Vermicomposting and Vermiculture Systems for Cold Climates

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Background and Introduction

The purpose of this publication is to provide information about worm or vermi composting with an emphasis on intensive low acreage organic food production in bed systems or protected cultivation including high tunnels, hoophouses and greenhouses. Two separate publications are available that cover a) worm biology and environmental conditions and b) using worm compost.

- The information provided here is the result of a research project initiated in May, 2010 with funding support from the MSU Office of Campus Sustainability and Residential and Hospitality Services as one of several strategies to address campus food system sustainability issues.
- An important part of this project is to explore the justifications for worm composting compared to hot composting and eventually whether worm compost has unique valuable properties compared to hot compost. For example, can nitrogen recovery and mineral availability be improved? Published reports not that microbiology in worm compost can protect plant roots from pathogenic infestation by certain fungi and that microbiology in the root zone of tomato transplants grown with vermicompost was measurably different in the root zone of the tomatoes in the field for several months after field establishment.
- Another important part of the project is to increase the collection and composting of kitchen preparation residue (KPR) and food waste (FW) for the purpose of returning valuable minerals and organic matter to gardens and farms while reducing the movement of KPR and FW to landfills and sewage treatment systems where the minerals are effectively lost to farming systems. A published estimate is that 40 to 45% of food in the US is not consumed by humans and that 90 to 95% of what is not consumed ends up in landfills.
- A third part of the project is to investigate and refine medium scale methods of vermicomposting. Small scale worm composting in 10 to 20 gallon plastic totes (a “worm bin”) (2 to 4 square feet of surface area each) suitable for processing family kitchen residue and home gardening is one common worm composting method. Large scale worm composting with flow through mechanized systems with thousands of square feet of bed surface area is less common but feasible. The focus here is on medium scale systems (50 to 1000 square feet) suitable for either a) a small scale commercial composting operations, b) an institutional vermicomposting operation or c) a market gardener or farmer with a diverse operation where worm composting to cycle nutrients from food residue or animal manure and make an on farm nutrient source and crop protectant is one of many daily responsibilities.

Outline

1. Worm Compost Comparison and Uses

Why Worm Composting in addition to or rather than Hot Composting?

- Can be done in small or large space. No minimal pile size although larger piles can reduce the risk of stressing the worms. Piles are normally shallow, with 1.5 to 2' maximum for active composting, but outdoor windrows can be deeper.
- Can be done with limited equipment; worms can do much of the work of "turning".
- More manageable / practical under winter weather conditions and in closed spaces.
- Turning of hot compost in an enclosed environment is not recommended due to negative potential health impact of gasses (ammonia) and molds on human lung function (breathing).
- Can probably retain more of the nitrogen that can be lost to the atmosphere in hot composting.
- Hot composting is by thermophilic bacteria at temperatures over 110 to 120^{o}F and up to 160^{o}F which can decrease the diversity of microorganisms.
- Vermicomposting is by mesophilic microorganisms in addition to worms at a temperature of less than 100^{o}F. Worms eat microorganisms which can increase in the gut of the worm. The diversity of microorganisms, including fungi, reportedly increases during vermicomposting. In the study cited, the diversity of microorganisms decreased after the worms were removed.
- Finished worm compost or castings reportedly can have a higher concentration of available minerals, particularly phosphorus.
- Can be fast (40 to 60 days; 6 to 8 weeks) if worm population is high; with reportedly no requirement for a maturation phase that is needed with hot composting. While freshly harvested worm compost can clearly be used for application to established plants, it is not clear if it is acceptable for seed germination or seedling production.
- High moisture materials with potential for unpleasant odors are transformed into easy to handle and odor free from materials (usually also true for hot composting).
- Worm composting is generally more exciting / interesting to the non-farming or gardening public and is a visual way of teaching the importance of organic matter and nutrient cycling for the long term sustainability of farms. The soil food web is more visible through the worms.
- Worm compost can sell for $0.25 to $1 per pound ($250 to $1000 per cubic yard) compared to $15 to $45 per cubic yard for municipal or manure based compost (10 to 20x).

Potential Limitations of Worm Composting Compared to Thermophilic Composting

- Seasonal temperature range and susceptibility to temperature extremes is more limited than for thermophilic composting.
- Anaerobic conditions can lead to rapid and total loss of the worm composting population.
- Dry or excess moisture conditions can lead to rapid and total loss of the worm population.
- Bacterial and fungal populations responsible for thermophilic composting can be developed or recovered much faster (hours or days) than worm populations (months or years).
- Seeds from the feedstocks will often remain viable after the worm composting process.
- Limited evidence is available to address human food safety concerns regarding possible human pathogens that may survive the worm composting process. The available evidence is that vermicomposting removes human pathogens as well as hot composting.

Why Worm Compost?

Worm compost can be used several ways in rural or urban commercial agriculture.

- An on-farm produced growing medium component (usually at 5 to 20% by volume but can be much higher depending on feedstocks) for container grown transplants or plants.
- An on-farm produced source of balanced available nutrients/minerals which can be applied as a dry surface application or extracted with water and applied as a fertigation (nutrients+water).
- An alternative to fish based fertilizers commonly used in organic farming.
- A source of microorganisms and micronutrients that can contribute to plant and soil health.
- A "crop protectant" that may help mitigate insect infestations and disease infections.

Is Worm Compost Significantly Different than Thermophilic Compost to Justify the Effort?

- A weakness of many claims or proposals relative to all types of compost is that the diverse effect of the feedstock and composting methods on the quality and characteristics (physical, chemical and biological) of the compost have not been carefully considered.
- Comparing worm compost made from high nutrient content dairy cow manure with thermophilic compost made from municipal yard and garden residue is not a good comparison.
- The maturity of thermophilic compost changes significantly over the first six to eighteen months and is a different process than occurs with worm composting.
- My current perception is that worm composting has more relevant comparisons (similarities) to hot composting than is generally accepted or recognized.

2. Generic components of a vermicompost production system

Vermicompost Systems for commercial production and selling compost have several key components in common regardless of the scale, labor and economics involved. By identifying these common generic components we can develop a better understanding of a variety of systems and potentially manage our specific system better. Whether a system is productive and profitable will be influenced by the scale of production, the availability and cost of human

1. People: to manage, monitor and move the process
2. Worms: type, quantity per unit area, reproduction rate, feeding rate
3. Feedstocks: either on farm production and collection or off farm delivery and storage
    a. Bedding – slowly degradable/decomposable medium to provide moisture and aeration
    b. Feed - quickly degradable/decomposable food
    c. Mixed feed/bedding application/addition system –
4. Container or retention/floor:
    a. keep the worms in one place, prevent migration
    b. allow routine addition of feed and either routine or scheduled removal
5. Moisture: regulation, addition or drainage/removal of water
6. Aeration / ventilation: regulation or addition
7. Harvesting:
    a. method for deciding when to harvest
    b. worm recovery system
    c. how to dry the vermicompost
8. Storage: container, moisture, environmental conditions (temperature)
9. Quality Control: analysis and evaluation
10. Marketing –
    a. Regulation and certification
    b. On-farm, retail or wholesale, number of clients
    c. education and advertising needed
    d. total volume and individual containers and or packaging,
    e. transportation
    f. financial evaluation

3. How and Where to Obtain or Purchase Worms

- It may be possible to find or isolate worms from farms with animal manure or wooded areas with leaf litter by placing a pile or crate of fresh bedding and feed and keeping it moist and dark.
- If purchasing, start by trying to identify vermicomposting or worm production facilities in your geographic region that can provide five to twenty pounds of worms or more with no or minimal transportation costs.

- While there are many suppliers that will sell one to two pounds of composting worms in the price range of $20 to $25 per pound plus the cost of shipping ($15 to $20), there appears to be only a limited number that are able to provide larger quantities (5 or 10 pounds or more) needed for starting commercial operations.
- In Michigan, two reliable worm suppliers are
  - Morgan Composting (www.dairydoo.com) (worms raised in Michigan)
  - Flowerfield Enterprises (www.wormwoman.com). (worms may come from outside Michigan)
- Other on-line options include
  - http://www.redwormcomposting.com/buy-composting-worms/
  - http://www.thewormfarm.net/ (California)
  - http://www.wiserwormfarm.com/ (Washington State)
  - http://unclejimswormfarm.com/ (Florida?) (reliability has been questioned on-line)
- Diversified farmers just starting with worm composting can reduce/minimize risk by starting with small amounts of worms (5 pounds or less) in order to develop a new system and favorable environment.
- It is important to have moist bedding prepared prior to arrival of worms.
- Worms that have been transported / vibrated may need an adjustment period and are reportedly more prone to trying to leave the new environment for the first few days.
- If fresh bedding is provided, feeding the worms can be delayed a few days to allow the worms to acclimate to the new environment.

A separate 13 page document that addresses worm biology, anatomy and reproduction as well as envirionmental conditions necessary for worm composting is available at:
http://www.hrt.msu.edu/assets/PagePDFs/john-biernbaum/Biology-Monitoring-Worm-Composting-2015.pdf

4. Estimating Feeding Rates and Process Time
Feeding Rates - Background

- A common estimate is that a pound of worms in a healthy and properly managed (biologically active) system can process approximately 0.5 to 1.0 pound (lb) of food residue per day. In other words, worms reportedly can eat approximately 50% to 100% of body weight per day.
- Current feeding recommendations usually do not differentiate between feed sources that are +80% water such as kitchen preparation food residue (vegetables and fruits) or lower moisture (30 to 50%) feed such as manure compressed to remove moisture or coffee grounds or grains. The amount of food content or value increases rapidly as the percent moisture or water decreases. For example, 100 lbs of preconsumer kitchen scraps at near 90% moisture content can provide about 10 lbs of dry matter food while 100 lbs of precomposted dairy manure and bedding at 60% moisture provides 40 lbs of dry matter food or approximately 4 times as much.
- Much of the current literature does not clearly explain that worms do not have teeth and likely are not directly "eating" the feed provided. In most vermicomposting systems, feed most likely is first digested by the activity of bacteria, fungi and other microorganisms before it is in a form consumed by the worms.
- Estimates from large dairy manure flow through worm composting facilities are that the feeding rate is more like 0.25 to 0.35 lb of feed per pound worms (25% to 35% of body weight) per day. These facilities use a flow through composter where the conditions stay more constant for the worms. The feed is also a mixture of "bedding and feed" and the moisture content of the feed is also more likely in the 50 to 70% moisture range.
- With batch systems, as in piles or bins, the conditions can change more over time as the worms stay in compost that is maturing and the feeding rate may slow due to increased soluble salts or other changing conditions like pH or moisture. Overall my current perception is that feeding recommendations have been oversimplified for the sake of small scale bin composters and that more details and specific recommendations would be helpful.

- For raising worms for bait, specific feeds such as Purina Worm Chow have been developed. A recipe for increasing the rate of worm growth is provided in the ATTRA/NCAT document on worm composting and raising worms for bait. The recipe is: 5 parts chicken starter (high-protein corn, ground); 2 parts bran (wheat or rice); 1 part wheat flour; 1 part powdered milk; 1 part agricultural lime; 3 parts alfalfa; all finely ground. Other recommendations have included a mixture of oat flour and corn meal flour.

Feeding Rates - Estimating

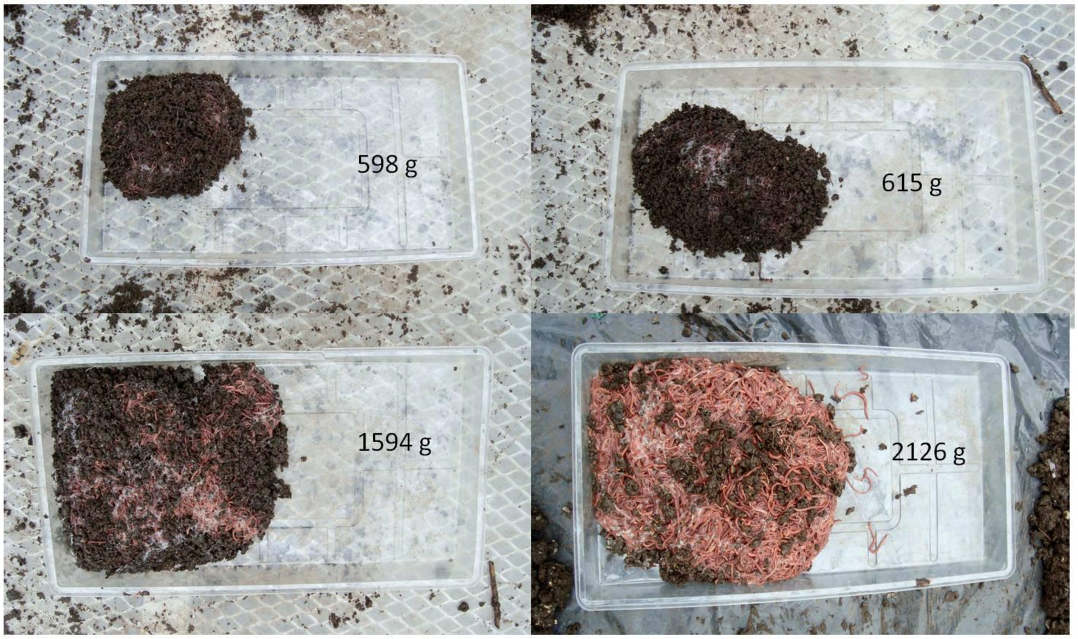
- One pound of worms is a minimum and 3 to 4 pounds worms is a maximum in an average sized worm bin (18 gallons or 12 inches wide by 24 inches long (2 square feet) by 20 inches deep).
- This corresponds to 0.5 to 2 pounds of worms per square foot of bed surface area.
- The bed volume necessary is about one cubic foot (2 feet of surface, 6 inches deep) to 2 cubic feet (2 feet of surface, 12 inches deep).
- So approximately 0.5 pound food per square foot of bed surface area per day (3.5 pounds per week) is possible but only in a biologically active moist environment with the correct mixture of feed and bedding at a favorable temperature. It may be hard to maintain stable conditions.
- It appears that a more realistic estimate in many settings that are not intensively managed or not under ideal environmental conditions – ie our current research setting - is 1-2 pounds of high moisture (60 to 80%) feed per square foot of bed surface area per week.
- For example, a five gallon bucket of fruit and vegetable waste might weigh from 15 to 20 lbs. If fed to worms weekly, the amount per day would equal 2.5 to 3 lbs per day requiring 5 to 6 lbs of worms and a minimum of 10 to 12 sq ft of surface area (~0.25 lbs food/sq ft surface per day or 1.5 to 2.0 lbs per square foot per week).

MSU Feeding Trial

A feeding trial was conducted in a heated greenhouse (65-70^{o}F) using 12, 18 gallon plastic totes. Approximately one pound of worms (400 grams) were established in each of 12 boxes with a mixed bedding. The worms were fed at 10 to 14 day intervals with an amount equal to either 50% or 100% of initial worm body weight per day of either fresh horse manure (~30% moisture) or ground pre/post consumer food waste (~70% moisture).

While the worms did well with 4 feedings over the 8 week trial period, without the addition of more bedding and without room for the population to expand, the initially healthy population declined for the food waste treatment, possibly due to ammonia accumulation, higher soluble salts, or lower oxygen due to the high rate of decomposition. The feed rate could not be maintained in the small container and even with feeding stopped some worms died. With some reflection and common sense, it is reasonable that a higher rate of feeding is possible in a system that is under more ideal and constant conditions where worms are constantly moving into fresh material compared to a bin or batch system where the conditions are fluctuating and or the rate of feeding acceptable in fresh bedding becomes excessive for decomposed bedding.

The picture below is an example of the worms isolated from one set of four worm bins after eight weeks of the feedings. With the horse manure, which in some respect has already been “composted” by the horse, there is less available feed and the population grew less. With the pulped food residue there was a great deal of feed available and the population grew very rapidly, most likely both increasing in size per worm and the number of worms.



Starting weight 400 g Nov 13; finish ~600 g (1.5 x) to over 2000 g (5X) Jan 13 or ~ 8 weeks.

Other Feeding Considerations:

- In the high tunnel - unheated greenhouse (PSGH) environment it has been important to bury fresh materials in the bedding in order to prevent fly populations from developing in warm conditions.
- This is contrary to recommendations for surface application of feed materials in more controlled environment conditions. Surface application reduces the potential for overheating if it can be done in a way that does not lead to fruit flies or other nuisance flies. (See precomposting below.)
- Under summer / high temperature conditions in the PSGH, regular applications of water are necessary to maintain bed moisture. Evaporation also helps with cooling. Shading methods that reduce evaporation may lead to reduced aeration and increased heating of the beds. Methods to minimize or eliminate leaching are important if collecting nutrients is the goal.
- Composting worms can survive in large piles (3 to 4 feet tall or deep) of relative stable or mature organic matter or compost; usually near the surface. But if there is actively decaying food, manure or organic matter present, the pile or bed needs to be shallow (6 to 18 inches deep) to prevent overheating (temperature over 90^{o}F), and to insure adequate aeration and feeding throughout the bed. In the high light greenhouse environment, surface feeding is reduced for at least part of the day.
- Food residuals can be very wet and may need to be mixed with bedding or another carbon source such as newspaper, leaves or straw if the bed is not already well prepared with bedding that can absorb the moisture.

Pros and Cons of Precomposting with Hot Composting

For food waste or manure feedstocks, hot composting prior to worm composting appears beneficial

- Reduction of food safety concerns related to animal manure or post-consumer food waste.
- Removal or reduction of weed seeds or seeds from foods such as tomatoes or melons.
- Removal or reduction of flies or other possible agricultural pest or disease concerns.

- Stabilization of high moisture or foul smells; balancing of the carbon to nitrogen ratio.

Precomposting reduces the feed supply available for the vermicomposting system and may contribute to a loss of nitrogen. However, with continued experience at MSU and with consideration of the skill level of the workers feeding the worms, and the willingness of workers to handle the raw food waste materials, precomposting is beginning to look like the preferred option for mid scale food waste vermicomposting.

The use of an "in-vessel" composter – that continuously mixes the ingredients for a period of 3 to 4 days in a rotating drum - allows high temperatures to remove seeds and possible human pathogen concerns quickly and efficiently. However, in-vessel composters of this type require a significant financial investment. Schools or institutions able to invest in longer term solutions are considering the use of in-vessel composting followed by worm composting.

For the MSU vermicomposting project we started with precomposting food scraps in excess of what was initially fed directly to the worm beds. We started with a pallet size pile and grew to larger windrows in a field adjacent to the worm house. Additional feedstocks included wood chips, straw, hay or municipal leaves. Outdoor composting of kitchen preparation scraps was not possible through the fall and winter due to weather and excessively wet conditions during rainy periods of weather. In the fall of 2013 a 32' x 34' cement slab was constructed and covered with a 30' x 32' Niftyhoop High Tunnel. We have been able to successfully use a small Toolcat loader to mix aged leaves, kitchen preparation food scraps and additional coffee grounds. The mixture heats to 110 to 130^{o}F in a few days and can be fed to worms after 10 to 14 days.

Larger scale worm composting operations like Worm Power and Sonoma Valley Warm Farm are precomposting dairy manure and feedstock mixtures using a batch or "in-vessel" type system. They are not using a rotating drum or vibrating platform bay system. A variety of insulated and aerated boxes are used so turning and mixing is not necessary. A plan for future research is to build a similar contained system that will provide benefits of an "in-vessel" at a fraction of the cost.

Examples of In vessel comp:

From England, 7.5 minutes http://www.youtube.com/watch?v=Ez3zrpuvXGw
Music Background, 3 minutes http://www.youtube.com/watch?v=okvUrIw45VI
Rotary Composter: http://www.jetcompost.com/index.html

How Much Time is Required for Worm Composting?

- Useable compost can be ready in as little as 5 to 6 weeks with high worm populations and frequent management; 2 to 3 months (60 to 90 cays) under favorable conditions; but 4 to 6 months is a better estimate with minimal management of the worm beds.
- With high volume flow through systems, it has been reported that a marker such as a coin placed on the surface of the bed will typically drop out the bottom of the bed in about 60 days.
- An important question for batch systems is how long a time is necessary from the last feeding until finished material can be harvested? With a high worm population, kitchen preparation residue or animal manure will be decomposed in 4 to 6 weeks. If the material is to be used in certified organic production systems, the required worm composting time for a batch system is four months (16 weeks). But from the first feeding or the last?
- Worm populations will clearly decline with no added feed for four months. Our current strategy is to begin removing worms with surface trap containers once food residuals are no longer visible (estimated one month from last feeding). Worms are extracted over a one month period. A low population of worms is left for up to one month prior to sieving the finished compost. This also allows time for additional worms to emerge from cocoons. We then hold the compost prior to use or sale so the time from last feeding to use is at least four months. The majority of the material has been worm composted for as much as eight to ten months as fresh feed is added weekly or biweekly.

- Our systems at MSU are going much longer than two months. The majority of composting is done in 6 months but we are allowing another 6 months for maturity and completion.

How Much Worm Compost is Produced by a Given Size Bed or from Input materials?

- A current estimate is that a well managed 25 ft^2 bed can produce 0.5 to 1 cubic yard of worm compost per year.
- A well managed 4' x 25' bed (100 ft^2) can produce 2 to 4 cubic yards of worm compost per year.
- Results reported from a North Carolina State University experiment were that 5200 lbs of swine manure applied to a flow through system resulted in 1,500 lbs of worm compost or a 29% recovery or *3.5 pounds in for 1 pound out*. It was reported that 42% of the input nitrogen and 85% of the phosphorus was recovered. (Conference presentation)
- A large scale vermicomposter of dairy manure with a flow through system reported approximately 10 million pounds in and 2 million out or *4 pounds in and 1 pound out*. The dairy manure had been extracted from barn cement floor scrapings using a screw press and then mixed with some bedding and old feed and precomposted for about a week so there was no dripping of excess fluid at the time of application.

6. Vermicomposting Systems

Choosing a system is in part based on the production area available and the amount of feed available for processing but also on the amount of finished product desired. In the compost use section that follows, example estimates of quantity of compost needed for production of farm transplants are provided. If the goal is compost production for farm income / sales, a sales target can be identified and a weight / volume of compost to be produced estimated. We do not currently have estimates of pounds of vermicompost produced per square foot of bed area for our systems, but we expect to be able to make such calculations in the future.

Other important considerations are the time available for management if worm composting is part of a diversified operation. Much like maintaining animals or honeybees on a farm, the worm beds must be regularly managed for consistent outcomes. Once an appropriate size population of worms is established in the culture bed, the primary maintenance is watering and feeding the bed with occasional turning. While an experienced manager is necessary to insure success, much of the routine work can be accomplished with inexperienced workers.

On the small scale farm the required financial resources and equipment investment is also important. Minimal equipment is necessary for managing beds less than 100 square feet (4' x 25'). As the size of the operation grows so does the potential required equipment investment. Our emphasis to date has been for a system with minimal required equipment investment.

Batch: buckets, barrels, boxes, bags

- As stated previously, the goal here is for systems other than a 10 to 20 gallon plastic tote/bin. We have used a variety of other plastic or wood containers.
- In a batch system, how to or whether or not to have drainage holes is an important decision. If the bedding becomes excessively wet due to lack of drainage, anaerobic conditions can develop. However, high moisture conditions can be tolerated to a point and often benefit worm activity and growth. Leaching of moisture from the bottom of a container can result in loss of valuable nutrients so if not prevented, the leachate should be collected.
- Plastic bulb crates, used to ship tulips and daffodils from the Netherlands to greenhouses and wholesalers, or bread delivery trays, can serve as worm composting containers that can be stacked. Worms can move from lower containers to upper containers. Containers of compost can also be used for raising crops if food safety concerns are addressed.

- A fruit bulk bin, approximately the size of a pallet has worked well at the MSU Student Organic Farm. The bin can be moved with a fork lift, loader or pallet jack so can be outside for part of the year and inside for the winter.
- We have also made use of 4”x4” pine lumber that was previously used to construct lofts or bunk beds in university dormitories. Each May the wood is removed from the rooms and is available for sale at the MSU Recycling Center. The available wood is 84” long so beds are 84” x 42”. By stacking 4 or 5 high we are able to make a bed that is large enough for easy feeding. One method we used was to connect the wood using 4” lag bolts and washers in counter sunk wholes (left picture). We also used a method of notching the ends to allow stacking and drilling a 0.75” vertical hole to accommodate a 0.5” x 2’ piece of rebar driven through the holes and into the ground. Both methods allow easy disassembly. The bottom of the bed is the sand floor of the greenhouse.


Bed above made with lag bolts and stacked 4x4. On right beds covered with 2 layers of frost fabric.

Bed below with notched ends and rebar anchor. Bed on right is 4’x8’ and 2’ tall from 2”x6” lumber.


Raised beds over bins made with 1.25” EMT (10’ cut to 5”) driven into the ground. Wood 4”x4” supports drilled with a 1.5” spade bit to rest on EMT. Pallets can straddle the beds and be used for a low cost growing surface.

We also constructed 4’ x 8’ wooden boxes using 2”x6” pine wood.

- 2 - 4"x4" x 8' - get cut in half to be the supports on the ground - one near each end and two equally spaced across the 8' length of the box.

- 21 - 2" x 6" x 8'   9 become the bottom boards (1 board has to be ripped to get 48" width). The others are used to make the walls - takes 3 for each layer - so the walls will be 4 2x6 high or (4 x 5.5"= about 22" tall).
- 2   2" x 2" x 8' cut into pieces for vertical joiners in the corners and inside the box.
- decking screws - 3" - need at least 150 – approximately a 1lb box.
- We started by attaching the 2x6 for the bottom to the 4x4 pieces that held the box off the ground.   4x4 were near each end and then 2 equally spaced. Don't put right on the end - leave about 4" for a handle for lifting and to have room to attach the 2x6 in the next step at the end. Remember to use a square or measure the diagonals to line up the boards.
- We then turned it upside down on top of the first row of 2x6 vertical side and end walls and put deck screws through the bottom and into the 2x6. The reminder of the side walls were simple attached to the vertical corner pieces inside the box and some additional verticals that split the box into thirds. The way it is shown, with an alternating pattern - either the end pieces had to be reduced by 3" or the side pieces had to be reduced by 3" to end up with a consistent size. If the wood is dry, pre-drilling for the deck screws will prevent cracking and splitting.
- Bedding and worms were placed directly in the box against the untreated wood. In hindsight we would prefer to have a sheet of plastic on the bottom to prevent leaching so have tried this in the second box. The hoops are used for shade fabric in summer and thermal blanket covering in winter. This box has not been through the winter yet so we need to monitor the temperature since it is not in direct contact with the greenhouse floor / soil.
- An above ground pile is a viable option for part of the year, but an in-ground insulated bed/corral is needed for the winter in northern U.S. climates.
- Cement block, straw or hay bales can be used to provide boundaries to contain composting material and worms. Plastic liner can be used to minimize leaching and worm migration.
- For a small farm or market garden, a worm composting area can be developed using straw or hay bales to provide an insulated wall or border. Over time the decomposing bales can be mixed into the worm bed and fresh bales placed on the perimeter. Bales placed over the top may provide adequate winter insulation. A rain shelter over the bed will prevent leaching of nutrients.
- Another system used to contain worm composting is vinyl or woven fabric bags or beds. We are planning a trial of bulk root media bags supported by a metal conduit frame.

On farm batch systems have been made from 50 gallon plastic barrels (food grade or non-toxic contents) cut in half either vertically or horizontally. Large diameter water or drainage pipes have also been cut in half for use as worm bins.

Systems in India that can be viewed on the internet include cement or cinder block beds and large woven vinyl bags. Both systems allow collection of leachate.

Larger plastic or metal containers often used for providing water to livestock can make effective batch worm bins.   Based on a discussion with a student returning from a study abroad in Sri Lanka, we researched *"vermiwash"* systems. We used a Rubbermaid livestock water reservoir with gravel and sand layers in the bottom separated by landscape fabric and worm bedding as the surface layer to produce a combination worm composting and vermiwash system.

Farm-scale Windrows or Angled Wedge Systems.

Large windrows of manure or food waste can be managed and vermicomposted outside if properly protected. Outdoor composting is either done in low rainfall areas or windrows are covered with a roof or maintained under breathable covers that provide aeration but limit moisture loss and prevent leaching from rainfall.   Windrows can also be maintained in temperature-controlled insulated buildings where the greater concern becomes keeping worms in the piles (lights or other methods) rather than keeping rain out.

Windrows can be managed by adding fresh material to the top, the small end, or the long sides. For long windrows managed with the angle wedge system, fresh material is added to one end or side of the sloped/angled piles and worm populations move laterally. Over time the finished material is removed from one side and new material continues to be added to the opposite side. When the edge of the available composting surface/floor area is reached, finished material can be collected from the older/aged side and the direction of the pile reversed so the "composted" side becomes the "fresh" side. The current method that seems to be working well is to remove finished compost from the back side, clear out the starting space, and then move the worms from the leading edge back to the starting place to start the cycle again.

We have maintained two 4' wide by 20' long beds with a 1.5' center walkway placed on an initial layer of greenhouse polyethylene covered by woven landscape fabric and bordered/contained by cement blocks on the outer perimeter and wood at the center walkway. Fresh feed is buried in trenches and covered weekly during the warmer months to prevent flies. In the winter months fresh material can be layered on the surface.

We initially used side applications similar to a wedge which was also successful but less effective to manage with manual feed additions. The method of trap removal of the bulk of the worms using crates of fresh bedding/feed to the surface of the beds has so far been an efficient method of removing the bulk of the worms to new beds.

Flow Through Systems

For larger, indoor commercial operations the beds are maintained in metal frames held off the ground. Fresh material is added to the top of the beds and finished material is removed from the bottom of the beds by mechanically moving a scraper bar across the open mesh or screened bottom of the bed so that finished material drops to the floor and is then collected. This system has been used for food residue processing in institutional settings and for very large scale processing systems for food waste and animal manure. See web sites for Worm Power (NY) and Sonoma Valley Worms (CA). The Charlotte, North Carolina Airport has also installed a large flow through system.

The investment required may not be possible or practical for a small scale farm. The cost is much more than the cost of a passive solar greenhouse that can serve multiple purposes on the farm. Another important factor is labor availability. These systems require minimal labor and are usually mechanized. Community based farms often benefit from member or volunteer labor that need entry level activities with no requirement for prior experience.

Recommendations for how to build a home or small scale flow through system are available and will be a part of our future research. If as effective as described, worm compost may be easier to harvest with this type system. http://www.redwormcomposting.com/vermbin-series-plans/

FloThr2 (10 min) http://www.youtube.com/watch?v=iKhDe8dWvhM&NR=1&feature=endscreen

Preventing or managing migration and predation

If conditions are unfavorable, worms will move out of the bedding and seek new lodging, particularly under the cover of darkness. If there are greener pastures nearby, you lose your worms. If there is nothing suitable (wet) nearby, mass migration means mass murder. Either way you lose as a worm farmer. Beds must be provided feed regularly or fresh bedding and feed placed nearby so migrating worms are not lost. Use of low intensity lighting will also reduce the probability of mass migration.

Worms are also a good food source for moles, voles and other scavengers such as raccoons. A large population of worms can disappear in a short time so take precautions.

Using Passive Solar Greenhouses

A key part of our project has been to test the use of a passive solar greenhouse (PSGH) also known as a high tunnel or hoophouse for maintaining worm activity through the winter in a northern climate (Climate Zone 5, winter low of -20^{o}F). Use of PSGHs for extending the production time of warm season vegetables and allowing winter harvesting of cool season vegetables is having a significant impact on the availability of local food. A PSGH with two layers of inflated polyethylene and rollup or drop down sides will cost in the range of $2.50 to $5.00 per square foot floor area. We are currently using 25% of the space for beds.

The greenhouse cover and typically a second interior cover of either polyethylene film or frost fabric trap the radiant energy of the soil or worm beds and prevent freezing conditions. In our trials in 2010-2011 and 2011-2012, worm beds were maintained at a temperature of 45 to 50^{o}F with no supplemental heating. Vermicomposting activity continued but at a slower rate.

We also are testing the addition of feedstocks to the worm beds that provide small hot spots (<0.5 ft^3) through thermophilic composting in order to maintain worm activity when outdoor temperatures drop below 10^{o}F for more than a few days. We were given 50lb bags of pig feed which primarily consisted of soybean and corn meal and oat seed. As little as a quart of moistened material could create a hot spot and we typically used 0.5 to 1 gallon of material. Liquid application of diluted molasses can also increase biological activity and provide warming for short periods of time. Future research will include legume hay and alfalfa meal.

MSU Compost Commons or WORMhouse

The high tunnel or passive solar greenhouse (PSGH) pictured on the next page cost approximately $10,000 to build in September 2010. The footprint size is 30' x 72' with drop down sides and thermostatically controlled end wall vent louvers. The interior tent pictured is 10' x 25' and is used for two worm beds 4' x 20'. Tent is covered with polyethylene in winter for heat retention and shade cloth in summer for cooling.

Our first beds were formed with cinderblocks and were 4' wide. We used old greenhouse polyethylene film and landscape fabric to contain the worms and help hold moisture. While the film can reduce aeration, our primary goal was to contain leachate. We managed aeration by not overwatering. We soon realized that larger beds have more forgiveness and room for worms to move in the case of problems due to heat or excess moisture.

We later developed the 42"x84" wood beds for further research. The bed is small but allows replicated units needed for research. These beds are open on the bottom and sit on the sand (2NS) that was purchased for the floor of the WORMhouse. The minimal bed size we are recommending to farmers is the 4'x8' bed constructed from 2"x6" lumber that is pictured.

Bed position and shape changed over time as we trialed several management methods.

30x72 PSGH with side and peak vents.

System in Fall 2010 just starting.

Initial interior tent in Fall 2010.

Revised system in winter 2011-12.

Summer shade cloth cover, now taller structure. Frost fabric cover over small beds and plants

Compost to Harves on left - Worms Under Hay on right

50' long wedge; Back/left side is cinder blocks

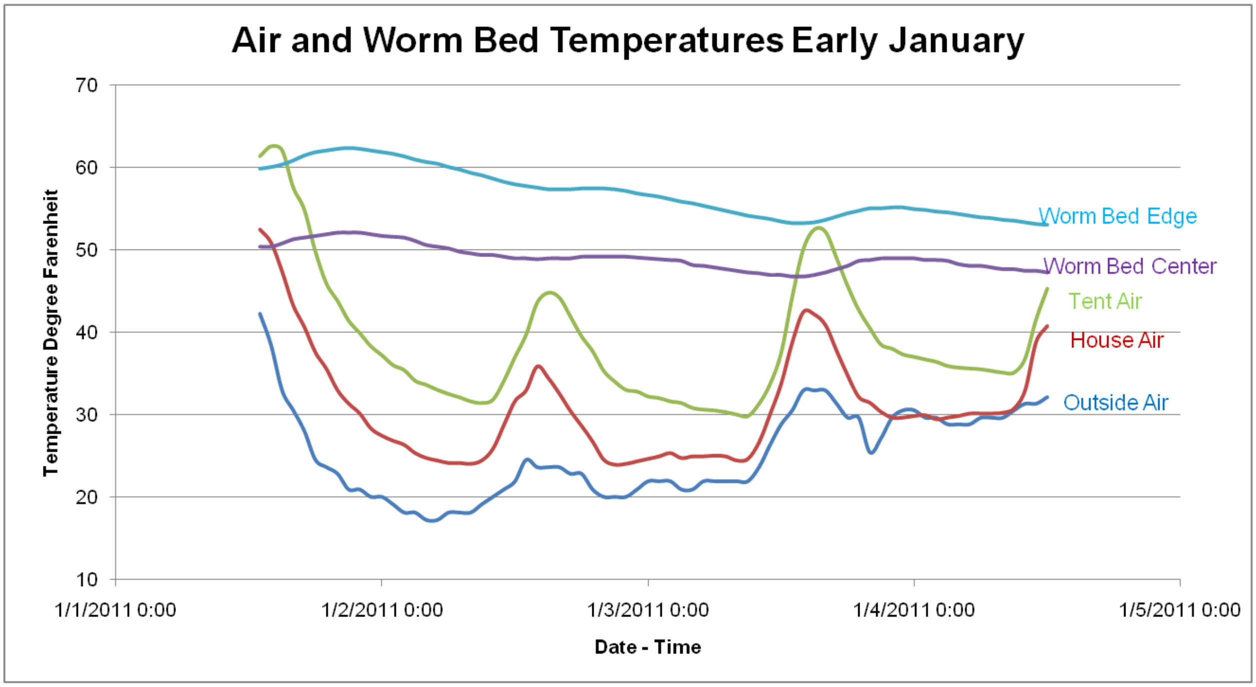
4’ x 8’ Home Made Flow Through System

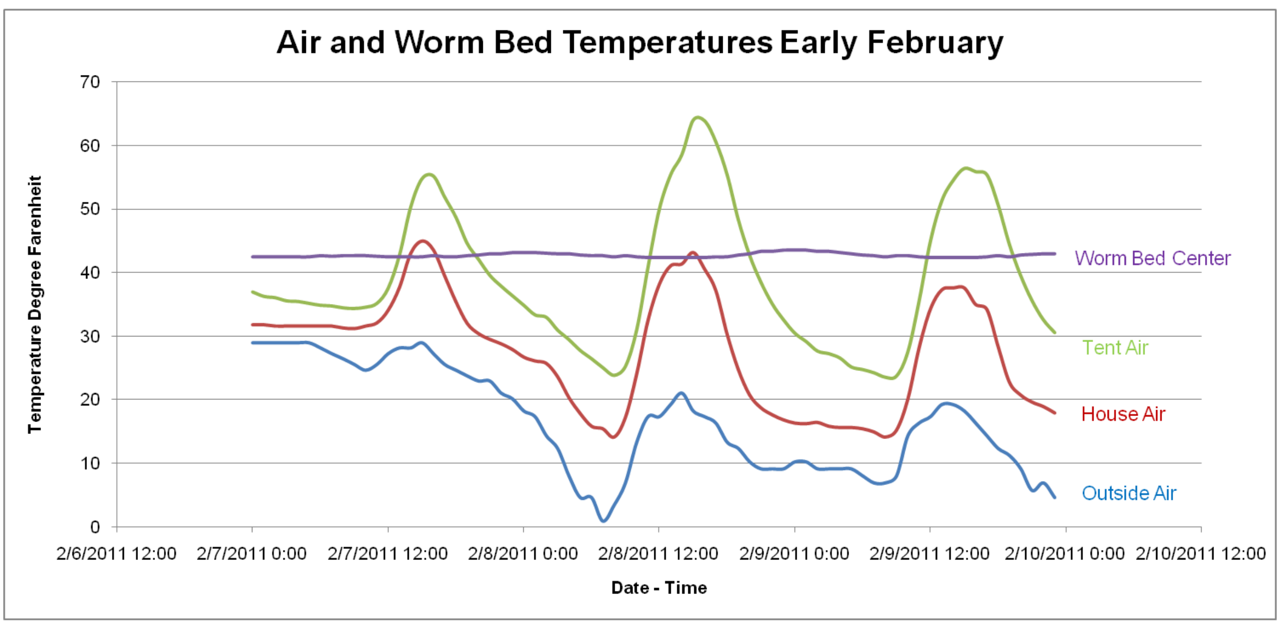
Bulk Bag System

Bulb Crates to Move or Hold Worms

Precomposting of kitchen prep scraps and leaves on cement pad under high tunnel

Examples of temperature data collected starting in late December; a) early January and b) early February 2011 of worm bed temperatures under an interior tent in a passive solar greenhouse (high tunnel). Temperature was recorded hourly by electronic recorders at a depth of 2 to 3 inches and is available as the hourly average. The edge of the bed remained warmer due to thermophilic composting of material added to the bed at two to three week intervals.





Worm Bed Edge recorder malfunctioned during the early February period but temperatures measured with analog thermometers were higher similar to January.

7. Harvesting of worms from finished compost or castings and screening finished compost

A key management process is separating the worms from the castings. There are at least four options:

- Option1 – Place fresh bedding and food adjacent to or on the surface of vermicompost beds and worms will move into fresh material. In Michigan several large greenhouse businesses import tulips, daffodils, hyacinths and other bulbs from the Netherlands. The bulbs are transported in plastic crates which can be purchased. These crates packed with fresh bedding and feed have worked well for collecting and moving worms. An 11" x 22" by 6" deep crate (about one cubic foot) can collect 2 to 3 pounds of worms and can be moved by one person.
- Option 2 – Keep worms moving up through fresh material and collect vermicompost from the bottom through a screen or by using stacking layers with large screen bottoms (variation of option 1).
- Option 3 – Use either light or drying to move the worms to the bottom of pile of finished worm compost and remove the surface layers of worm compost. This works well if workers can be doing other tasks in the PSGH and occasionally removing the next layer of material as worms move down. If taken to an endpoint a "worm ball" will form and worms can be collected, weighed and redistributed in new beds.
- Option 4 – For commercial production of worms for fishing bait, the bedding can be passed though a rotating, pitched screen that will sieve out the castings and collect the worms at the end of the screen. Based on our limited experience primarily the larger worms are collected and smaller worms pass through the screen with the finished compost. The small worms can be extracted from the finished compost by placing fresh bedding/feed at the surface of the pile as an attractant.

Screening

- A first step for providing uniformity and a consistent particle size is to screen the material. Common screen sizes are 0.125 (1/8th), 0.25 and 0.5 inch.
- We started with a simple wooden frame with hardware cloth that was designed to rest on a large wheelbarrow. Later the screen was set up as a swing screener that was suitable for compost where the worms were already removed. As pictured below the materials cost was about $100.
- We recently purchased a Jet Worm Harvester that cost about $3400 and $900 to ship from Nevada to Michigan. http://www.jetcompost.com/harvesters/index.html
- Either 0.125 (1/8) or 0.25 (1/4) inch hardware cloth will work for most applications. The 0.5 (1/2) inch screen is good for removal of large clumps or for course screening of inputs.

- We used the 0.125 for finished product to sell. It removes cucurbit seeds from the compost and greatly improves the quality of the product.
- For use in teas or bed production, material with larger particles (0.25 and 0.5) will usually be adequate.
- As much as 30 to 40% of the material did not pass through the 0.125 screen initially. Aggragrates/clumps were broken up by hand and the material was passed through the screen again with about a 50% recovery rate, bringing total recovery over 75%. We plan to look at roller based methods of crushing the larger aggregates. Or using the aggregates in root media.
- Smaller batches of vermicompost with a variety of feedstocks can be mixed together for a more uniform larger batch of final product.

8. Organic Certification Requirements

For organic certification, vermicomposting requirements (as opposed to hot composting) are:

- Allowed feedstocks – must provide records of feedstocks used and how non-allowed substances were excluded.
- Applied in shallow layers – presumably to allow rapid composting without heating.
- Aerobic conditions (can't use worms any other way)
- High moisture (70-90%) – information is not provided regarding the basis for this requirement but the high moisture favors rapid decomposition.
- Duration: 12 months for outdoor windrows, 4 months for indoor container systems or angled wedge systems, or 2 months for Continuous Flow Reactors

It is interesting that there does not appear to be any requirement for an average or recommended worm population per square foot of bed surface area or cubic foot of bedding/feed. As previously presented the worm population density will impact the rate of composting. This is also no recommendation for feeding rate. Excessive feeding will not likely allow for complete composting.

For the USDA National Organic Program and Organic Certification Handbook see:
http://www.ams.usda.gov/AMSv1.0/nop

9. Additional Sources of Information

Web Sites

- MSU Power point http://www.michiganorganic.msu.edu/uploads/files/31/biernbaum%202.pdf
- NCAT-ATTRA Publication: https://attra.ncat.org/attra-pub/summaries/summary.php?pub=256
- North Carolina State Extension Vermicomposting Site (Rhonda Sherman) publications: http://www.bae.ncsu.edu/topic/vermicomposting/
- Ohio State Research Laboratory: http://www.biosci.ohio-state.edu/~soilecol/
- Vermicomposting at Wikipedia - http://en.wikipedia.org/wiki/Vermicomposting
- Worms for urban farming - http://www.cityfarmer.org/wormcomp61.html#wormcompost
- Flower Field Enterprise: www.wormwoman.com
- Largest commercial worm composter in United States http://www.wormpower.net/
- Sonoma Valley Worm Farm - www.sonomavalleyworms.com California, flow through system
- Vermicompost Operation in Wisconsin - Wiggle Worm http://www.vermiculture.com/

Books and Publications:

- Vermiculture Technology; Earthworms, Organic Wastes, and Environmental Management. 2011. Edited by Clive Edwards, Norman Arancon and Rhonda Sherman. CRC Press. 600 pgs.
- The Complete Guide to Working with Worms: Using the Gardener's Best Friend for Organic Gardening and Composting. 2012. Wendy Vincent. Atlantic Publishing Group. 288 pgs.
- Beyond Compost: Converting Organic Waste Beyond Compost Using Worms. 2009. Tom Wilkinson. Create Space Independent Publishing Platform. 116 pgs
- The Worm Book; the complete guide to gardening and composting with worms. 1998. Loren Nancarrow and Janet Hogan Taylor. 10 Speed Press. 150 pgs.
- Raising Earthworms for Profit. Revised edition 1994 (original 1959). Earl B. Shields. Shields Publications. 126 pgs.
- Worms Eat My Garbage. 1997. Mary Appelhof. Flowerfield Enterprises. 162 pgs.

YouTube Videos of Possible Interest

There are many, many videos. Here are a few to get started.

- Overview of many ideas (6 min) Music background – fast moving images http://www.youtube.com/watch?NR=1&v=cRAq2chA7HA&feature=endscreen
- Dirty Jobs (9 minutes) http://www.youtube.com/watch?v=44AvH-fPxp0&feature=related
- Tank Method (8 minutes) http://www.youtube.com/watch?v=2SuBT7SukdI
- Worm Power (6 minutes) http://www.youtube.com/watch?v=X6TiawLx0J8
- Simple Harvester (4 min) http://www.youtube.com/watch?v=KRI69IO5y3c&feature=related
- Morgan Composting (10 min) http://www.youtube.com/watch?v=U27Aizi64Wg
- Flow Through in Hoophouse (4 min) http://www.youtube.com/watch?v=vQEQ-gWLHJU
- Stacking Tray System (8 min) http://www.youtube.com/watch?v=VMdJxfPuMOE
- Flow through System (17 min) http://www.youtube.com/watch?v=ZWb5knRBRM8
- FloThr2 (10 min) http://www.youtube.com/watch?v=iKhDe8dWvhM&NR=1&feature=endscreen
- Hanging Bag Idea (5 min) http://www.youtube.com/watch?v=VxDrkGRKXt4
- Ideas from a tropical setting (8 min) http://www.youtube.com/watch?v=E-PKWnVeuSo
- Hoophouse Setting (6 min) http://www.youtube.com/watch?v=kNl_4Axd3BE

Vermicomposting Learning Based Groups or Opportunities:

- www.vermicomposters.org
- Linkedin vermicompost group
- http://www.redwormcomposting.com

Contact Information

This document is under development/review and while every effort has been made to insure the accuracy of the information, there still may be some mistakes. Comments or concerns about the information presented are appreciated. *This document is not for publication or reproduction without permission of the author.*

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10. Appendix: Historical Perspective and Project Background

I remember "discovering" the large population of composting worms that developed in horse manure piles at our home farm. I was using a bucket loader to place llama and horse manure compost in a small trailer. I happily gave the compost to an enthusiastic gardener who had asked if I wanted to be paid for the compost. While I did not take any payment for the compost, the next day I realized that I had likely given away easily $100 worth of worms. From that point I started managing the manure piles in a way that the worms could easily move from one pile to the next when composting was completed and the finished material was ready for application to a pasture. I also started using the worm composted horse manure in my hoophouse for vegetable growing.

In January of 2010 I was invited to participate in a discussion about quantifying, minimizing and managing food waste on the Michigan State University campus. Some efforts were already underway including construction of an anaerobic digester. My proposal to use worm composting and to focus on the importance of cycling nutrients from farm to fork and then back to the farm was accepted more with curiosity than confidence. I was aware that worm composting was used more or less successfully at a variety of institutions from schools to prisons. I was also aware that a new organic certified greenhouse production facility in Michigan was purchasing significant quantities of worm compost from New York State at a price of $800 per ton.

Hot composting and the use of compost for transplant production and passive solar greenhouse management were already essential components of the year round farming program that I helped start in 2003 at the MSU Student Organic Farm (www.msuorganicfarm.org and www.hoophouse.msu.edu). A key component of our worm composting project has been to demonstrate how a PSGH can be used for year round worm composting. While the winter temperatures are low and summer temperatures high for the worms, if properly managed the moderate cost structure ($2.50 to $5.00 per square foot) can be used for additional farm activities such as transplant, leafy green, culinary herb, mushroom, or fish production. Internal covers are used to trap the thermal radiant energy and increase temperature during cold winter nights and roll-up or drop-down side wall ventilation is used to reduce temperature during the summer so energy costs are near zero.

I am grateful to the past and ongoing support of Michigan State University Office of Campus Sustainability, the Division of Residential and Hospitality Services, and the campus Recycling Center and Surplus Store who financially and enthusiastically supported the development of worm composting methods for campus and for use by farmers and students. Several staff and students at MSU were instrumental in the development of the important objective to "close the food cycle loop" on campus by keeping food waste from landfills and keeping the nutrients available for future farmers and gardeners. The shared commitment and passion was critical for me and the students involved in the project.

I now (2015) have twelve plus years experience with the worms in our horse manure piles at home and four full years of experience with food waste vermicomposting in a PSGH at the MSU Student Organic Farm. I have read many publications and websites about vermicomposting and looked at a lot of on-line videos. I am sorting through all that experience and information and thinking about what is most important to share with future worm farmers. And here is the first attempt. Enjoy!

John Biernbaum, December 2012- Updated July 2014