my latrine.
3/22/2014	1:30pm	70	88	4		No more smell or flies!!, using ash now.
	Mean Temp	88	102			
Lidia						
1/19/2014	2pm	100	95	3	3	No smell, No flies, looks wet on top but material on bottom is harder and dry, no very much compost, don't use cover material, not a lot of maggots, seems like not always being used
1/27/2014	2pm	98	85	3.5		Wet, no smell, black color on walls, no flies, three inches of compost
3/4/2014	3pm	82	77	4.5		No smell or flies, not using cover material
3/22/2014	11:45am	68	73	5		Too wet, told to put in ash to dry it out, no smell or flies
	Mean Temp	87	83			

Virginia						
1/19/2014	4:30pm	100	96	3	3	No smell or flies, use sawdust and ash, vapor coming off of pile, maggots, holds shape like mine but more damp
1/27/2014	1:45pm	98	90	3.5		no smell or flies, looks like little use (they have modern bathroom), told me lots of use during party on jan 4th, three inches of compost
3/4/2014	3:15pm	83	87	4.5		No smell or flies, using sawdust
3/22/2014	11:15am	68	94	5		Good level of dryness, no flies or smell, using sawdust, lots of toilet paper.
	Mean Temp	87	92			
Evarito						
1/27/2014	2:30pm	98	91	6	1	No smell or flies, uses sawdust, looks damp enough for compost, no maggots
3/27/2014	12pm	84	85	8		No smell or flies, very little use…they have bano moderno.
	Mean Temp	91	88			
Claudio						
1/29/2014	11am	104	87	6	3	No smell or flies, use too little sawdust, liquidy compost (thermometer couldn't stand up by itself), maggots present

3/4/2014	4:45pm	76	81	7		No smell or flies, very wet, Need to use more cover material
3/27/2014	10am	82	88	8		NO flies of smell, still using too little cover material, told to use more ash or sawdust.
	Mean Temp	87	85			
Benito Gonzalez						
1/29/2014	12pm		Can't get reading because of seat design	6	2	No flies of smell, can't look inside because seat is made from bricks, use sawdust and ash
Juan						
3/21/2014	1pm					Didn't seem to want me to go into bathroom, told me there weren't too many flies and the smell wasn't too bad.
Angelica						
3/22/2014	2:30pm	75	85	1.5	1	No smell, no flies, using sawdust